POTENTIAL APPLICATION OF REMOTE SENSING IN MONITORING INFORMAL SETTLEMENTS IN DEVELOPING COUNTRIES WHERE COMPLIMENTARY DATA DOES NOT EXIST

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Abstract

The burgeoning of informal settlements constitutes one of the most complex and pressing challenges facing developing countries (Fekade, 2000). Informal settlements make up 30-60% of urban settlements in developing countries. Research shows that living conditions in these settlements are causing a direct and daily threat to the wellbeing and quality of life of the entire community, creating cities defined by poverty and high levels of crime and violence (Amis, 1995; Hope, 1996; Pugh, 2000; Jenkins, 2001). The dynamic nature of informal settlements presents data, information and resource challenges to authorities trying to cater for the basic needs of these settlements.

One of the possible solutions is remote-sensed data. Much has been written about the potential of remote-sensed data as a source to identify and track changes in informal settlements (Mason *et al*., 1998; Hurskainen *et al*., 2004; Hofmann *et al.,* 2006; Lemma *et al.,* 2006), yet the application of remote sensing in urban planning in South Africa remains marginal.

Recent advances in computing power and the increasing availability of remote sensing imagery, such as QuickBird, have revived renewed interest in remote sensing as potential data ware for planning support, modelling and simulation practices; however, the application of remote sensing to specific problems has proceeded more rapidly in agriculture, geology and natural resource management than in urban analysis and research. In practice, when observing key characteristics of formal urban settings, information is predominantly sourced from official municipal records, such as approved building plans. Informal settlements are relatively dynamic in nature, municipal records, when available, are often incomplete, outdated or simply cannot keep pace with rapid changes. Combining remotely sensed data with these 'islands' of municipal data records may provide added benefit for planners.

The paper starts off describing some of the most common challenges faced by government in sourcing data on informal settlements. It then goes further providing an overview of past attempts and current practice in the monitoring of informal settlement behaviour, using remote sensing. The paper concludes with the results of a recent case study of the greater Soweto area in South Africa. The case study explored the kind of morphological human settlement attributes that can be observed from QuickBird. These attributes are used to (a) assess their applicability to support existing urban settlement typologies, applied by leading public and private sector institutions in South Africa; (b) propose an urban settlement typology for informal settlements based on morphological attributes with the aim of incorporating this in (c) an automated data extraction and classification procedure that could then be combined with socio-economic data and statistical methods to render planning support and monitor informal settlements. The paper concludes with lessons learned and remaining challenges.

Keywords

Informal settlements, planning, remote sensing, classification, built-up environment, South Africa

Background

Informal settlements are a common feature of developing countries (Huchmeyer *et al.,* 2006). Informal settlements are known by a variety of names such as shacks, slums, squatter areas, shanty towns, irregular settlements and such like nomenclature. Nevertheless, whatever the name, the common phenomena that distinguish informal settlements from formal settlements are as follows: do not adhere to local building codes, have either low levels of infrastructure or no infrastructure altogether, are either poorly serviced or not serviced at all, have no security of tenure and are characterised by a rather non-functional pattern.

The UN (UNSTAT, 2005) describes informal settlements as (a) areas where groups of housing units have been constructed on land that the occupants have no legal claim to, or occupy illegally; and (b) unplanned settlements and areas where housing is not in compliance with current planning and building regulations. Cities Alliance defines slums as neglected parts of cities where housing and living conditions are appallingly poor. Slums range from high-density, squalid central-city tenements to spontaneous squatter settlements without legal recognition or rights, sprawling at the edge of cities. In 1999, the World Bank and UN-Habitat introduced a ‘Cities Without Slums’ initiative with the defined goal of achieving a significant improvement in the lives of at least 100 million slum dwellers by the year 2020. This target, commonly known as Target 11 under Millennium Development Goal 7 ensures environmental sustainability and gives a new meaning to the term ‘slum’, which was then defined as any area that met the following six criteria: lack of basic services, inadequate building structures, overcrowding, unhealthy and hazardous conditions, insecure tenure, and poverty and exclusion (Huchzermeyer *et al.,* 2006).

Informality in the form of unregulated and unlawful land use, settlement establishment and unauthorised housing are on the rise in developing countries and are proving to be the starkest material manifestation of a grotesquely divided, unequal society. Factors that have led to the mushrooming of informal settlements in developing countries, most particularly in Africa, are massive rural urban migration, poverty and unequal distribution of wealth, poor land delivery systems, political instability, inability of the government to define a clear and long-term land and housing policy and, lastly, high demand from very low-income groups that makes the management and upgrading of these settlements more difficult (Mosha, 1996). Reasons for the increase in migration are mainly attributed to cities offering better possibilities for employment, education and access to social infrastructure.

