

## Extraction of low cost houses from a high spatial resolution satellite imagery using Canny edge detection filter

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### Abstract

*Since its democratic dispensation in 1994, the South African government enacted a number of legislative and policy interventions aimed at availing equal housing opportunities to the previously marginalized citizens. Mismanagement and unreliable reporting has been widely reported in publicly funded housing programmes which necessitated the government to audit and monitor housing development projects in municipalities using more robust and independent methodologies. The objective of this study was therefore to test and demonstrate the effectiveness of high spatial resolution satellite imagery in validating the presence of government funded houses using an object-oriented classification technique that applies a Canny edge detection filter. The results of this study demonstrate that object-orientated classification applied on pan-sharpened SPOT 6 satellite imagery can be used to conduct a reliable inventory and validate the number of houses. The application of the multi-resolution segmentation and Canny edge detection filtering technique proved to be an effective means of mapping individual houses as shown by the high detection accuracy of 99% and quality percentage of 96%.*

*Keywords: Houses, Remote Sensing, SPOT 6, Canny edge detection, Multi-resolution Segmentation, Object-Oriented Classification*

### 1. Introduction

Provision of state-subsidized housing to low income and marginalized citizens has longstanding been a key priority area of most governments worldwide (Abbott, 2002; Huchzermeyer, 2003; Kenna, 2005). Since its democratic dispensation in 1994, the South African government enacted a number of legislative and policy interventions aimed at availing equal housing opportunities to the previously marginalized citizens (Wilkinson, 1998; Huchzermeyer, 2001). Prominent housing policies and legislations implemented by the government include the Housing Act of 1997, the 1994 White Paper on Housing and the Urban and Rural Act. These legislative and policy prescripts were implemented through publicly funded programmes to accelerate the construction of low income houses across the country (Del Mistro and Hensher, 2009). In 2005, the Comprehensive Plan for Sustainable Human Settlement programme was launched to the accelerate the delivery of low cost houses with a specific thrust on quality and housing environments by integrating communities and settlements. To date,

more than 10 programmes have been implemented in government to address the housing crisis in South Africa and these include the Informal Settlements Upgrading Programme, Integrated Residential Development Programme and the Rural Housing Programme (Abbott, 2002; Charlton and Kihato, 2006; Graham, 2006; Huchzermeyer, 2009). However, the number of government subsidised houses built under these programmes are usually estimated and inconsistent (Tissington, *et al.*, 2013). This creates a need to explore other ways of gathering information on the number of houses built at different projects areas. Information of the number of houses built is required to support planning of services such as electrification, water, and sanitation and health.

Satellite-based remote sensing is considered as one of the most optimal approaches to provide systematic collection of human settlements spatial information (Jensen and Cowen, 1999; Herold, 2009; Gamba and Herold, 2010). The proliferation of high to very high spatial resolution satellite sensors such as Worldview-2, Pleiades, SPOT 6&7 and the advent of advanced image classification algorithms are increasingly making it feasible to extract buildings and inventory housing units with higher accuracy. Traditionally, the building boundaries are delineated through manual digitization from digital images, however this process is time-consuming and resource-intensive. Research on the automation of building extraction has been an area of interest in computer vision in the past decades to improve the availability of urban maps which are required for many urban applications including urban planning and infrastructure development (Shyu, *et al.*, 2005; Zhao, *et al.*, 2013; Bhadauria, *et al.*, 2013).

Many algorithms to extract buildings from high spatial resolution satellite imagery have been explored in literature with varying success rates. Some of the most commonly used algorithms include edge detection, feature optimization, linking edge chain, line extraction, graph matching algorithms, and building construction from primitive features. Significant success have been achieved in extracting building through the integrated use of image classification techniques and a Digital Surface Model (DSM) extracted from stereo imagery and Light Detection And Ranging (LiDAR) data. Many studies indicate the significance of surface elevation in building extraction (Alharthy and Bethel, 2002; Xu, *et al.*, 2010; Shaker, *et al.*, 2011). Xu *et al.* (2010) highlighted that LiDAR point clouds are valuable in improving the accuracy of building extraction. A number of studies have also attempted to use either interferometric and radargrammetric Synthetic Aperture Radar (SAR) to map urban areas with varying degrees of success (Bolter and Leberl, 2000; Gamba, *et al.*, 2000; Simonetto, *et al.*, 2001).

