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Towards a strategy for control of suburban informal buildings through automatic change detection

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A R T I C L E I N F O

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A B S T R A C T

The problem of informal settlements is of significant importance and has similar causes worldwide. In Greece, such buildings are relatively well built and number nearly 1,000,000 across the country. This social and economic issue requires a combined approach. In this paper, a proposed solution to this problem is developed at a technical and administrative level, taking into consideration the criteria of least possible cost and maximum benefit from usage of modern technology. The basic idea is the development of a system that allows for periodic, automatic monitoring and detection of new buildings. With additional field control applied only to specific locations, immediate detection of informal construction projects prior to completion is enabled, at which time measures to halt their development can be more easily taken. The suggested procedure is based on the use of high resolution images and the application of automatic change detection by computation and comparison of digital surface models and building extraction techniques. Results from a pilot application of the proposed procedure are given together with an estimated cost for application of this method to the coastal zone of eastern Attica, a Greek prefecture with many existing and emerging informal constructions.

1. Introduction

A combination of social, economic, legal, and administrative parameters leads, in several countries, to unplanned development and to the creation of a considerable number of informal buildings. In countries like Greece, the majority of such informal buildings do not resemble dense slums at the edges of big cities. On the contrary, informal buildings are of good construction, in some cases being two-story buildings, or even more luxurious constructions. Such buildings can usually be found scattered within agricultural land at the urban fringe of big cities or in areas close to the coast, mainly due to an increase of the population in the major urban centers, new improvements in the road and railway network that reduce commuting times, and to the high demand for urban land in areas with better environmental conditions. The lower prices of agricultural land parcels and the low profit from agricultural products, especially in comparison to the profits expected through the urbanization of land, are also significant factors. These informal constructions are used either for permanent residence or, in the coastal zone, as second houses for vacation purposes. However, as the numbers of such buildings increase, many problems may arise:

- State and local revenue may decrease since these structures are not fully taxed, as the informal buildings are not registered; nevertheless, they demand additional provision of infrastructure and services.
- They may pose a serious social and economic impact on the owners, the national economy and the real estate market. The owners may be charged with high penalties; also, such properties cannot be transferred or mortgaged, and, moreover, there is a risk of creating an informal market.
- When found on a massive scale, they may have a negative environmental effect.

The state government has applied high penalties to owners in cases where informal constructions have been detected, but this alone cannot solve the problem. Sound update of land-use planning according to changing needs and a series of other fiscal and social measures are also necessary. From a technical point of view, one common reason for the administration's inefficiency to control unplanned development is the difficulty of locating, quickly and in time, the construction of informal buildings in a cost-effective way and stopping the construction as its beginning or applying a penalty within a short time of its completion. Classic administrative control procedures have proven inefficient, especially when public administration suffers from a lack of employees, bureaucracy, and increased responsibilities. It is difficult to place inspectors in each area to stop illegal construction work, thus encouraging corruption.

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The contribution of modern techniques and tools is necessary for the design of an automated and objective procedure for the detection of informal constructions. Such procedures have already been tested in some countries. For example, India has started pilot projects in a small area of 20 km^2 in Delhi, which monitors construction activities using high resolution satellite imaging and a special multimedia mapping to build a 3D Geographical Information System (GIS) with live cameras. This system has been developed jointly by the Indian Department of Science and Technology, the Russian Academy of Science and other private partners, at a nominal cost. Their optimistic time schedule includes full coverage of the capital city by next year, with potential applications in crime surveillance and forecasting and garbage collection (GIS development, 2007).

In any case, in order to monitor the urban and suburban environment for detecting illegal buildings, dense periodic measurements must be made, spread over large areas of interest. The automation of modern photogrammetric techniques can significantly increase the productivity and reduce the cost of detection. Over the last 20 years, research has been done in the field of automatically detecting and monitoring man-made objects, mainly roads and buildings, with promising results (Mayer, 1999). The problem is complex, and the technical matters that arise are difficult to overcome. International experience shows that a global solution has yet to be introduced. However, in many well-defined cases, there have been successful applications of automatic informal building monitoring (Hurskainen & Pellikka, 2004; Karanja, 2002).

This paper discusses briefly the problem of informal settlements in Greece, touching on the current situation and the available fundamental statistics and technical characteristics of such settlements. Also, it investigates the imagery data currently available in the market, which can be used in automatic change detection and building extraction applications. Finally, an integrated approach is developed to support construction monitoring in areas where no formal urban plan exists. The fundamental criteria of this proposal are to maximize the benefits of appropriate modern technology and to minimize costs.

2. Informal settlements in Greece

According to the existing legal framework, "informal construction" in Greece is characterized by any construction that (Potsiou & Ioannidis, 2006):

- Exists without a building permit.
- Has any kind of excess or violation to the building permit.
- Is in violation of any valid urban and spatial regulation, regardless of the existence of a building permit.

For the purposes of this research, our interest is focused on the first category – constructions without a building permit – and on buildings located at the urban fringe or generally in areas without urban plans, which gradually lead to the creation of unplanned settlements. The term "urban plan" refers to a formal set of rules and plans that define the zoning and building regulations applicable to both private plots and plots selected for common use and common benefit activities. In areas without an urban plan, construction is only permitted on land parcels bigger than 0.4 ha and only for a building size up to 200 m^2. Also, these land parcels must not have been characterized as archaeological sites, forest land or environmentally sensitive areas, and they should not be under any other protection restrictions, e.g., for coastal zones.

Informal settlements in Greece do not have the characteristics of slums. The quality of the construction and the living conditions in these areas are of a satisfactory or even high level (Fig. 1). Also, illegal constructions have not created major conflict or violence with the state to date, mainly because they are built on legally owned land parcels. The lack of cadastre in Greece has a multidimensional impact on land management issues: it is the major factor that makes spatial planning procedures extremely time and cost consuming, and it enables the creation of informal settlements. Also, there is no other system for reliable statistical spatial data provision to support the development of land, the real estate market, and decision-making processes for applying sound land use regulations and efficient land policy.

Illegal construction in Greece began soon after the enforcement, mandated by the Housing Law of 1955, of the requirement for a building permit prior to any kind of construction. The reasons for illegal construction are complicated and have varied through the years, leading to the creation of informal settlements in several regions within the Greek jurisdiction, each with different characteristics. Starting with informal settlements within industrial zones (Fig. 2) or at the urban fringe areas, today's current activity takes place in attractive vacation areas, or in areas close to or within coastal zones (not to mention the numerous violations of building permits within formal urban areas, mainly related to increased building area or to deviation from the permitted use). Several attempts have been made to minimize the problem either by applying procedures toward massive, nation-wide legalization of informal settlements with a parallel provision for urban planning improvements (Laws of 1977 and 1983) or by applying tough penalties (Law of 2003), or locally through extensions of existing urban plans. Nevertheless, none of the applied procedures has proved to be efficient; on the contrary, most of them have proved to be time and money consuming due to the outstanding lack of a modern