According to UN-Habitat 2005, Africa’s urban population is increasing at above three percent and is the fastest urbanising continent, now surpassing the annual urban growth rates in Latin America and Asia. The extent of squatting is frightening: over 60% of Kampala’s (Uganda) population live in squatter settlements (Kulabako *et al.,* 2007); almost 70% of the population of Dar es Salaam (Tanzania) live in the slum belt (Kombe, 2005); at least 60% of the population of Kisumu (Kenya) live in dilapidated housing. According to UN-Habitat (2005) the slum to urban population in South Africa is sitting at 33%. UN-Habitat’s projections indicate that the trend towards urbanisation will continue to increase with 40% of the continents population expected to be urbanised by 2015.

Introduction

Peruvian economist Hernando de Soto (2000), contends that formal and planned developments constitute the exception in developing countries, while unplanned developments are the norm. He believes that informality can readily be incorporated into the formal, thereby providing access to the benefits of the market or capital. Other schools of thought label informal settlements as a threat, not only to the value of individual properties but also to cities ability as a whole to attract international investment. In this context failure to intervene in a manner that improves residents' quality of life may lead to social and political unrest.

In both contexts there is a critical need to understand the social and spatial dynamics of informal settlements if authorities are to effectively incorporate these entities into formal planning mechanisms. This is difficult as informality and the dynamic nature of these settlements result in limited, up-to-date information required for planning for basic infrastructure and services.

The objective of this paper is to describe some of the challenges government faces in sourcing data on informal settlements. The potential application of high-resolution remotely-sensed data, such as QuickBird, for monitoring informal settlements is also explored. This is done by reviewing applicable applications elsewhere in the world. Following from this, the paper uses the greater Soweto area in South Africa as a case study area to explore what kind of morphological human settlement attributes can be observed from QuickBird. These attributes are used to (a) assess their applicability to support existing urban settlement typologies, applied by leading public and private sector institutions in South Africa; (b) propose an urban settlement typology for informal settlements based on morphological attributes with the aim of incorporating this in (c) an automated data extraction and classification procedure that could then be combined with socio-economic data and statistical methods to render planning support and monitor informal settlements. The paper concludes with lessons learned and remaining challenges.

Challenges faced by government in sourcing data on informal settlements

Government recognises that the existence of informal settlements is a serious concern as they accommodate a large proportion of the urban population who lives in sub-standard living conditions. In addition, it is also realised that an increase in migrants to urban areas inevitably leads to a shortage of basic engineering services such as water, sewerage and solid waste removal, and places essential services such as health and education under pressure. One of the fundamental difficulties that authorities face when planning a response to the formation and growth of informal settlements is the paucity of spatial and temporal data to assist in recognising and quantifying the understanding of settlement morphology, services/infrastructure, growth, population distribution and emerging settlement patterns. Reasons for the inability to obtain data include:

1. *Informal settlements are generally characterised by a dysfunctional settlement structure.* The distribution of plots follows no planned structure or conventional planning principles and streets and technical infrastructure are not catered for. Plot boundaries are unknown or non-existent, and plot sizes varies greatly;
2. *Settlements are highly condensed and difficult to access for surveys.* In certain situations, it is also considered to be too dangerous for official enumerators to do house-to-house data collection;
3. *Informal settlements are dynamic.* Population fluctuations and the erection and removal of structures over short time periods, mean that traditional survey methods cannot effectively

capture temporal reality. Traditional surveys may take several months to process, rendering the results outdated at the time of release;

4. *Unclear municipal boundaries and overlapping administrative responsibilities*. Deficits in manpower, lack of finance and technical equipment are additional challenges; and
5. *As a result of these difficulties informal settlements are often not spatially documented*. There are no maps indicating the position, patterns, size, complexity and influence of the settlements. Maps are regarded as unbiased and neutral sources of information about the world. Such is the power of the map that if authoritative, official maps and atlases fail to map places, the impression is given that those places do not exist (Stickler, 1990).

Monitoring of informal settlement behaviour using remote sensing

High-resolution satellite imagery has become more readily available over the past few years. This category of satellite commonly includes IKONOS (1999), EROS (2000), QuickBird (2001), SPOT-5 (2002) and ALOS (2006). Urban geographers have recognised the potential of this information for various applications, including updating of maps, extraction of urban features such as road networks and other engineering and social infrastructure, generation of urban models, land-use mapping, and a wide range of other possible applications (Volpe and Rossi, 2003; Paulsson and Bengt, 1992). Despite its potential application Herald *et al.* (2006) noted that remote sensing remained an under-utilised data source in urban studies. In addition, the majority of studies that have been undertaken concentrate on first world examples. The use of high-resolution remote-sensed satellite data in developing countries is sparser, although examples are available.