Edges are important features in an image for many remote sensing applications including image segmentation, object recognition and building extraction. Edge detection techniques examines the local discontinuity of pixels within an image to find sharp contrast intensities (Bhadauria, *et al.*, 2013). Commonly used edge detection techniques include Sobel, Canny, Prewitt and Roberts. Comparison of the effectiveness of these four techniques shows Canny as optimal edge detection algorithm (Bhadauria, *et al.*, 2013; Katiyar and Arun, 2014). Canny edge detection algorithm uses a multi-stage approach to detect edges in an image which enable the detection of true edges than other edge detection algorithms (Shin, *et al.*, 2001). Several studies explored the use of edge detection

techniques to extract building structures and achieved highly accurate results (Bhadauria, *et al.*, 2013, Benarchid, *et al.*, 2013; Zhao, *et al.*, 2013).

Whereas the South African government achieved considerable success in the provision of state subsidized low income housing, the government housing programmes has been riddled with severe challenges resulting in a slow delivery rate (Huchzermeyer, 2009). The uncontrolled proliferation of informal settlements for instance continues to strain government's initiative to eradicate them through the provision of low cost housing to the economically deprived citizens. Mismanagement of public housing funds has also been widely reported among some of the challenges impeding the planned delivery of low cost houses (Cross, 1999; Huchzermeyer, 2001; Burgoyne, 2008; Lizarralde and Massyn, 2008). These problems elicited the government to meritoriously audit and monitor low cost housing development projects in municipalities using more robust and independent methodologies. The objective of this study was therefore to test and demonstrate the effectiveness of high resolution satellite imagery in validating the presence of low cost houses using an object oriented classification technique that applies a Canny edge detection filter.

## 2. Study area and methods

### 2.1. Study area

The study area is located in Freedom Park in Bojanala District Municipality in the northern fringes of Rustenburg city in North-West Province, South Africa, see Figure 1.