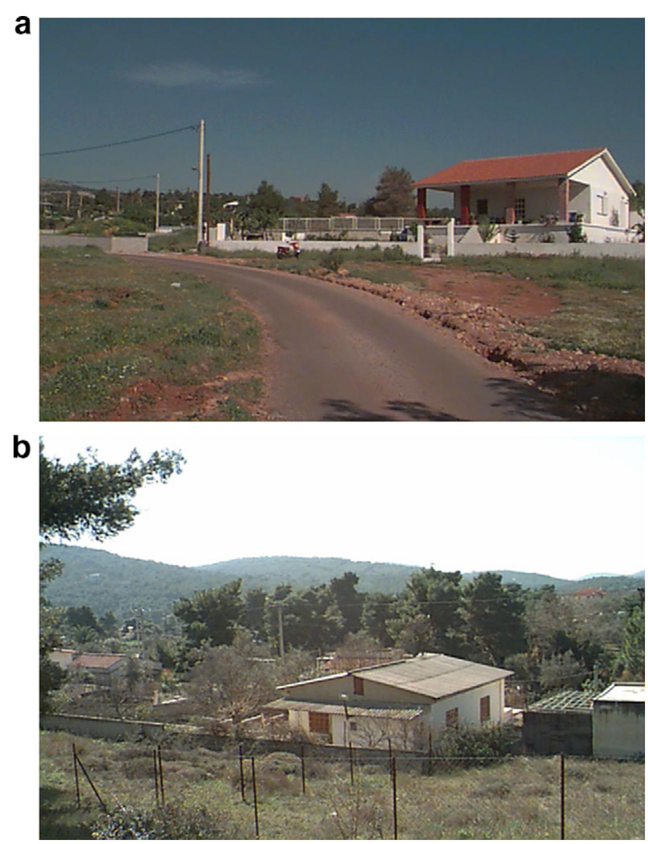

Fig. 1. Informal buildings on legally owned land parcels in Attica.

Fig. 2. Informal settlements next to an industrial area in Attica.

tool (e.g., spatial information system) for applying coordinated and sound land policy.

Until recently, the real size of the problem has been difficult to estimate due to a lack of information. In Greece, there are approximately 6.9 million residences for a population of 11 million. It is roughly estimated that almost one quarter of the residences recently constructed were built without building permits. A rough recent estimation by the General Inspector of the Greek Ministry of Environment, Physical Planning and Public Works shows that, in total, informal settlements in Greece number as many as 1,000,000 residences. The majority of them lie within 7–10 prefectures (out of a total of 13). The "new generation" of informal buildings is constituted by constructions of 1 or 2 stories of medium or large area size (>50 m^2), which are estimated to lie on an average land parcel size of 1000–1500 m^2. According to a statistical study (Karavassili, 2004) for the period 1991–2001, approximately 93,000 legal and 31,000 informal residences were constructed each year; 40% (i.e., about 12,500 buildings) are in the area of Attica. This is equivalent to the size of a small town. Thus, it can be concluded that the biggest problem exists within the region of Attica, primarily in its coastal zone.

Fig. 3 shows a typical example of unplanned urban sprawl in an area of Southern Attica. This area is approx. 1.5 km from the sea and is characterized as agricultural land. Many land parcels are small (most are under the minimum area size for a building permit) and not cultivated. Until recently, most construction in this area was exclusively for vacation purposes. The construction development in the sample area is shown at four different time periods. Aerial photos of the years 1975, 1980, and 1989 and a satellite image from 2001 are shown. All construction made before 1974 was legal, since the government, for a short period, gave permits for vacation houses in smaller parcels. The government later changed these regulations to require all new construction to be on parcels of 4000 m^2 or greater. The upper left area on the photos, with a dense road network, shows a part of the sample area that has a formal urban plan, where development of land is permitted even in land parcels sized at 500 m^2. All the remaining area lies outside of the urban plan.

Observation of the above four images shows that:

- In 1975, the entire area was agricultural land; the few buildings seen were mainly used for agricultural purposes. Few vacation houses appeared due to the temporary governmental decision to permit this type of construction.
- In 1980, more buildings appeared: those that are legal fell within the urban plan, where construction is comparatively larger and denser; informal construction also appeared in the outside of the urban plan area.
- By 1989, almost all the area within the formal urban plan was developed legally. There was significant development within the neighboring area where no urban plan existed the majority of these buildings are informal, having been built without a building permit.
- In 2001, informal development in the area without an urban plan continued at even higher rates.

3. Technical aspects

3.1. Available platforms and high resolution data

Today, a wide variety of sensors and platforms is available, providing many choices for high resolution imagery and complementary data, such as digital surface models (DSMs), that are suitable for the detection of buildings. Such high resolution sensors can be divided into two broad categories: airborne and spaceborne.

Concerning airborne sensors for very high resolution imagery, digital aerial cameras are the standard choice. There are two types of digital aerial cameras: the linear array CCD and the area array CCD (Jacobsen, 2005). Large format digital area array cameras include the DMC© and the UltraCam$_D$©. Both use multiple CCD arrays to synthesize an image of 8000 × 14,000 and 7500 × 11,500 pixels, respectively. They employ electronic forward motion compensation, and, in addition to the usual R, G, B channels, they also have a near infrared channel, with 4–5 times fewer pixels than their panchromatic channel. The Leica ADS40 2nd Generation©, on the other hand, is a linear CCD camera using 8 or 12 CCD lines (in SH51 and SH52 sensor heads, respectively) with 12,000 pixels each and a pixel size of 6.5 μm. It captures four multi-spectral bands (panchromatic, R, G, B and near infrared) simultaneously at the same true high resolution. In the case of airborne sensors for DSM collection, the most probable solution would be light detection and ranging sensor (LIDAR), which can offer dense and accurate DSMs, albeit with a significant cost.

Spaceborne sensors are also a good source for high resolution data. Satellite images may have lower ground resolution than aerial images, but, in general, they are more cost efficient in cases where the area of interest is considerably large. Very high resolution spaceborne imaging systems like IKONOS, KOMPSAT-2 and CartoSat2 provide panchromatic images of 1 m ground resolution and multi-spectral channels with 4 m resolution. QuickBird II and EROS-B offer even better ground sampling distance (GSD), 0.6–0.7 m, whereas the newly launched WorldView-1 and GeoEye-1, with an estimated launch date of the early second quarter of 2008, offer 0.5 m resolution in panchromatic imagery. In the field of spaceborne SAR sensors, TerraSAR-X is able to deliver DSMs for large areas with 1 m ground resolution, making dense DSM acquisition affordable.

3.2. Change detection strategies

Monitoring the suburban environment for illegal buildings is, in fact, a change detection problem augmented by some spatial information concerning land use zones and building regulations. The solutions proposed to the problem depend on the image scale. A schematic overview can be seen in Fig. 4.

In small scales situations (e.g., cases of informal settlement monitoring), the problem is being addressed by various classification–segmentation techniques from the field of remote sensing.