Hofmann (2001) showed how informal settlements can be detected from other land-use-forms by describing typical characteristics of colour, texture, shape and context using remote-sensed data from IKONOS in Cape Town. He showed that results are very dependent on the data used. In cases where the settlements were not appropriately classified, visual inspection was carried out or a final correction was performed by hand with eCognition. He concluded that while high resolution IKONOS data is well suited to detect informal settlements areas, using pure IKONOS image data was not sufficiently feasible to detect a single shack.

Hurskainen (2004) used black and white and true-colour aerial photography from 1985, 1993 and 2004 for studies of growth and change of informal settlements in Voi, Kenya. The images were processed in EnsoMOSAIC and Erdas imagine software whilst the segmentation and classification procedures were implemented in the eCognition software. Scale, shape and compactness parameters were adjusted and thematic layers were incorporated to improve the classification accuracy. Results showed that iron sheet roofs were segmented and classified with 95 per cent accuracy. Limitations encountered were related to misclassification, e.g. grey tones for roofs were not spectrally distinct enough to separate them from the background. In such cases, visual inspection of the classification was done in Arcview and necessary corrections were made.

Stasolla *et al.* (2007) used SPOT-5 images with 2.5m spatial resolution to detect informal settlements (refugee camps) in Darfur, Sudan. They developed a semi-automatic procedure adopting an unsupervised approach that allows detecting, with high precision, the boundaries and the extent of the settlements, both formal and informal, and, to some extent, were able to separate these two classes based on differing building densities. This was achieved by using variance measures and K-means algorithm. Once the position of the settlement had been detected, the next step in the procedure was to try and identify different building densities to discriminate the city core from the refugee camps. The inability to differentiate single buildings due to scale and resolution, and similar textural properties between certain vegetation classes and settlements leading to incorrect classification were cited as limitations.

Nobrega *et al.* (2007) explored the use of IKONOS images to detect and classify roads in informal settlements in São Paulo, Brazil. Rules were created to cater for unique land cover and land use. The methodology employed three software technologies, namely Erdas Imagine, eCognition and ArcGIS. Misclassification problems involved confusion between large buildings and parking lots with streets. The problem was minimised by creating filtering rules based on geometric properties. The accuracy assessment for the resulting classification was 65%.

In conclusion, available literature can play a role in monitoring informal human settlements.

The applications examined, however, also indicate that the urban environment presents a challenge to existing algorithms due to the heterogeneous nature of urban areas. Successful feature detection ranged from 60-97%, depending on the application of the examples studied. Scale, feature size, shape and composition as well as context therefore play an important role in determining suitable applications. Various authors have indicated that the detection of single elements can be problematic; e.g. in the case of informal settlements where dwellings are often constructed so close together as to appear contiguous.

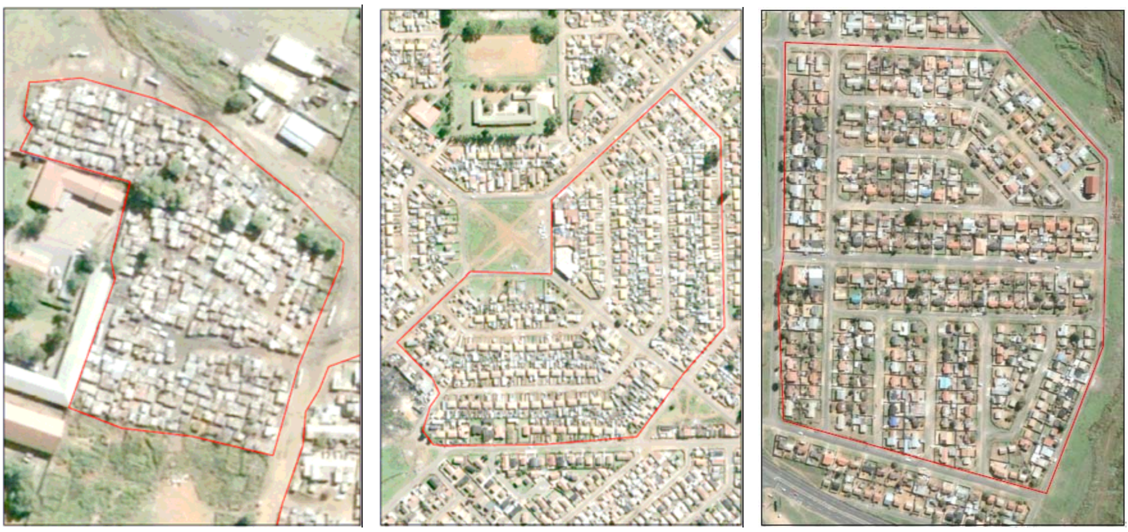
None of the processes examined were fully automated and, due to feature misclassification, rely on manual intervention, introducing a significant time component.