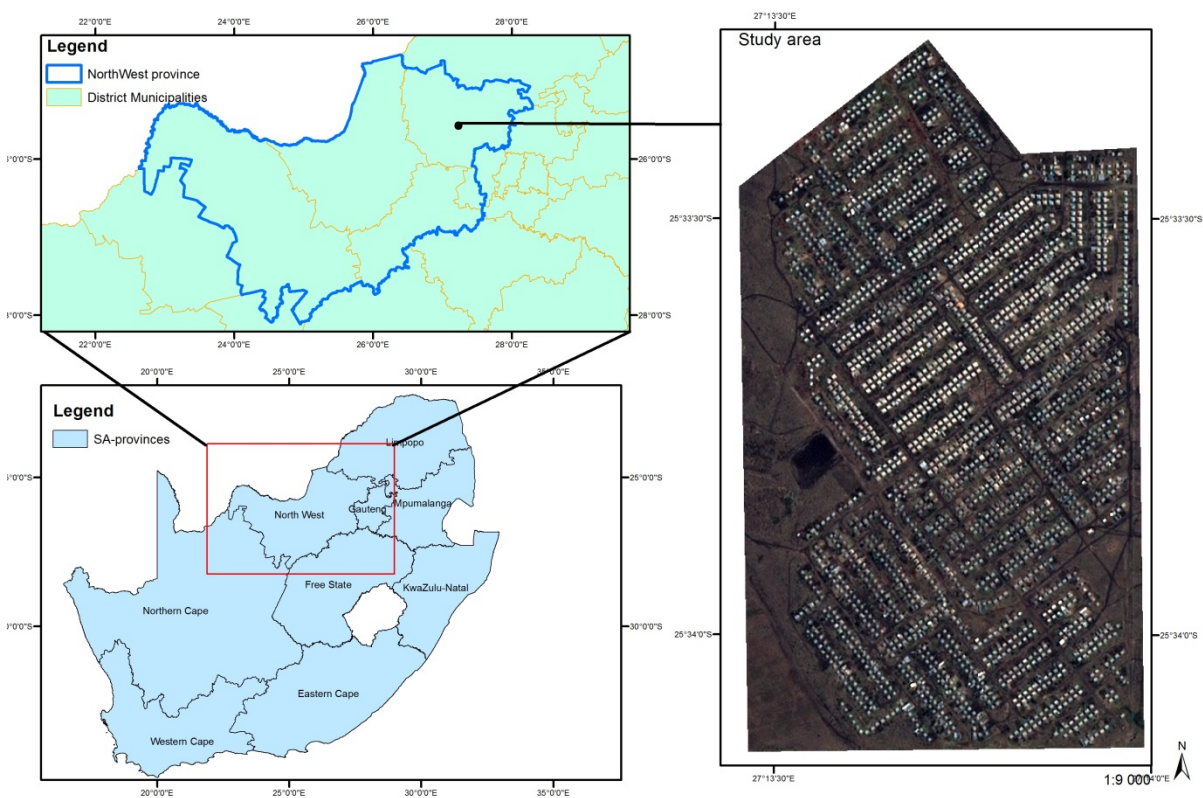


Figure 1. Location map of the study area, North West province, South Africa and a pan-sharpened SPOT 6 image of Freedom Park Phase 2 development project.

The study area forms part of Freedom Park Phase 2 human settlement development project, covers 1.2km<sup>2</sup> and is located at 25°33' S latitude and 27°13' E longitude. This development project is a greenfield project located on the north-western side of Freedom Park informal settlement. In 2005, the government initiated this low cost housing project as part of the Informal Settlements Upgrading Programme (ISUP) that was aimed at providing state subsidized houses to the marginalized residents of Freedom Park informal settlement. Mosiane (2011) noted that Rustenburg provides a rich context for assessing the transformation of socioeconomic activities and urban policy in South Africa. Freedom Park provides a classical example of how the South African government is transforming informal settlements into formal suburban through the ISUP. This study area has single storey free-standing houses of at least 40m<sup>2</sup> area developed by the government and a mining company operating next to Freedom Park informal settlement. The biggest house size in the study area is about 90m<sup>2</sup>.

## 2.2. Methods

We used orthorectified SPOT 6 multispectral and panchromatic imagery captured on 05 April 2013. Launched on 9 September 2012, SPOT 6 satellite provide imagery in multispectral (Blue (450 – 525nm), Green (530 – 590nm), Red (625 – 695nm) and Near-Infrared (760 – 890nm)) bands at a spatial resolution of 6m and Panchromatic (450 – 745nm) band at a 1.5m spatial resolution. For accuracy assessment, we used 25cm spatial resolution aerial photography acquired in 2010. The workflow used in this study is shown on Figure 2. This approach consisted of pan-sharpening, edge detection, image segmentation, building extraction and quality assurance.