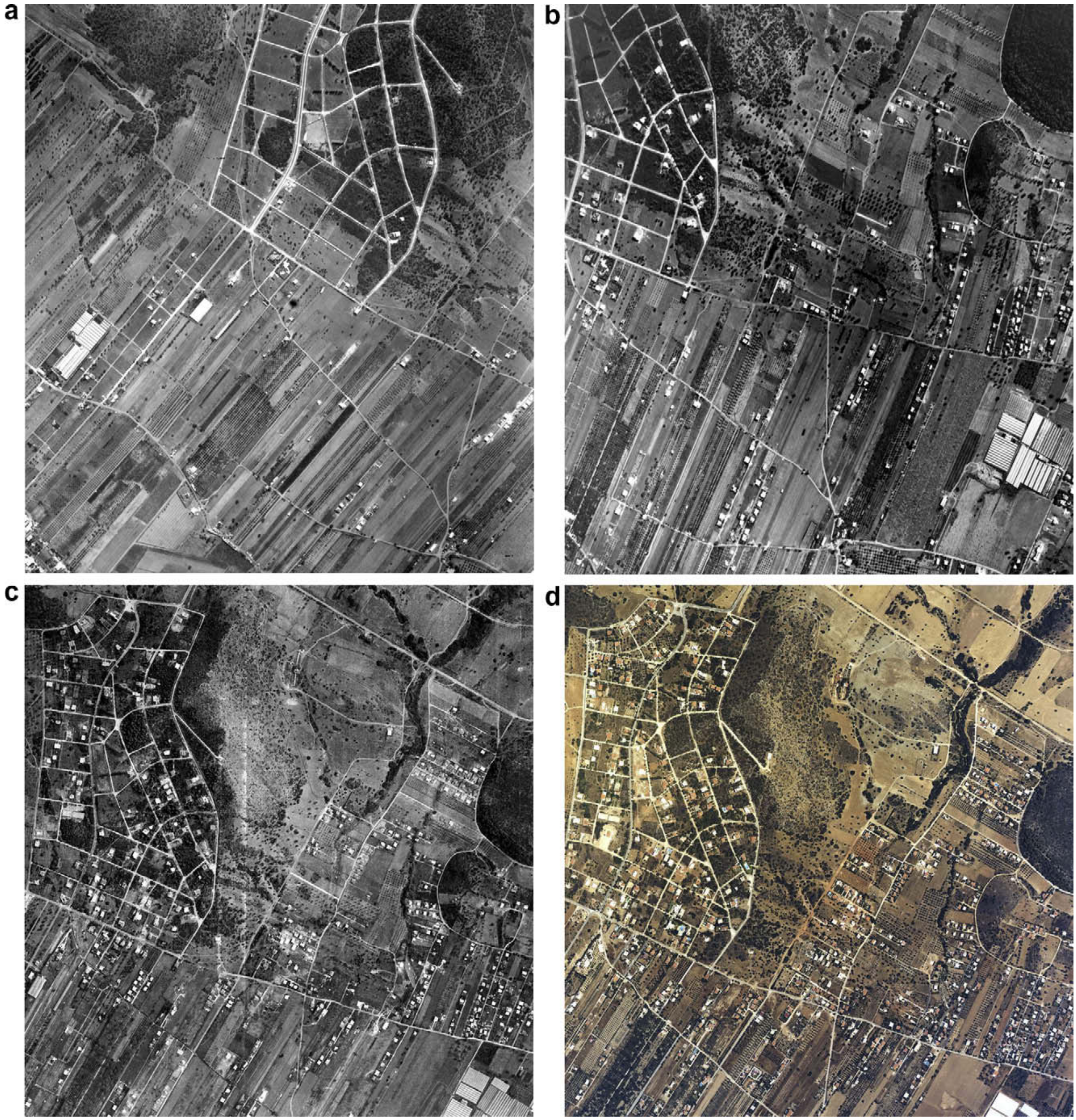

Fig. 3. Example showing construction development in an agricultural area of Attica, which gradually has been turned into vacation area and, in some cases, permanent residential area; the observed area includes both a part within a formal urban plan and areas with informal settlements: (a) aerial photo taken at 1975, (b) aerial photo taken at 1980, (c) aerial photo taken at 1989, and (d) satellite IKONOS image taken in 2001.

Such techniques can be categorized as low-level, mid-level and high-level, with respect to the information used to address the problem:

- Low-level techniques consider information at the pixel level to facilitate change, and include methods like image differencing, rationing and principal component analysis (PCA) (Pratt, 2001).
- Mid-level techniques, including object-oriented classification, feature and texture segmentation, are widely used today (Blaschke, Lang, Lorup, Strobl, & Zeil, 2000; Busch, 1998; Walter, 2004). These techniques are more robust than the low-level methods, as they use a more complex level of information to detect change.
- High-level techniques, also known as knowledge-based methods or expert systems, are currently the most frequently used techniques. They incorporate cognitive functions to improve image-scene analysis and make use of a wide variety of data. Recent studies show that they are very robust and effective at monitoring small-scale, unplanned developments (Hofmann, Strobl, Blaschke, & Kux, 2006; Hurskainen & Pellikka, 2004; Karanja, 2002).

At large scales (e.g., monitoring individual buildings), the problem is more complicated. A basic procedure of this type can be seen in Fig. 5. First, buildings are extracted and then back-projected to the reference data, where it is determined if there has been a

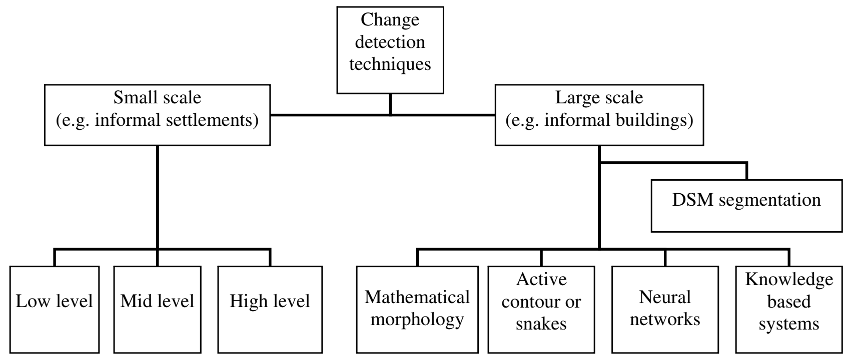

Fig. 4. Change detection techniques categorized by scale.

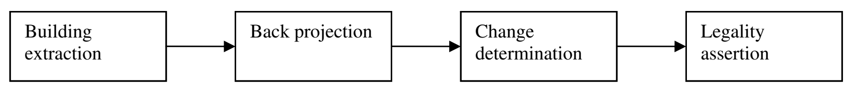

Fig. 5. Phases of informal building monitoring.

change. All of the above procedures can be automated, but with different levels of difficulty and success.

Building extraction is by far the most difficult task to automate. The algorithm might miss certain objects or include some objects that are not buildings, such as trees. Due to the complexity of the problem, many different methods have been proposed, which will be discussed more thoroughly in the next chapter.

Assuming that the data are georeferenced, the process of back-projection is easily automated, as it is just a matter of overlaying building-polygons from different time periods.

Change determination is also relatively simple to automate. After overlaying the building-polygons, a similarity measurement is executed, and a proper threshold value defines whether actual change has taken place.

3.3. Building extraction

Building extraction is the most crucial step in change detection at the single building scale, but it is also useful in applications like 3D city modeling and automatic GIS revision. Because of the wide range of applications, there has been significant research in the field, and many algorithms for building extraction have been proposed. Some of the most popular approaches are: mathematical morphology, DSM segmentation, active contours or snakes, neural networks and knowledge-based systems.

Mathematical morphology employs a set of image operators to extract image components based on the shape and size of quasi-homogeneous regions. The extraction can be multi-scale using the differential morphological profile (DMP), which keeps a variant size for the structuring element (Pesaresi & Benediktsson, 2001), and the only necessary data are imagery. Unfortunately, the results lack completeness even in cases where additional data, like shadow footprints, are used (Jin & Davis, 2005; Shackelford, Davis, & Wang, 2004).