Case study area: Soweto, South Africa

Introduction

Soweto is an urban area in the Greater Johannesburg Metropolitan area, in Gauteng, South Africa. Recent demographics are not readily available at the time of writing this paper but South Africa's 2001 census put its population at approximately 900 000, which translates to about one-third of the city's total population. To analyse the complexity of the informal settlements, satellite images of QuickBird dated from 2005 with 0.60m spatial resolution respectively were sourced and polygons were created to delineate homogeneous areas (see Figure1).

Figure 1: QuickBird images of different types of settlements in Soweto



Observing urban settlement attributes

A list of physical settlement attributes were compiled and used as a basis to assess the extent to which these attributes can be observed from QuickBird. Table 1 specifies the list of urban settlement attributes with the corresponding results.

Table 1: Observed human settlement attributes, using QuickBird

Spatial attributes	Characteristics	Description	Manual extraction from QuickBird (Y/N)
Structure size	Uniform size *vs*. different size	Building size	Y
Settlement layout	Planned *vs*. irregular layout of settlements	Road layout; Erf/lot demarcation	Y
	Open space	Number of open space available, Presence of trees	Y
Housing structure	Building materials	Corrugated iron sheets, wood, plastic, cardboard, bricks etc	Y
	Colour of roof	Homogeneous *vs*. heterogeneous	Y
	Density	Low *vs*. high, Adequate space between houses	Y
Engineering services	Roads	Tarred *vs*. gravel/paths	Y
	Telecommunication	Telkom/Vodacom/MTN/Cell C poles	N
	Electricity	Electric poles/substation	N
	Water and sanitation	Tap and toilet facilities and reservoir	Y
	Storm water drainage	Presence of man holes	N
	Waste management	Presence of dumping grounds/landfills	Y
Infrastructure	Education	Presence of schools, colleges	Y
	Business opportunities	Presence of shops, food outlets	Y
	Social facilities	Presence of sports ground/stadium, clinics, community centres, police stations	Y
	Transport facilities	Presence of bus/taxi ranks, stations/railways	Y

The results of the manual extraction of the attributes show that size, layout, housing structure and infrastructure could be identified from the QuickBird images whilst establishing whether the settlements had access to different types of engineering services were not conclusive.

Existing urban settlement typologies

Using the above attributes in Table 1, the applicability of using existing urban settlement typologies, applied by leading public and private sector institutions in South Africa, was assessed. The chosen public institutions were the Department of Land Affairs and Statistics South Africa whilst Knowledge Factory was the selected private sector organisation. The Department of Land Affairs developed what is known as the South African National Land Cover Classification Legend as shown in Figure 2. Figures 3 and 4 indicate the existing typologies of Statistics South Africa and Knowledge Factory respectively.