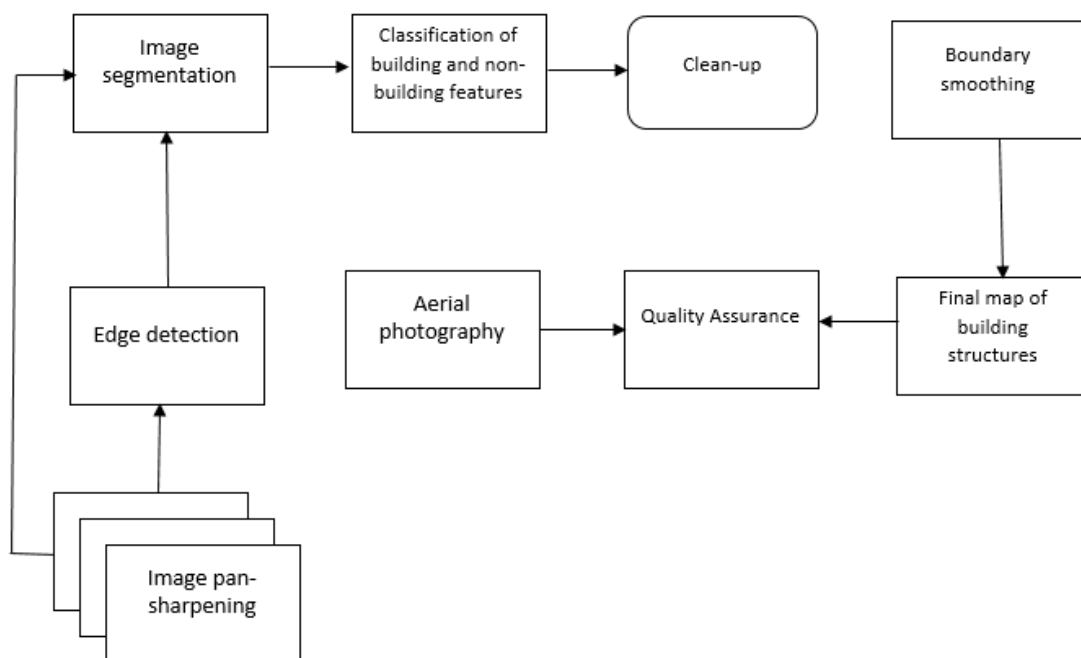


Figure 2. Flowchart of the proposed methodology to extract government subsidised houses

Pan-sharpening processing increases the spatial resolution of multispectral image bands and has proven to improve image segmentation results (Johnson, *et al.*, 2012; Sarp, 2014). To pan-sharpen

the imagery, high spatial resolution panchromatic 1.5m spectral band was fused with the 6m lower resolution multispectral bands to produce a higher resolution pan-sharpened image. Brovey Transformation was selected for pan-sharpening due its ability to retain the spatial and spectral details required for the extraction of houses. Elher *et al.* (2010) compared advanced pan-sharpening algorithms such as normalisation spectral sharpening (CN), Gram Schmidt fusion, modified intensity-hue-saturation (IHS) fusion, Ehlers fusion, University of New Brunswick (UNB) fusion, Wavelet-based fusion, Proportional Additive Wavelet fusion (AWLP), traditional Brovey Transformation and Principal Components (PC) fusion techniques and concluded that traditional Brovey Transformation algorithm provided the best structural and spatial improvement results. The Brovey Transformation algorithm applies a combination of arithmetic operations whereby each spectral band is first divided by the sum of the chosen bands and then multiplied with the panchromatic image (Hallada and Cox, 1983; Ehlers, *et al.*, 2010).

Edge detection is an important step in image processing applications such as feature extraction or object segmentation (Vijayarani and Vinupriya, 2013). Canny edge detection algorithm was used to detect edges in the image using eCognition software. During Canny edge detection, the image is smoothed to reduce noise, gradient magnitude and direction of each pixel is computed and two thresholds are applied in the image to find strong and weak edges. Once detected, edges that are not connected to a strong edge are suppressed through a “hysteresis”, resulting in more accurate edges (Canny, 1986.). Canny edge detection algorithm has been proven to detect accurate building edges from high resolution imagery than other edge detection algorithms, (Bhadauria, *et al.*, 2013; Katiyar and Arun, 2014; Singhal and Radhika, 2014). To achieve accurate edges, Canny edge detection was applied to the Red band of the pan-sharpened image, both the lower and higher thresholds were set zero and Gauss convolution FWHM was set to 1.