DSM segmentation is another popular technique for extracting buildings because it is simple and straightforward. The basic idea is to segment a DSM into two object classes: ground and above-ground. There are two basic approaches to this. The first subtracts a DTM from a collected DSM, resulting in a normalized DSM that includes only the above-ground objects. The second directly segments the DSM using simple algorithms, like multi-height bins (MHB), which is achieved by grouping homogeneous height regions (Baltsavias, Mason, & Stallmann, 1995), or similar DSM filtering to that done in point cloud data (Sithole & Vosselman, 2004; Tovari & Pfeifer, 2005). The problem with these methods is that the final above-ground objects will include vegetation as well as buildings, so the results might be complete but not correct. Because of this, DSM segmentation is mainly used to approximate the positions of buildings before the application of a more complicated and precise algorithm.

An active contour is a set of points that aims to enclose the target feature. The initial contour is placed outside the building, but it later evolves to match its shape. This approach can be viewed as an energy minimization process. The final position of the snake around the building is one that minimizes its energy (Nixon & Aguado, 2002). Automated snake applications show promising results (Oriot, 2003), but they also introduce some problems. First, there must be a way to automatically initialize the snake. Second, the algorithm has difficulty distinguishing between buildings and nearby trees of about the same height, thereby degrading the extraction accuracy. However, these methods can be further enhanced with the use of multi-spectral data and height information (Guo & Yasuoka, 2002).

Neural networks are capable of scale- and rotation-invariant matching of predefined neuron graphs to images (Barsi, 2004; Bellman & Shortis, 2004). The whole operation is done in two steps. First, the neurons are trained to detect specific building models in a selected training dataset, after which time they are ready to automatically detect the same models in other datasets.

Knowledge-based systems are probably the most popular method for building extraction. Since they can be very flexible, incorporating various kinds of methods and data in an intelligent way, they are more effective in extracting accurately buildings (Baltsavias, 2004; Mayer, 2008). The basic concept is to calculate the values of certain predefined criteria, referred to as cues (Hahn & Stätter, 1998), and from these to automatically decide if an object is a building (Fradkin, Maitre, & Roux, 2001; Khoshelham, Li, & King, 2005; Lu, Trinder, & Kubik, 2006; Rottensteiner, Trinder, Clode, & Kubik, 2005; Shufelt & McKeown, 1993) and what are its exact properties (e.g., shape, size, etc.). The data used in these methods can be imagery, multi-spectral information, height data and even GIS information. In fact, the more diverse the base data, the easier it is to formulate robust cues. For example, if only a panchromatic image were available, then it would be difficult to automatically distinguish vegetation from buildings. However, the use of a near infrared channel and the normalized difference vegetation index (NDVI) makes the same task easier to accomplish. The total number of cues used and the way the system makes its decisions depend on the complexity of the problem. For situations where scene elements must be classified into several categories (e.g., "buildings", "water", "vegetation"), a hierarchical approach is usually implemented. By gradually eliminating all objects from unwanted classes, only the "buildings" class remains. The members of this class are then subjected to a refining stage where their exact geometric properties are defined. In cases where more detailed classes must be discerned and localized, more cues are needed, and a more complex decision system is necessary (Straub, Wiedemann, & Heipke, 2000; Zimmermann, 2000).

In general, all the aforementioned methods involve problems concerning the completeness and correctness of their results, depending on the complexity of the scene. Reports show that about 10% of existing buildings are not extracted at all and almost 10% of the final results are incorrect. Furthermore, the minimum size of the extracted buildings must be relatively large, depending on the scale of the imagery and the density of ancillary data like DSMs.

4. Proposed procedure

A potential long term approach to solving the problem of informal settlements in Greece might be the development and validation of a spatial planning and zoning system that would define, with accuracy and consistency, sound land-use regulations and permit systems. In addition, a modern multipurpose land administration system is needed at a national level, which will not only secure tenure but will also combine cadastral maps with planning and zoning maps and record any construction and development of the land parcels. For an interim approach, an appropriate solution might involve a governmental decision for a legal reform of unregulated land in order to unblock land and facilitate the housing needs of the people and the national economy, as needs develop and change through the years. Very strict, almost unrealistic restrictions and/or the use of police in order to control and supervise the situation have proved, in practice, to be inefficient. Speed and flexibility in planning and applying urban plans in order to meet the demand for developable land is of significant importance.

In the short run, the solution may be to control and systematically monitor informal constructions using an objective and reliable method. This will also gain public acceptance and create the necessary culture, by increasing political will and awareness of the availability of a technical solution, to detect illegal constructions and apply the law. Such an integrated procedure is to be developed, accompanied with a proposal to solve administrative and technical issues.

In most cases, the difference between areas with informal settlements and those in suburban areas with a formal urban plan lies in the pattern of development. Informal development usually has a dense pattern of medium- or small-sized buildings in an area with highly fragmented land parcels. Therefore, the building extraction techniques and the detection of change selected for this project were those that could better fit to specific geometric characteristics of unplanned development in Greece. The most important and critical factor of the proposed action plan, however, is its innovative, holistic approach, which also makes it appropriate for application to the economic and administrative conditions in Greece. The proposed procedure combines technical and administrative aspects with the coordinated involvement of the public and private sectors. The current lack of an objective, reliable, and flexible system for a timely detection of illegal buildings has allowed for their increasing appearance in Greece, hindering the efficient control of the problem. The proposed system should operate independently of the will, negligence or inefficiency of the responsible agencies or the involved individuals. It should provide results before the final occupancy or operation of such buildings as residences or for other use (e.g., store house, industry, etc), since occupancy and use could possibly stabilize the situation and make its reversal almost impossible.

Obviously, this system can support, but not be a substitute for, the legal, social, financial, and other initiatives that must be integrated into the state's land policy in order to minimize the problem and avoid the creation of new generations of informal settlements. Improvement of national and regional spatial planning for sustainable development and compilation of the Hellenic Cadastre Project are the main and necessary tools needed to achieve improvement in Greece.

4.1. Technical approach

First, we discuss the technical part of the proposed system, which is based on periodic control (for short time periods) for the detection of new construction at areas of interest, using automated procedures. The proposed approach for informal building monitoring is a knowledge-based change detection method, employing high resolution aerial or satellite imagery, DSM and multi-spectral data. The main purpose is to devise a technique that is easy to use, cost efficient, robust and accurate. The output of the presented strategy will be automatically derived polygons on an orthophoto denoting possible informal buildings. A user will then assess the results and decide whether there has actually been a change in the area or not.