Figure 2: The South African national land cover classification legend

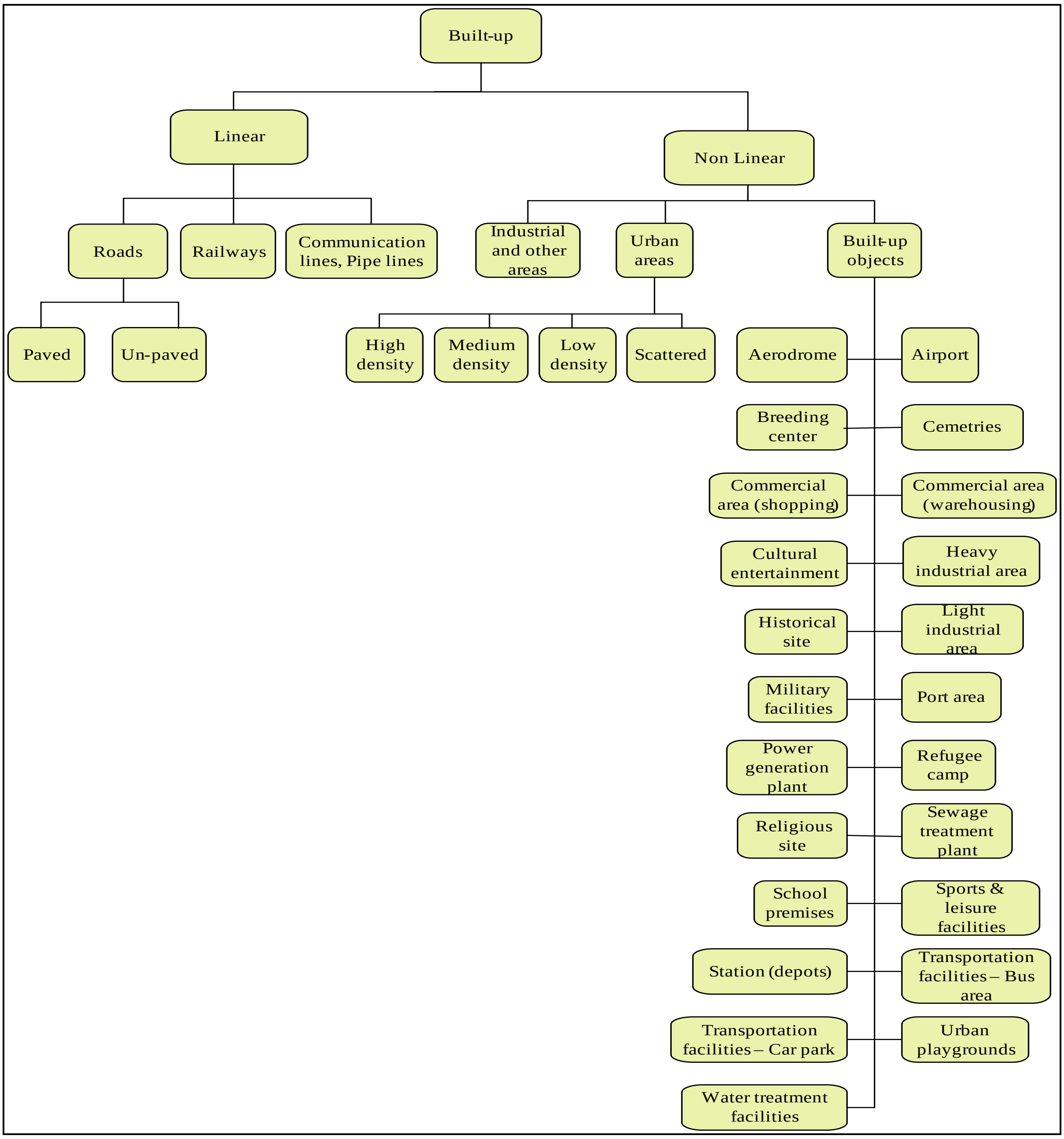


Figure 3: Typology of statistics South Africa

EA type	Geography Type	Urban/Rural
Vacant Small holding Urban settlement Recreational Industrial area Institution Hostel	URBAN_FORMAL	Urban
Informal settlement	URBAN_INFORMAL	
Farm Small holding Recreational Industrial area Institution Hostel	RURAL_FORMAL	Rural
Vacant Tribal settlement Recreational Industrial area Institution Hostel	TRIBAL_AREA	

