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Quantifying the spatial implications of future land use policies in South Africa

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ABSTRACT

Land use policies have a definite and lasting impact on the way that cities grow; however, it is difficult for policy- and decision-makers to observe and quantify the implications of their land use policies and strategies. There is thus a need for information and tools that can adequately support policy debates and influence decision-making through scientific evidence. Land use change models provide such a tool and have often been applied and tested in developed countries but lack the ability to simulate many of the multifaceted social problems observed in developing countries. Some more advanced models also require large amounts of data that are normally not available for South African cities. In this research, we adjust the existing Dyna-CLUE model to accommodate the unique multifaceted problems such as informal settlements, backyard shacks, rapid population growth and government interventions with regard to social housing projects and test the model for the city of Johannesburg. Two scenarios (AS-IS and Policy-Led) in combination with an urban development boundary (UDB) were tested and their effect was evaluated based on their influences on the cities spatial inequality, densification of the urban spatial pattern and increase in access to public transport. Results indicated that the Policy-Led scenario can improve the wealth and economic distributions between the north and south of the city. It can also provide more economic opportunities for the households living in the south of the city. Enforcing an UDB has a positive impact on urban sprawl and will result in increased densities across the city. The effect of the policies on the commuter distances indicated that both scenarios will lead to an overall increase in the number of households that have access to public transport, but the Policy-Led scenario will allow a greater number of low-income earners to have access to the public transport systems. We see great possibilities for using the existing model to simulate land use change in South African cities. The model requires less input data compared to some other modelling techniques and with small adjustments and adaptations can prove to be a useful tool for urban planners.

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1. Introduction

Cities and towns play an important role in modern society by providing livelihoods to 52% of the world's population. By 2050, this figure is estimated to grow to 67% with more developed countries urbanising from 78 to 86%, while developing nations will see an urban dwelling increase from 47% to 64% (UN ESA, 2011). Urban growth rates in Africa are the highest in the world at 3.3% per year (UN ESA, 2011) and although South African urbanisation rates are slightly less than other African countries, it's still projected that 7.8 million people will migrate to South African cities by the year 2030 (The Presidency, 2011).

There is a need for effective management and planning of urban regions to ensure land use practices that enhance the livelihoods of the city's inhabitants (O'Meare, 1999). Failing to effectively plan and manage the projected growth and the subsequent demand on service delivery will add to the multifaceted social problems of service delivery backlogs (such as water and sanitation supply), poverty, informal settlements and backyard shacks that are already troubling cities in developing countries (UN, 2009). It also adds to ineffective land use practices and fragmented cities (Bertaud, 2001), ultimately effecting the livelihoods of the urban population. Land use policies and regulations have proven to have a direct impact on people's livelihoods by impacting and shaping the urban spatial structures and land use patterns of cities (Bertaud & Malpezzi, 2003).

In South Africa, past apartheid's policies resulted in unintended consequences that are currently affecting the livelihoods of the country's citizens and economy (The Presidency, 2011), leaving a legacy of sprawled, low-density, two-tier cities that are reflected in stark income inequalities and high operational costs, population dispersion and long commuter times (Bertaud, 2001). Post-1994, strategic local spatial planning had a strong focus on breaking down the apartheid's geography legacy and reshaping South African cities through land use reform policies and regulations (Todes, 2012). These policies were meant to densify and compact cities, provide sustainable public transport and provide equal employment opportunities to its citizens (The Presidency, 2011). Twenty years later and South African cities are still fragmented and dispersed and people are still commuting long distances to reach employment opportunities. The vast majority of the poor are still located on the peripheries of the cities and in some cases, this was exacerbated further by new low-cost government housing projects also located on the cities' fringes (The Presidency, 2011).

It is difficult for policy- and decision-makers to observe and quantify the implications of their land use policies and strategies. There is thus a need for information and tools that can adequately support policy debates and influence decision-making through scientific evidence (Jantz et al., 2004; Koomen & Stillwell, 2007).

Land use change models provide such a tool as these models were designed to analyse the causes and consequences of land use change and to understand the functioning of the land use system for the purpose of supporting land use planning and policy (Koomen & Stillwell, 2007; Verburg et al., 2004). Through the years, various models based on different modelling techniques and theories have been conceptualised, developed and applied. Parker et al. (2003) describe modelling techniques as driven either by equations, statistics, expert knowledge, cellular automata (CA) or agent-based techniques. Very few of these urban land use change models have however been applied and tested in developing countries with even fewer examples of the modelling of informal housing.