Multi-resolution segmentation was used to create image objects that delineate houses in the pan-sharpened image using Trimble’s eCognition software. Multi-resolution segmentation is a multiscale segmentation algorithm that is able to delineate high quality meaningful objects such as houses from satellite imagery (Nikfar, *et al.*, 2012). This segmentation approach uses a bottom-up region merging procedure that amalgamates individual pixels into bigger segments at multiple levels in an iterative process using scale, shape and compact parameters (Baatz and Schäpe, 2000; Tian and Chen, 2007; Duro, *et al.*, 2012; Witharana and Civco, 2014). We segmented the edge layer using a scale parameter of 15, shape and compactness homogeneity criteria of 0.3 and 0.5 respectively. The Red band was included during segmentation process and assigned weight value of 2 due to its capability to distinguish urban environments from other land cover features (Toll, *et al.*, 1990).

We separated building structures from non-built-up land cover types by thresholding edge outlines with a digital numbers greater than 0.2. The classification results were further improved using a threshold based ruleset that combines the mean Canny edge detection values and the Red band. Digital Numbers of Red band above 208 were used to classify the outstanding houses. The final step of the building extraction process was to smooth the boundaries and merge the image objects classified as building structures.

The quality evaluation of the results was done using statistical parameters defined by McGlone and Shufelt, (1994). The evaluation of the results was done at both pixel and object level throughout the study area. This statistical quality assurance method has been used to assess the quality of automated buildings extraction studies (Koc and Turker, 2010; Shaker, *et al.*, 2011; Benarchid, *et al.*, 2013; Shufelt, 1996; Lee, *et al.*, 2003). Reference building structures were manually digitized from aerial photographs acquired in 2010. The buildings extracted using the proposed automated approach were assessed against the manually delineated buildings. For the area level evaluation, parameters True Positives (TP), False Positives (FP), True Negatives (TN) and False Negatives (FN) were used to derive Detection Percentage (*DP*), Branching Factor (*BF*), Quality Percentage (*QP*) and Miss Factor (*MF*) metrics as defined by McGlone and Shufelt, (1994). These metrics were calculated using equations [1] to [4] below:

$$DP = \frac{100 \times TP}{TP + TN} \quad [1]$$

$$BF = \frac{FP}{TP} \quad [2]$$

$$QP = \frac{100 \times TP}{TP + FN + FP} \quad [3]$$

$$MF = \frac{FP}{TP} \quad [4]$$

Object level assessment was done through evaluation of Correctness and Completeness metrics (Koc and Turker, 2010). These metrics were calculated using equations 5 and 6 below:

$$Correctness = \frac{TP}{TP + FP} \quad [5]$$

$$Completeness = \frac{TP}{TP + FN} \quad [6]$$

### 3. Results and discussion

Canny edge detection algorithm applied on pan-sharpened SPOT 6 image was successful in detecting and distinguishing structural edges of different objects in the study area, as shown in Figure 3 a. and b. The Canny edge detection results show that houses have stronger edges compared to other land use objects, however stronger edges were observed in areas where houses have a size bigger than 40m<sup>2</sup> than in areas where houses have smaller sizes. The multi-resolution segmentation scale parameter of 40 was used during segmentation using Canny edge layer and pan-sharpened image bands was effective in creating individual house objects.