Figure 4: Typology of Knowledge Factory

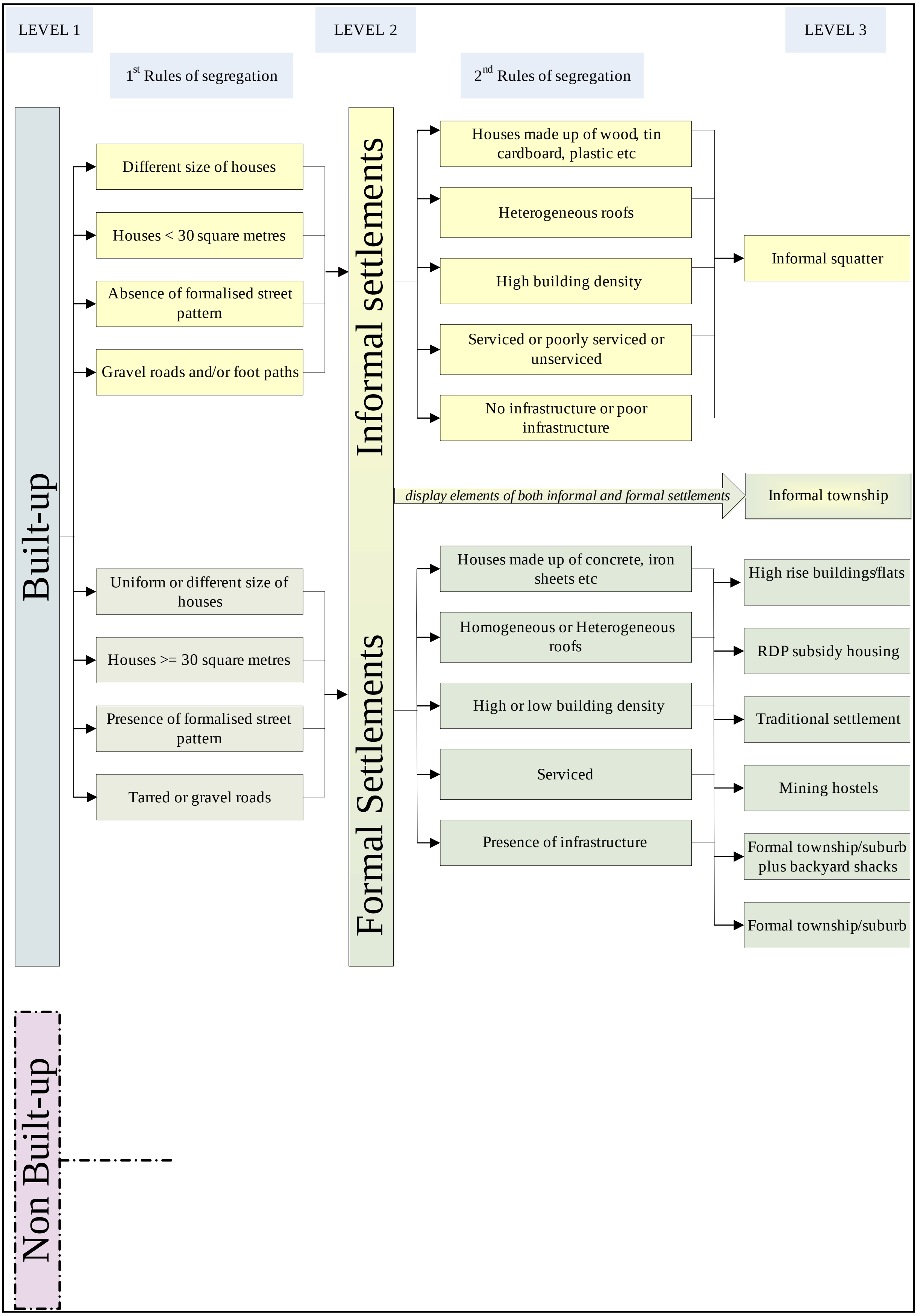
Private sector : Knowledge Factory
Below the Breadline: Forgotten People
Below the Breadline: ekaya
Below the Breadline: Tin Town
Dire Straits: The Other Town
Dire Straits: Poor Neighbours
Dire Straits: Chakalaka
Towering Density: Tenement Trenches
Towering Density: Wilted Neon
Towering Density: Modest Masala
Towering Density:City Strugglers
Township Living: Basic Town
Township Living: eKasi
Township Living: Kwaito Corners
Township Living: Council's Clutter
New Bonds: Young Blues Town
New Bonds: Struggler's Reward
New Bonds: Developer's Dream
New Bonds: Bond Battalions
Labour Pool: Rusty Blues Town
Labour Pool: Family Strugglers
Labour Pool: Family Street
Labour Pool: Suburban Stagnation
Community Nests: Modest Main Street
Community Nests: Melting Pot
Community Nests: Silver Threads
Middle Suburbia: Small Town Families
Middle Suburbia: Settled Suburbia
Middle Suburbia: Pram Pushers
Upper Middle Class: Platteland Pearls
Upper Middle Class: Retreat
Upper Middle Class: Terracotta Terraces
Upper Middle Class: Dish and Decoder Set
Upper Middle Class: Suburban Bliss
Silver Spoons: Big Fish
Silver Spoons: Fashion Cafe Society
Silver Spoons: Cheese and Wine
Silver Spoons:Pearl Strings
Silver Spoons: Upper Crust

The typologies of Department of Land Affairs and Statistics South Africa are very limited. On the other hand, the typology by Knowledge Factory includes socio-economic variables other than physical features, namely, (a) socio-economic rank which includes income, property value, education and occupation, (b) life stage which includes age, household and family structure and (c) dwelling type, which includes the age of the structure. Visual interpretation alone cannot identify features like income or education level by merely looking at the satellite imagery. This limits the application of the Knowledge Factory typology, especially in informal human settlements where socio-economic data, or any type of data for that matter, are unavailable as stated in the section describing the challenges that Government face in sourcing data on informal settlements.

Proposed settlement typology

The need to propose a refined settlement typology therefore arises. The purpose of the proposed settlement typology is to allow classification of settlements using only satellite images. The proposed settlement typology integrates three elements that are of particular importance. The first refers to the physical features describing the building size, the layout of the roads and settlements; the second is the intrinsic features that describe the building materials, the colour of roof and the building density; and the third describes the contextual features relating to the geographical relationship between the different attributes, i.e. presence of engineering services and infrastructure. The proposed settlement typology follows a hierarchical approach, which means that each class has one or more sub-classes that enable inheritance of class features, thus making the typology more versatile. The aim is to develop a typology that is flexible enough to accommodate different settlement types. Figure 5 shows the proposed settlement typology.

Figure 5: The proposed settlement typology



The typology incorporates three levels of classification: the first level of classification differentiates *built-up environment* from *non built-up environment*; the second level of classification distinguishes *informal settlements* from *formal settlements* whilst the third level of classification refers to sub-classes. Informal squatter is a sub-class of informal settlements whilst RDP subsidised housing, high-rise buildings/flats, mining hostels, traditional settlement, formal township/suburb plus backyard shack and formal township/suburb are all sub-classes of formal settlements. The typology also consists of certain rules of segregation that allow the interpretation of the remotely sensed images to easily classify whether a particular settlement falls into the informal or formal settlement category. However, because of the complex nature of 'informal townships' in South Africa, the settlement type could not be clearly classified as either informal settlement or formal settlement. This is because 'informal townships' display characteristics of both informal and formal settlements. For example, some informal townships have formalised street patterns but have poor access to engineering services and infrastructure, such as basic sanitation and social/transport facilities respectively. To facilitate effective classification of informal townships, the sub-class is placed between informal settlements and formal settlements as shown in Figure 5 above.