The main factors that influence the choice of the imagery data used are the size of the area of interest, the image resolution and accuracy, the possibility of having stereoscopic images, and the existence of multi-spectral channels. By examining these factors, it can be said that:

- For cases where the area of interest is especially large, for spatial planning purposes at a national or multi-prefecture level, or for cases where the area is comparatively small, of a size of 100 km^2 (which is the equivalent of a municipality), the use of satellite imagery is the most logical solution in terms of cost. This is primarily due to the very large number of aerial images necessary for the coverage of such an area and to the huge volume of photogrammetric work required. A second reason is the disproportionately high cost for aircraft flight expenses, in comparison to the few aerial images needed; one more factor that may increase flight costs is the distance between the area of interest and the airport from which the aircraft has to start. For all intermediate cases, the use of aerial images seems to yield a more cost effective solution, taking into consideration the purchasing cost of the high resolution satellite stereoscopic scenes, which still remains very high.
- Considering that the minimum size of an informal building that might be worth detecting is 50 m^2, a high resolution image is needed; therefore, aerial imagery at a medium photo-scale is the best solution. An alternative choice would be high resolution satellite imagery, with pixel size 1 m or smaller, like IKONOS, EROS-B, Quickbird, CartoSat2 or Worldview-1.
- For the automated DSM extraction, it is necessary to acquire image stereopairs by an air- or space-borne sensor; sample spaceborne sensors providing image stereopairs include the IKONOS and Worldview-1. The best solution in terms of accuracy is to directly acquire a DSM with an airborne LIDAR system, but the cost is too high.

- To augment the robustness of the method, ancillary data such as multi-spectral images with a near infrared channel must be used. Many high resolution spaceborne sensors offer this feature, like IKONOS or Quickbird, as do the majority of the digital airborne cameras.
- Consequently, in order to satisfy all the above factors, two options exist given the characteristics of the area of interest: use of a digital aerial camera (airborne solution) or of IKONOS imagery (spaceborne solution). It is predictable that, in the near future, there will be many more possible options related to satellite data.
- A series of field and office works, whose products will be used for building monitoring and change detection, follow:
- Set up a network of ground control points, placed mainly at the periphery of the area of interest; measure their coordinates with GPS receivers. Considering the fact that these points will be useful in every period of measurements, it would be prudent to make at least some of them permanent on rooftops or other prominent spots.
- Bundle adjustment aerotriangulation and automatic DSM extraction in a Digital Photogrammetric Workstation (DPW). Considering that the smallest informal buildings to be detected are about 50 m^2, the DSM should be very dense – in a grid with a 5 m cell size – so that at least a few DSM points will be on top of each building.
- Finally, using the DSM, an orthophoto-mosaic for the area of interest can be produced. The two last steps are standard photogrammetric procedures and will be repeated in each measurement period.

The basic idea behind the proposed approach to monitoring construction of informal buildings is that the construction of a new building will appear as a change in the DSM in the area of the construction site. Unfortunately, errors in the automated DSM process, the natural growth of plant life and changes in the ground elevation due to unpredicted factors can all affect the success of the procedure. To cope with these effects, each scene is considered to be a sum of four object classes: "water", "trees", "ground" and "buildings." After a general identification of the elevation changes in the scene, each non-"buildings" class object is eliminated with the use of suitable cues. In general, this technique is a knowledge-based method that uses DSM differentiation to facilitate buildings' construction monitoring. A more detailed description of the eight-step change detection process follows and assumes a reference DSM (DSM_{REF}) and a recently collected new DSM (DSM_{NEW}):

- A near infrared (NIR) channel is used to eliminate "water" areas in DSM_{REF} and DSM_{NEW}. One may notice that, since in many cases the area of interest is coastal and the DSM is produced automatically, many points will be erroneously placed in sea area. To filter out these points, the NIR channel can be very useful. NIR light is absorbed by water, which causes the water to appear almost black in the NIR channel. Setting a threshold on the NIR channel that excludes very dark tones can eliminate the "water" class from an image and the corresponding points from the DSMs.
- An initial assumption is made for candidate change regions by DSM differentiation. Since the DSMs no longer include points in "water" areas, the following initial assumption about change regions can be made through DSM differentiation:

$$\mathrm{CHANGE} = \mathrm{DSM}_{NEW} - \mathrm{DSM}_{REF} \tag{1}$$

The two DSMs must cover exactly the same area, and only positive values are accepted as evidence of change, because the purpose is to locate new buildings rather than collapsed, old buildings. Height values must refer to the same horizontal point, which is determined by interpolation.

- A threshold to changed height is applied to initial candidate objects. To further refine the candidate regions, the method takes into account the expected height of the new buildings. Informal buildings are typically one- or two-story houses, with a standard height of 3–7 m, respectively. These values can be used as a threshold to identify the change candidates.
- Blobs of candidate change areas are formed, but those that are only a few pixels in size are discarded as probable noise. The threshold of the minimum blob size is decided based on the ground resolution of the provided data and the minimum size of the buildings that should be detected.
- At this point, the candidate regions include "trees", "ground" and "buildings". "Trees" are excluded from among the candidate objects by employing the normalized difference vegetation index (NDVI):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \tag{2}$$

NIR: the pixel's reflectance value in the near infrared channel, and
RED: the pixel's reflectance value in the red channel.NDVI values larger than 0.15 strongly indicate the existence of some type of vegetation, so pixels with such NDVI values are considered to belong to the "tree" class.
- The pixels of remaining change candidates are again used to form blobs, and small blobs are erased as in Step 4. A morphological erosion operation is then performed, followed by dilation with the same size and shape of structuring element. This way, blobs with irregular shapes are entirely deleted and large blobs with bays and holes take on a more rectangular shape, better representing a building.
- In the final step, the orthophotos from the two time periods are differentiated, and the blobs and resulting values are replaced by their absolute values. For each blob, the corresponding mean pixel value and standard deviation is calculated. Blobs showing low standard deviation values are rejected because it is very possible for the DSM extraction algorithm to fail in radiometrically homogeneous areas. Blobs that correspond to areas with a very low mean are also rejected as there is only a slight possibility that they are change areas. The criteria mentioned should be rather loose, because image differentiation is strongly influenced by noise and illumination differences between the two images. Assuming the pixel values are normalized and range from 0.0 to 1.0, areas with a standard deviation value less than 0.10 and a mean value less than 0.20 can be safely rejected.
- Polygons are formed around the remaining "buildings" change candidates using a convex hull algorithm; the vector result is projected on the orthophoto.

Following the above technical procedure and using a given a set of reference data (e.g., the situation at the area of interest as it stands today or at a particular time point in the near past), it is possible to detect changes in the class of "buildings" at various future time periods. Whether these changes are really related to buildings and, furthermore, whether these detected new buildings are indeed informal must be determined by user-made checks; these controls can be done either by using automated procedures, such as comparisons of the detected building footprints with spatially defined land-use zones and urban plans or by on site visits.

4.2. Administrative and financial issues

For an efficient informal building control system, the technical procedure for building detection should be part of an integrated administrative procedure. This procedure should involve:

- The central administrative agency (Ministry for the Environment, Physical Planning, and Public Works), which will have responsibility for the project, necessary legal reforms, decision making, strategy and regulations.
- The regional administration, Prefecture or County, which will have responsibility for the commissioning and supervision of the project and validation of the measures and decisions. It is preferable for this responsibility to be at the regional level and not at the municipal level, since the areas of interest for control usually span multiple municipalities; the problem can also be better addressed from a technical and administrative standpoint.
- The private sector, which will have the responsibility for the compilation of studies related to the detection and in-situ control of informal buildings.