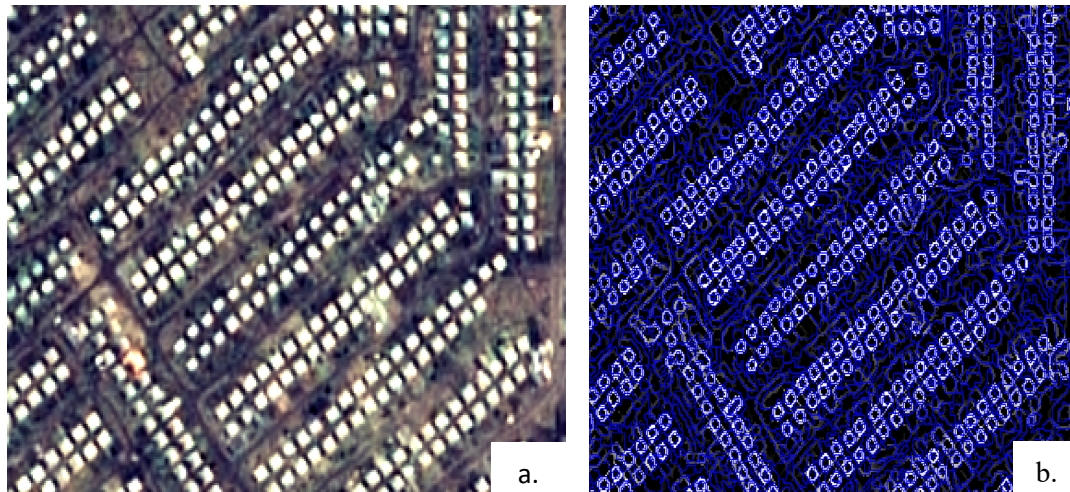


Figure 3. a. Satellite image and b. Canny edge detection filtered image showing the edges of the houses in white and segmented image objects in blue

Thresholding technique applied on Canny edge layer and the Red band was effective in classifying almost all the houses at the study area as shown in Figure 4.