An example of work done on modelling informality is the work by Sietchiping (2004) on the modelling of informality in urban systems through the use of CA models and geographical information systems (GIS) with examples of applications in Tanzania and Cameroon. Most of the urban land use change models focus on the growth of urban environments and prediction of urban sprawl (Barredo, Demicheli, Lavalle, Kasanko, & McCormick, 2004; Watkiss, 2008). These models, however, still lack a comprehensive understanding of the unique driving forces of land use change experienced in developing countries.

South African cities face many challenges similar to developing countries such as poverty, income disparity, informal settlements and backyard shacks. Academic references to urban land use change models developed and applied in South Africa are extremely limited with documented models of multi-criteria analyses by Cilliers (2010), agent-based simulation by Shoko and Smit (2010) and agent-based simulation using UrbanSim by Waldeck (2013). With the exception of the work done by Waldeck (2013), none of the other models have a comprehensive inclusion of various land use classes nor simulate the implication of policy scenarios on land use change.

This research paper therefore explores the usability of the urban land use change model Dyna-CLUE to accommodate unique multifaceted problems such as informal settlements, backyard shacks, rapid population growth and government interventions with regard to social housing projects. The research is illustrated with a case study area for Johannesburg. The structure of this article is as follows: (2) introduction to the case study area, (3) description of the adapted model, (4), parameterisation of the model for the case study and (5) results and discussion of the findings.

2. Study area: Johannesburg

Johannesburg is the financial capital of Gauteng, in the heart of the economic hub in South Africa, and the largest contributor to the country's gross domestic product (GDP). Johannesburg is home to 4.4 million people in approximately 1.4 million households (Census, 2011) and occupies a large geographical extent of 1645 km^2.

2.1. Johannesburg's current landscape

Johannesburg's complex spatial form can be ascribed to: the city's location on the Witwatersrand mineral rich basin, past policies and the many restructurings the city experienced since the end of apartheid (Beavon, 1997). This resulted in Johannesburg facing three important problems: (1) the division of the city into two distinct parts (the affluent north and deprived south) segregated by the mining and industrial belt, (2) stark income and density inequalities and (3) dependency of the southern and periphery townships on the northern economies, resulting in long commuter distances and households spending a large percentage of their income on transportation (GDS 2040, 2011).

For modelling purposes, Johannesburg's residential housing can be divided into three classes: (1) formal housing, (2) informal housing and (3) government-provided low-cost housing.

Formal housing is driven by the market and consists of three types of densities: (1) low (typical suburban houses of one dwelling unit on an erf), (2) medium (cluster housing including security complexes, duets, sectional titles, duplex and town houses) and (3) high-rise housing (higher density accommodation, such as hostels and flats).

Informal housing can be categorised as either[1] informal dwellings/shack or[2] informal dwelling/shack in backyard (referred to as mixed housing in the modelling typology). These types of informal housing experienced a rapid increase with the fall of apartheid when many new labour workers and people previously banned from occupying residences in the city migrated to the city in search of a better livelihood. The subsequent housing demand resulted in many new informal settlements occupying land illegally throughout Johannesburg. The city of Johannesburg estimates that 800,000 people are living in 189 informal settlements (GDS 2040, 2011) throughout the metropolitan area. The city states that 103 of these settlements are deemed not suitable for[3] *in-situ* upgrade and need to be relocated to other suitable sites (GDS 2040, 2011). Backyard shacks is a critical source of affordable informal rental housing in South African cities and has played a fundamental role in absorbing demand for low-income housing (Shapurjee et al., 2014). It is estimated that informal backyard structures have grown by 59% (Census, 2011) in Gauteng and that the city of Johannesburg alone has experienced a rapid growth in backyard shacks with an additional 45,000 households occupying these dwellings between 2001 and 2011 (Census, 2011).

The third category of low-cost government housing is a medium-density low-income formal housing that is a government-driven response to the severe housing backlog. State-funded and supported housing includes[4] RDP and[5] social housing. Income categories separate it from the formal housing market. The government-subsidised housing stock have been historically (due to apartheid's legislation) and in practice (due to cheaper available land) provided on the periphery of the cities.

2.2. Johannesburg's future drivers of land use change

In order to understand the long-term spatial impacts (land use change) predicted for the city of Johannesburg, it is necessary to understand the population projection as well as the spatial policies envisioned for Johannesburg.

Based on projected macro demographic trends ([6]Global Insight, 2011), it was estimated that the Johannesburg city will experience a positive population growth of 2.06 million people (2010–2030). The significant increase in population is the result of in-migration, urbanisation and the natural growth of the population. This increase in population and the fact that household sizes are decreasing will result in an enormous demand for houses that will directly influence the land use of the city. Failure of the government to provide adequate low-cost-subsidised housing to the poor will result in an even bigger backlog of houses and an increase in both informal and backyard shacks throughout the city.