Evaluation of the proposed settlement typology

The proposed settlement typology was applied to a number of areas throughout the study area by various experts. The aim was to get a representative sample of each class and subclass. The result of the classification was evaluated and compared. There was a good correlation amongst the experts as far as broad classification was concerned, differentiating between formal and informal; however, defining the sub-classes led to some discrepancies. One example is when elements of different types of settlements overlap with one another. Such circumstances seemed to infringe on the second rules of segregation.

Automated data extraction and classification procedure

Extracting data from remote sensing images, in particular informal settlements, is one of the most challenging tasks within urban-remote sensing and is often tedious and time consuming. The aim, therefore, is to develop automated methods to support the generation of settlement type maps from the raw remote-sensing data. One such automated method to urban-settlement classification is based on granulometric texture features and is in the process of being developed by the Meraka Institute at the CSIR.

The first step towards the development of such an automated mapping method is an assessment of the spatial attributes and their underlying characteristics (See Table 1) that are to be used to classify the various settlements.

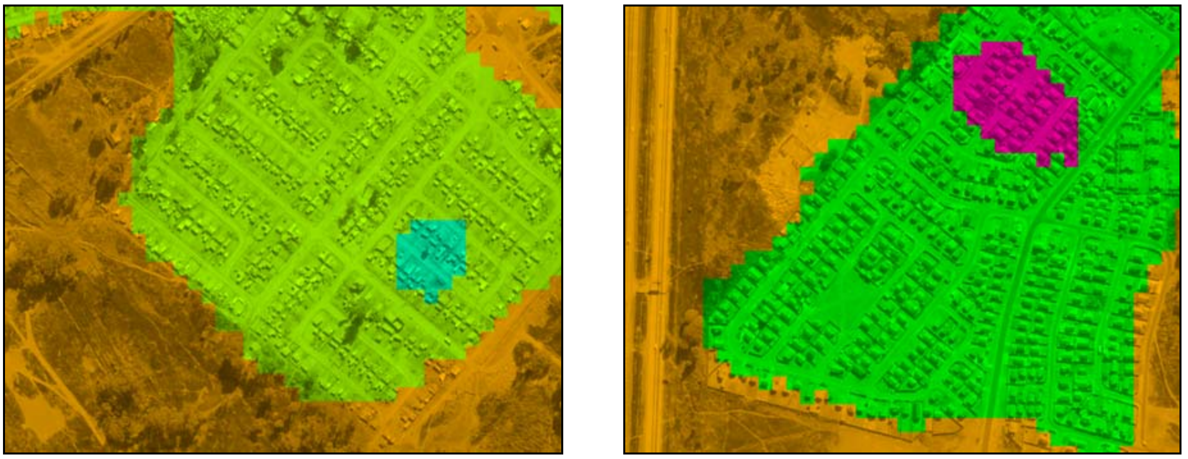
The task of automated settlement classification is done, using a method similar to that described in van den Berg (2007). The first step is to generate a training data set of image tiles of dimension 120m by 120m. The image tiles are generated by randomly sampling from a set of polygons labelled by settlement type (i.e. informal versus formal settlement). These features are used to 'train' a Support Vector Machine (SVM) to classify these features using 10-fold cross validation procedure. By applying different feature extraction algorithms to the set of training tiles, the relative performance of different feature-extraction algorithms can be assessed. For example, granulometric features achieved an overall classification accuracy of 85% using QuickBird images (van den Berg, 2007). Ongoing research into other feature-extraction algorithms has revealed that a classification accuracy of 97%

can be achieved using Local Binary Pattern texture features, which represents a considerable improvement over the granulometric features.

Having established that the Local Binary Pattern features appeared to capture the necessary information required to characterise the various settlement types, a mapping tool was developed using the open source OSSIM framework. The mapping tool slides a 120m by 120m window over the input image in 15m increments to produce an overlapping set of tiles.

The tiles are classified using the support vector machine trained in the first phase to produce a classification map (see Figure 6).

Figure 6: Support Vector Machine derived classification map



(a) (b)

In Figure 6(a), the method is able to separate the formal township (green) from the surrounding natural environment (orange) fairly well. A small region of the formal township is incorrectly classified as the informal settlement class (cyan). In Figure 6(b), the built-up region is identified fairly reliably, exhibiting a few misclassifications around the edge of the green region. The magenta patch, representing a class containing both formal buildings and backyard shacks, is mistakenly identified inside the green region.