According to the above administrative framework, the whole procedure involves the following stages:

1. Compilation of the technical specifications for the studies for the detection and control of informal buildings, by the Ministry; this includes the methods and technical procedures, products, accuracies, etc. Also, the necessary specialized software, which will apply the proposed technical approach, should be developed. The research conducted here should be improved by statistical controls in order to check the efficiency of the proposed method at various specific areas of interest with various characteristics. Furthermore, the achieved level of success should be determined so that the system will be improved.
2. Creation of the responsible division at the County or Prefecture level, which will manage and supervise each project and will apply the necessary final penalties. A few of the employees of this division would need to be specialized technicians, and the division should operate under a flexible administrative framework.
3. Commissioning of a study that will provide the necessary reference data for each area of interest by the Prefecture or the County to the private sector. Attention should be paid to evaluating all available relevant data, such as recent aerial photos at scales 1:25,000–1:40,000, DTM, and orthophotos of acceptable accuracy. In-situ controls of the completeness and accuracy of the products should be included in the requirements of the study.
4. Signing of contracts with the private sector for compilation of the studies on the detection of informal buildings in a County or Prefecture. The contract should have long duration (e.g., 5 years) so that the private company will be able to apply governmental policy efficiently and without narrow time limits. The time schedule and the selection of target application areas can be made in cooperation with the public administration. Two options are possible: periodic (e.g., annual) application of the procedure on the whole area of interest in a Prefecture or County, or frequent sample control testing by applying the procedure on random smaller areas (e.g., of a size of a satellite scene). The second choice has the advantage of "lower cost" and can be completed in "less time" (e.g., within 3 months).
5. Application of the study using IKONOS satellite images or acquiring digital aerial images. The localization of new buildings that are potentially informal will occur automatically when the method is applied to areas where no urban plan exists. In-situ control should follow up to prove the correctness of the results.
6. Administration of judgment, such as penalties, an injunction against continuing construction, removal of the construction, or other actions, by the responsible administrative agency, which should be determined by the central administration and applied consistently in the whole jurisdiction.
7. Frequent repetition of the whole procedure so that the goal to control and eliminate massive informal urban development (new illegal buildings or informal large extensions to the existing buildings) will be achieved. The challenge is to detect all illegal buildings before they are completed. Therefore, it is important to make periodic controls for illegal constructions within short time periods. If this becomes too costly, an alternative is to apply sudden sample controls.

Of additional benefit from the procedure are the derived byproducts, like orthophotos and dense DSMs, which are useful for a variety of other applications such as spatial planning, real estate market monitoring, environmental protection studies, coastal zone management, risk assessment and disaster management for floods or fires.

5. Applications

5.1. Application to eastern Attica: technical and financial issues

The most appropriate area in which to investigate the applicability of the proposed procedure is the eastern part of Attica (Fig. 6). From available statistics about informal settlements, it is evident that this area is one of those most afflicted by a preponderance of informal buildings; in addition, it is close to the city of Athens, and land values are especially high. A coastal zone 3 km wide, which is attractive for permanent residence or for vacation housing (marked on Fig. 6 with a cyan line) and where the biggest percentage of illegal buildings exists, is of special

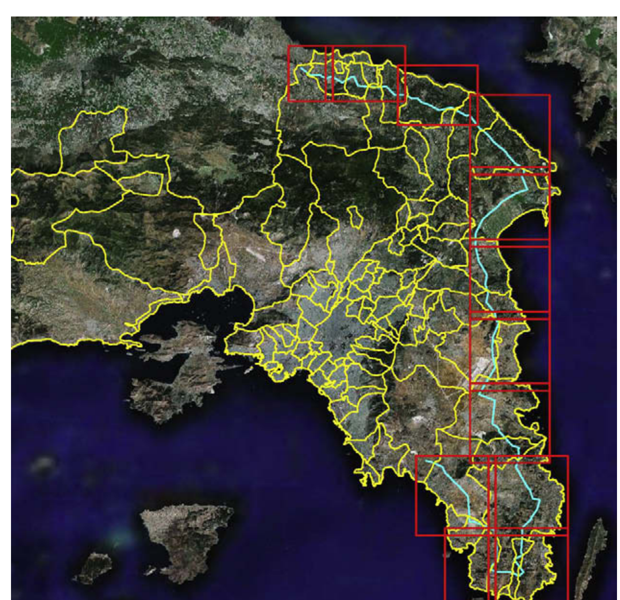

Fig. 6. Attica peninsula with the municipality boundaries and footprints of the IKONOS images covering the eastern coastal zone.

interest. The area includes 43,500 ha, with a coastal line 160 km in length; administratively, it includes 22 municipalities, all of which are in the County of Eastern Attica. Consequently the County is the most appropriate agency for exacting the proposed procedure.

The cost to run this project may be distinguished into two parts: the cost for the implementation of the proposed strategy and the cost for every application period.

The implementation cost includes:

- *DSM and base map production.* An amount of approximately 35,000 € is required to have full coverage of the area with IKONOS stereo-pairs, with an overlap of 10% so that an aerotriangulation adjustment can be applied; the footprints of these scenes are marked in red in Fig. 6. If the area is covered with digital stereoscopic aerial images, with a pixel size of 60–80 cm on the ground (equivalent to photos at a scale of 1:30,000), approximately 80 images and an amount of 20,000 € are required. So, using aerial images is the least costly approach. In both cases less than ten ground control points, measured by GPS and scattered at the periphery of the block, are enough for the aerotriangulation adjustment. When aerial images are used measurements using differential GPS made during the aircraft flight should be available. The expected cost for the compilation of all photogrammetric work for the DSM and orthophoto map production is 20,000 €.
- *In-house production of software.* An indication of this cost might be the purchase price of available commercial packages, appropriate for automatic change detection (e.g., eCognition©, Feature Analyst©), which is 3,500–5,000 €. Consequently, the total implementation cost, for the area of 43,500 ha, is approximately 45,000 €.

The cost for the application of the proposed strategy per measuring period includes:

- *DSM and orthophoto production.* When using digital aerial images the cost, as estimated above, is 40,000 €.
- *Change detection.* The use of the in-house produced software demands 1 man-week of a suitably trained user, for the area of 43,500 ha. So, the cost is about 1,000 €.
- *In-situ quality control.* It depends on the number of the detected new buildings. Based on the existing statistics about the number of new constructions (legal and illegal) in the area, it is estimated that for the in-situ control 4 man-weeks are necessary, costing about 4000 €.

Consequently, the total cost for the application is estimated to be 45,000 € per measuring period, which when divided by the area size results to approximately 1 € per ha. The estimated cost for each one of the 22 municipalities of the region is about 1000–3000 €, which is considered to be reasonable and affordable even for a frequent repetition of the procedure.

An attempt for cost comparison between the above proposed automatic detection procedure and the traditional field inspections method does not comply with the general concept of this research. The major objective is to develop a method which reduces the human involvement and thus reduces the risk for corruption or any agreement between the inspector and the constructor or the owner of the informal building. In addition, the cost estimation for field inspections includes considerable uncertainty due to the accessibility problems of informal constructions in each area, and the technical issues related to the method that should be used for an accurate updating of the base map in the field (in terms of location and size of the new construction).

5.2. Experiment: technical procedure and results

The proposed technical approach using real data was applied, for practical reasons, to a small area of the municipality of Ag. Stefanos in Attica. The test area is located outside the old urban plan, where residential buildings of a medium or large size are mixed with agricultural activities and heavily vegetated land (Fig. 7).