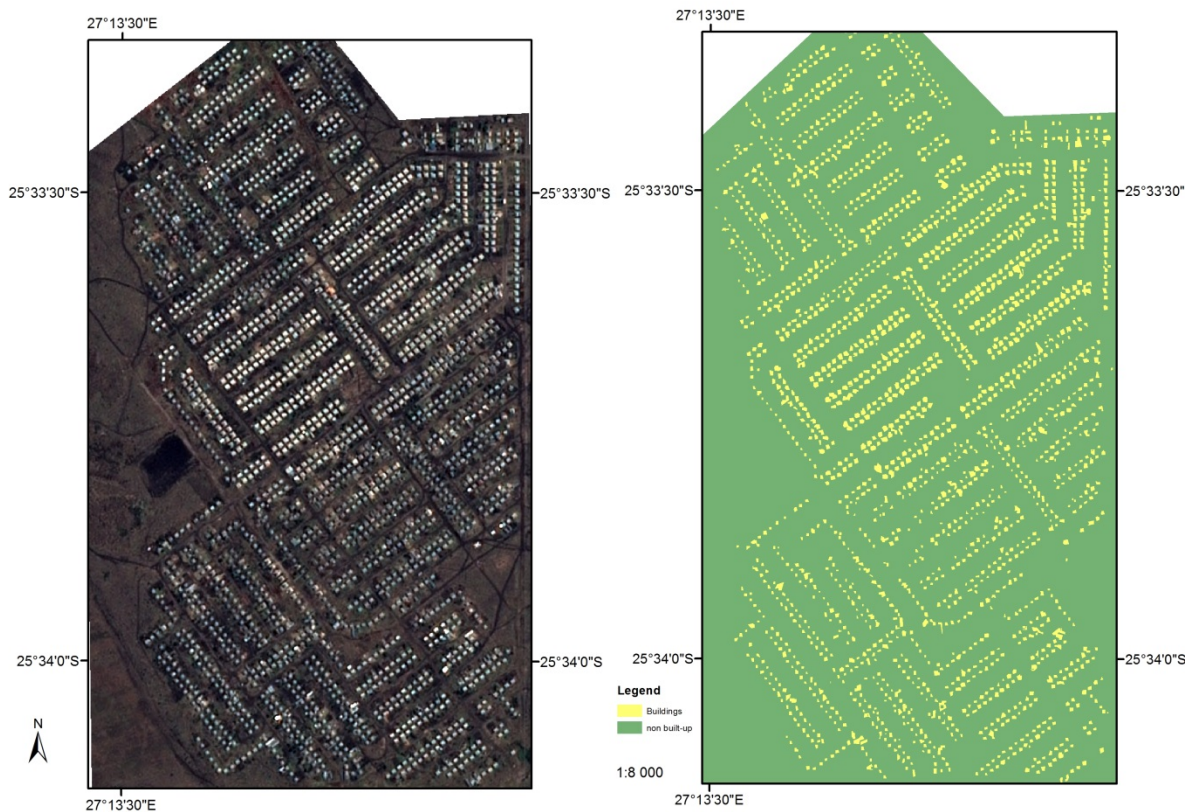


Figure 4. Pan-sharpened image and house extraction results

A total of 2038 object were classifies as houses. The accuracy assessment results show that 2015 True Positives, 51 False Negatives and 23 False Positives were achieved. High accuracy results were attained at both area and object levels. At area level, detection and quality percentages of 98.87% and 96.46% were obtained whereas at object level, we achieved completeness and correctness accuracies of 0.99 and 0.98 respectively, refer to Table 1. The quality assessment results are comparable to the

results achieved using advanced building detection approaches that used DSMs and very high resolution imagery (Shaker, *et al.*, 2011; Yastikli and Uzar, 2013; Benarchid, *et al.*, 2013).

Table 1: Quality assurance results

TP	FN	FP	Detection Percentage	Quality Percentage	Miss factor	Branching Factor	Completeness	Correctness
2015	51	23	98.87%	96.46%	0.01	0.03	0.99	0.98

While the applied methodology was successful in classifying houses with corrugated roof material, it achieved lower levels of accuracy in classifying houses with dark coloured roof tiles. This resulted in the misclassification of houses with dark coloured roof tiles and non-built-up area. There were few cases where houses and surrounding open areas or additional building structures next to the houses were merge into one segment due to similarity of their spectral responses which resulted in irregular house shape. The applied methodology was also unable to separate few smaller man-made objects such as vehicles from houses as they have strong structural edge properties.

The study has shown the feasibility of Canny edge detection technique for classification of government subsidized houses using pan-sharpened SPOT 6 satellite imagery. The success of this methodology depends highly on multi-resolution segmentation parameters that produce image objects that represent houses. Once these parameters and classification thresholds are identified, it is possible to detect houses with minimum errors of commission and omission. Whereas appropriate thresholds to detect buildings were identified by evaluation of building edges, edges alone could not detect all the houses within the study area. This could be attributed to a number of factors such as varying house sizes and the proximity of building structures to land use and land cover features such as trees, roads, cars or bare ground which affect the outline of detected building structures. However, for the purpose of validating and inventory of houses, the outline of building structures did not affect the expected results. The proposed method produced reliable results which may be used to independently monitor government housing projects. The proposed methodology has significant cost advantages over methodologies that use commercial DSM, LiDAR or very high resolution imagery and could be considered as cheap and fast alternative method of verifying and quantifying government subsidised houses over a large areas. The implementation of such reliable remote sensing approaches in housing development projects may improve accountability in the delivery of low cost houses and reduce mismanagement of housing funds in South Africa.

#### 4. Conclusion

The results of this study demonstrate that Canny edge detection algorithm applied on pan-sharpened SPOT 6 satellite imagery can be used to perform a reliable inventory and validate the



number of houses constructed through publicly funded housing programmes in South Africa. The application of the multi-resolution segmentation and Canny edge detection filtering techniques proved to be an effective means of mapping individual houses as shown by the high detection accuracy of 99% and quality percentage of 96 %. This study also proves that satellite remote sensing techniques can be used to independently monitor developments in government public infrastructure programmes and could be used to support financial auditing processes. The approach demonstrated in this study provides alternative to manual digitizing and traditional field surveys to inventory housing units.

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