Conclusion

This study focused on the potential application of QuickBird images for monitoring informal settlements. The paper also described the challenges that government is currently facing in sourcing data about informal settlements. Using the greater Soweto area, South Africa, as a case area, the authors manually extracted a list of human settlement attributes that can be observed from QuickBird images. Based on the findings of this study, the authors noted that applying existing typologies from Knowledge Factory and Statistics South Africa to classify human settlements in Soweto was not possible. Reasons for this were because the typology of Statistics South Africa is limited whilst the typology of Knowledge Factory contains a socio-economic data dimension that cannot be assessed by merely interpreting the images. The research was motivated by the need to propose an urban settlement typology to facilitate the effective classification of informal settlements in South Africa. The proposed settlement typology integrates three elements of settlements that are of particular importance, namely: the physical features, the intrinsic features and the contextual features. It provides a tool for the visual, systematic and representative analysis of South African settlements from remote sensing images.

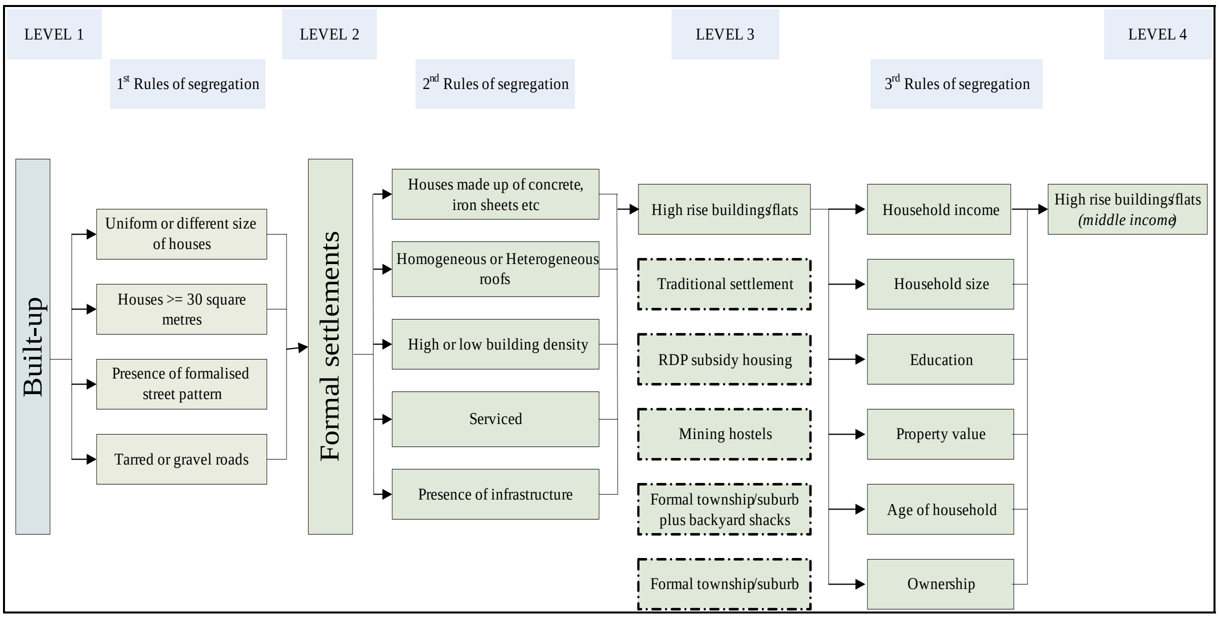
Lessons learned

Visual interpretation of QuickBird images and classifying settlements are by no means an easy task. However, with the help of a representative settlement typology the task can become easier. This does not imply that the proposed settlement typology is the ultimate definition of informal and formal settlements. The proposed settlement typology works well when attempting to classify settlements according to formal and informal but clearly distinguishing among the sub-classes requires more insight, for example, how does one differentiate whether a high-rise building is low, middle or high income, without the use of contextual information? One can assume it is either low or middle or high by identifying the intrinsic and contextual features but there are bound to be misclassification.

Remaining challenges

Further improvement of the classification method might be achieved by adding an ‘auxiliary or secondary data’ dimension to the proposed settlement typology to distinguish among the sub-class groupings of the informal and formal settlements. With the inclusion of global parameters such as household income, household value, education, property value, age of household and ownership, among others, incorrect classifications will be reduced and a third level of classification would be possible (see Figure 7).

Figure 7: Extended settlement typology



With the settlement typology suitably refined with the addition of ancillary data, i.e. the third rules of segregation, the authors believe that the proposed settlement typology can potentially make a valuable contribution to the South African National Land Cover Classification Legend for the built-up environment.

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