The image data acquired for this area were a strip of three b/w aerial photos from 1996 at a scale of approx. 1:10,000, used as a reference, and an IKONOS satellite image stereopair (panchromatic, RGB and NIR) from 2001. The test area has a size of 21.3 ha and, in 2001, it included 88 buildings, of which 47 did not exist in 1996. The average size of each building is 180 m^2, and the land parcel area per building is 2400 m^2.

The first stage of the application test was a photogrammetric process, which included orientation of the images. The required ground control points (GCPs) were measured by GPS, and the aerial triangulation was done in the Leica Photogrammetric Suite™ (LPS). An attempt was made to measure GCPs visible in both periods to provide better co-registration of the periods. Ten GCPs were measured, and aerial triangulation with bundle adjustment was performed separately for each period because LPS version 8.7 does not support simultaneous aerial triangulation of satellite and aerial images. In more detail:

- For the 1996 period, 6 GCPs were used for orienting the strip. The aerial triangulation results were rms $(X,Y,Z) = 0.14 \div 0.18$ m was derived.
- For the 2001 period, the panchromatic, red multispectral band and near infrared band were oriented simultaneously with 5 GCPs, 3 of which were common to the previous period. The aerial triangulation results were rms $(X,Y,Z) = 0.46 \div 0.69$ m.

The next step was the DSM extraction for each period, which was performed automatically in LPS with a grid GSD of 3 m; the DSM from 2001 with the IKONOS imagery was derived from the panchromatic stereopair. Visual examination of the results showed that about 85% of the total points extracted were correct, as expected based on previous experience with LPS. There was no man-

Fig. 7. Location of a test area in the municipality of Ag. Stefanos, in Attica.

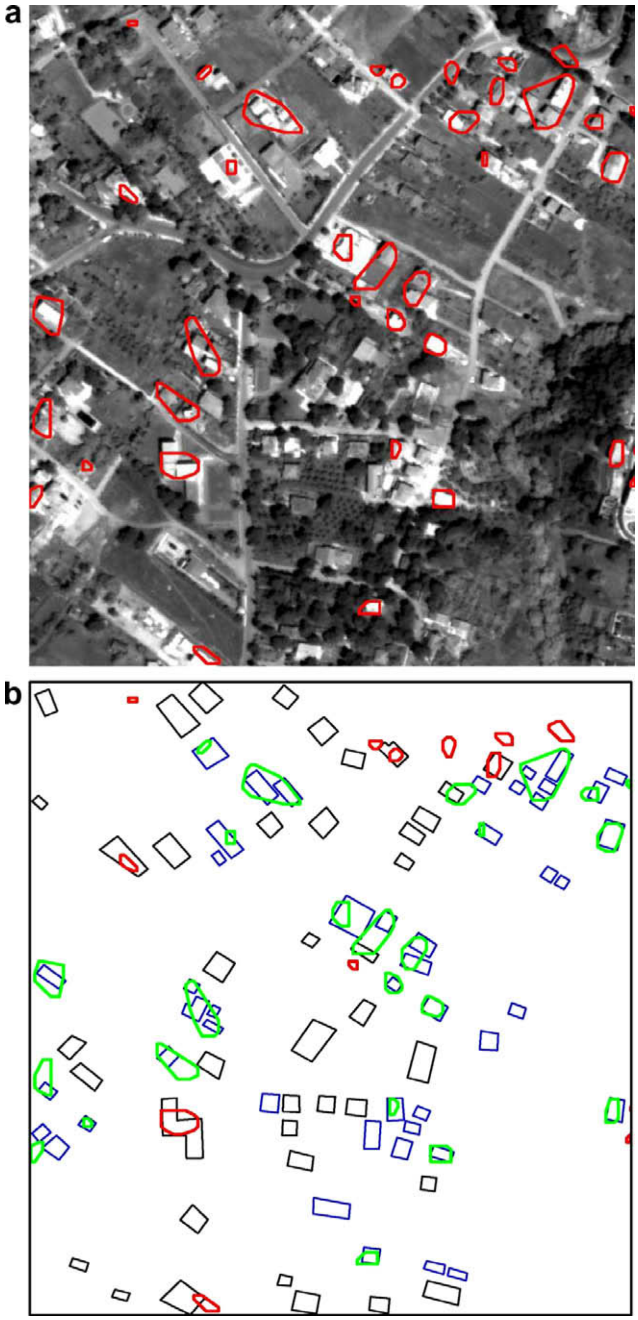

Fig. 8. Overlay of automatically detected change polygons: (a) on the orthophoto of 2001, and (b) on the manually created change map.

ual editing of the DSMs, and they were used directly to produce orthophotos with 0.5 m ground resolution. These DSMs and orthophotos were cut to the borders of the selected test area. The exact borders were defined by their ground coordinates.

The next stage of the test was the application of the developed change detection algorithm to the selected test area. The inputs were cut DSMs in ASCII format, cut orthophotos in tif format, and the criteria for filtering the change candidates (height change range, minimum blob size, NDVI, structuring element, standard deviation threshold, etc). The algorithm returned 37 change polygons; note that the test area actually included 47 new buildings in the period under study.

The assessment of the results was made by examination of a reference map of the actual changes, which had been created manually after stereoscopic observations of the images of the two periods and manual restitution of the footprints of the buildings. The detected change polygons were overlaid on this map, and those that represented actual changes were noted. These results show that, in the 37 returned change polygons, 34 changed buildings are included; there are also 13 falsely detected polygons. Consequently, in some of the returned polygons, more than one new building is included.

Fig. 8a shows the detected change polygons overlaid on the orthophoto of 2001, while Fig. 8b shows the results of the assessment procedure. The correct change polygons, which were returned from the proposed strategy, are shown in green, and the false positives are shown in red. Also, the footprints of the buildings that remain unchanged are outlined in black, while the footprints of changed buildings are outlined in blue.

Consequently, with the proposed algorithm, using fully automated procedures, 72% of new buildings were detected, and 35% of the returns did not refer to real changes. The quality of the DSMs has a major impact to the final results. Better results are expected if more accurate DSMs are used, such as the ones acquired from LIDAR sensors, but this would have a negative impact to the overall cost of data acquisition. The accuracy of the method is also influenced by the efficiency of the filtering stage, where empirically determined coefficients are included. However, the large percentage of incorrect polygons could be easily dismissed by a human operator, since many false positives usually include profound errors like roads, vegetation or barren land. Thus, the additional burden on the user is not directly proportional to the number of false returns and accuracy, but rather on the nature of the false changes.

6. Conclusions

Unplanned urban development is still a major issue in Greece, as it is in several other countries around the world. According to this research and to the authors' experience, the creation and extent of informal settlements are not always directly dependent on the country's GDP or the level of prosperity. The persistence of good quality but illegal construction is due to several administrative, legal, social, fiscal, and cultural parameters that influence the development of land in the area. The remedy is complicated and demands a series of combined actions at several levels.

The proposed procedure for the detection of informal buildings can contribute to the control of unplanned urban development and to the elimination of the creation of new informal settlements, until the planning and application of the appropriate long-term actions has been achieved. From a technical perspective, it is a robust, automated and easy-to-use process for obtaining the approximate location, although not necessarily the shape, of a building, with satisfying results. It benefits from the modern "know how" in monitoring of changes and in automatic building extraction using high resolution images. It is not especially sensitive to the characteristics of the detected objects and the accuracy of the results is not dependent upon user choices. No special investment in expensive hardware is needed; only GPS receivers and Digital Photogrammetric Workstations are required. All other processing is done by software that does not demand any specialised knowledge.

Administratively, the proposed system may be easily applied at a regional level without significant requirements for state acts (e.g., a new legal framework). The method is cost-efficient, taking into consideration the benefits of solving the problem of loss of state revenue and the impact on the national economy that such informalities bring, until the necessary reforms are in place.

References

Baltsavias, E. P. (2004). Object extraction and revision by image analysis using existing geodata and knowledge: Current status and steps towards operational systems. *ISPRS Journal of Photogrammetry and Remote Sensing, 58*(3–4), 129–151.

Baltsavias, E. P., Mason, S., & Stallmann, D. (1995). Use of DTMs/DSMs and orthoimages to support building extraction. In A. Grün, O. Kübler, & P. Agouris (Eds.), *Automatic extraction of man-made objects from aerial and space images* (pp. 199–210). Basel, Switzerland: Birkhäuser Verlag.

Barsi, A. (2004). Object detection using neural self-organisation. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXV*(B3), 366–371.

Bellman, C. J., & Shortis, M. R. (2004). A classification approach to finding buildings in large scale aerial photographs. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXV*(B3), 337–342.

Blaschke, T., Lang, S., Lorup, E., Strobl, J., & Zeil, P. (2000). Object-oriented image processing in an integrated GIS/remote sensing environment and perspectives for environmental applications. In A. Cremers & K. Greve (Eds.). *Environmental information for planning, politics and the public* (Vol. 2, pp. 555–570). Germany, Metropolis-Verlag: Marburg.

Busch, A. (1998). Revision of built-up areas in a GIS using satellite imagery and a GIS. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXII*(4), 91–98.

GISdevelopment. (2007). *3D GIS system for monitoring illegal constructions in India's capital city to be implemented fully by next year* [Retrieved January 25, 2007]. <http://www.gisdevelopment.net/news/catapp.asp>?sub=Urban%20 Planning.

Guo, T., & Yasuoka, Y. (2002). Snake-based approach for building extraction from high-resolution satellite images and height data in urban areas. In *The 23rd Asian conference on remote sensing, unpaginated CD-ROM.*

Fradkin, M., Maitre, H., & Roux, M. (2001). Building detection from multiple aerial images in dense urban areas. *Computer Vision and Image Understanding, 82*, 181–207.

Hahn, M., & Stätter, C. (1998). A scene labeling strategy for terrain feature extraction using multisource data. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXII*(3/1), 435–441.

Hofmann, P., Strobl, J., Blaschke, T., & Kux, H. (2006). Detecting informal settlements from Quickbird data in Rio de Janeiro using an object based approach. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVI, 4/C42, unpaginated CD-ROM.*

Hurskainen, P., & Pellikka, P. (2004). Change detection of informal settlements using multi-temporal aerial photographs – the case of Voi, SE-Kenya. In: *Proceedings of the 5th African association of remote sensing of the environment conference, unpaginated CD-ROM*.

Jacobsen, K. (2005). Photogrammetry and geoinformation trends in large scale mapping. In: *1st annual map middle east conference, geospatial information and knowledge economy, unpaginated CD-ROM.*

Jin, X., & Davis, C. H. (2005). Automated building extraction from high-resolution satellite imagery in urban areas using structural, contextual, and spectral information. *EURASIP Journal on Applied Signal Processing, 14*, 2196–2206.

Karanja, F. N. (2002). *Use of knowledge based systems for the detection and monitoring of unplanned developments*. Doctor thesis, Institute of Photogrammetry and Engineering Surveys. Hannover, Germany: University of Hannover.

Karavassili, M. (2004). Procedure simplifications to facilitate application of urban planning and environmental legislation through control mechanisms and inspections. *Workshop on urban planning and construction, technical chamber of Greece* (in Greek).

Khoshelham, K., Li, Z. L., & King, B. (2005). A split-and-merge technique for automated reconstruction of roof planes. *Photogrammetric Engineering and Remote Sensing, 71*(7), 855–862.

Lu, Y. H., Trinder, J., & Kubik, K. (2006). Automatic building detection using the Dempster–Shafer algorithm. *Photogrammetric Engineering and Remote Sensing, 72*(4), 395–403.

Mayer, H. (1999). *Automatic object extraction from aerial imagery – A survey focusing on buildings* [Retrieved January 23, 2007]. <http://www.ipb.uni-bonn.de/readings/1999/mayer99.automatic.pdf>.

Mayer, H. (2008). Object extraction in photogrammetric computer vision. *ISPRS Journal of Photogrammetry and Remote Sensing, 63*(2), 213–222.

Nixon, M., & Aguado, A. S. (2002). *Feature extraction and image processing*. England: Newenes (pp. 220–243).

Oriot, H. (2003). Statistical snakes for building extraction from stereoscopic aerial images. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXIV*(3/W 8), 65–70.

Pesaresi, M., & Benediktsson, J. A. (2001). A new approach for the morphological segmentation of high-resolution satellite imagery. *IEEE Transaction on geosciences and remote sensing, 39*(2), 309–320.

Potsiou, C., & Ioannidis, C. (2006). Informal settlements in Greece. The mystery of missing information and the difficulty of their integration into a legal framework. *5th FIG regional conference.* [Retrieved February 25, 2007]. <http://www.fig.net/pub/accra/papers/ts03/ts03_04_potsiou_ioannidis.pdf>.

Pratt, W. K. (2001). *Digital image processing* (3rd ed.). New York, USA: John Wiley & Sons Inc (pp. 289–294).

Rottensteiner, F., Trinder, J., Clode, S., & Kubik, K. (2005). Using the Dempster–Shafer method for the fusion of LIDAR data and multi-spectral images for building detection. *Information Fusion, 6*(4), 283–300.

Shackelford, A. K., Davis, C. H., & Wang, X. (2004). Automatic 2D building footprint extraction from high-resolution satellite multispectral imagery. *Proceedings of International Geoscience and Remote Sensing Symposium, 3*, 1996–1999.

Shufelt, J., & McKeown, D. (1993). Fusion of monocular cues to detect man-made structures in aerial imagery. *CVGIP: Image Understanding, 57*(3), 307–330.

Sithole, G., & Vosselman, G. (2004). Experimental comparison of filter algorithms for bare earth extraction from airborne laser scanning point clouds. *ISPRS Journal of Photogrammetry and Remote Sensing, 59*(1–2), 85–101.

Straub, B. M., Wiedemann, C., & Heipke, C. (2000). Towards automatic interpretation of images for GIS update. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXIII*(B2), 525–532.

Tovari, D., & Pfeifer, N. (2005). Segmentation based robust interpolation – a new approach to laser data filtering. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXVI*(3/W19), 79–84.

Walter, V. (2004). Object-based classification of remote sensing data for change detection. *ISPRS Journal of Photogrammetry and Remote Sensing, 58*(3–4), 225–238.

Zimmermann, P. (2000). A new framework for automatic building detection analysing multiple cue data. The international archives of the photogrammetry. *Remote Sensing and Spatial Information Sciences, XXXIII*(B3), 1063–1070.