3. Land use change models

A myriad of land use change models exist that can simulate future land use and policy scenarios. Comparative literature studies done by Agarwal et al. (2000), US EPA (2000), Parker et al. (2003), Verburg et al. (2004), Wegener (2005), Wainger et al. (2007), Pontius et al. (2008) and Haase and Schwarz (2009) discusses more than 65 models. From each one of these studies, it is clear that various models exist that have been developed, applied and tested throughout numerous countries. It is also clear that each one of these models was designed for a very specific purpose, location and application in mind.

3.1. The Dyna-CLUE model

From the various models reviewed, the Dyna-CLUE model was chosen for its simplicity as a CA model that is capable of (1) modelling local drivers of change, (2) incorporating external demographic models, (3) modelling various policy scenarios, (4) simulating dynamic land use change and (5) simulating the competition between land uses. The Dyna-CLUE model is also one of the most used allocation models in the planning field, with numerous examples of applications in countries such as the Philippines (Verburg et al., 2002), China (Chen et al., 2009; Rui et al., 2010) and Vietnam (Castella & Verburg, 2007).

Dyna-CLUE consists of two sub-models: a non-spatial demand component and a spatial allocation model (Verburg et al., 2002). The non-spatial demand module calculates the area demand per land use for the various land use classes. These inputs are obtained from regional drivers of change (e.g. population and economic dynamics) and can be derived from simple trend extrapolations, external complex demographic and economic models or from development policies. The spatial allocation model translates these calculated demands into land use changes at various locations in the study area through utilising a series of driving forces (e.g. biophysical and socio-economic) and conversion rules (Verburg et al., 2002).

The spatial allocation of land use is dependent on four factors:

(1) Location suitability – a process of determining the preference of land use suitability through actual land use patterns and local driving forces of change.
(2) Conversion rules – the transition rules for various land use types to change into other land use types.
(3) Spatial policies and restrictions – protected areas, restriction areas and development areas.
(4) Land use demand – calculated from the non-spatial demand module.

The land use change allocation is an iterative process that consists of the four primary steps described below (Verburg et al., 2002).

Step 1 calculates the total change potential (*Ptot*) for each land use (*lu*) at time (*t*) at location (*i*) based on the highest total probability of change through;

$$Ptot_{i,t,lu} = Ploc_{i,t,lu} + Pnbh_{i,t,lu} + Comp_{t,lu} + ELAS_{lu} \tag{1}$$

where $Pnbh_{i,t,lu}$ is the impact of neighbouring cells, $Comp_{t,lu}$ are the location-specific preference maps, ELA_{Slu} is the cost of conversion of the current land use type and $Ploc_{i,t,lu}$ explains the location suitability calculated through a logit model (Verburg et al., 2002)

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} \dots + \beta_n X_{n,i} \tag{2}$$

'where P_i is the probability of a grid cell for the occurrence of the considered land use type on location (*i*) and the (*X*'s) are the location factors. The coefficients (*β*) are estimated through logistic regression using the actual land use pattern as dependent variable' (Verburg et al., 2005, p. 11).

Step 2 involves the checking of rules to confirm if conversion is allowed based on the conversion rules set up by various spatial policies and restrictions. These rules include the conversion matrix which specifies if land use types may change into other land use types as well as restricted areas, e.g. residential development outside the urban development boundary (UDB). Conversions can also be forced after a specific time elapsed (Verburg et al., 2002).

Step 3 is the confirmation that the allocated land area per land use type is equal to the demands specified by the non-spatial sub-model. As long as the demand and allocation area differ, the model will keep on iterating (Verburg et al., 2002).

In Step 4, the cells are assigned a land use type. When the allocation and the demand are equal, the time series is saved (Land use = $t + 1$) and the next year's simulation is started (Verburg et al., 2002).

3.2. Adapting the model for the case study area

The Dyna-CLUE model has to be altered to cater for the unique challenges South Africa is facing. The model falls short in specific aspects, namely:

- Density constraints: Housing densities (quantity) of land use types per cell are not a direct output of the model and therefore not possible to directly model the effect that policies will have on the city's density.
- The inability of the model to include more than one land use class in the same 100-m raster cell makes it difficult to simulate the mix of informal and formal housing.
- Incorporation of unique multifaceted problems (informality, poverty, etc.) and their drivers of change. There is no documented literature for creating a land use typology incorporating driving forces that are capable of representing informality, social housing and income inequalities as part of the land use classes within the Dyna-CLUE model.

Due to the shortfalls mentioned, it is clear that using a normal functional land use typology (e.g. residential, commercial, industrial, mining, etc.) will not be sufficient in modelling the case study area and a more nuanced, data rich urban land use typology is required. According to Rodrigue et al. (2009), land use types can be defined in three ways: the land use function, the intensity with which the activity occupies the land and an additional income attribute. We propose combining these three types into one land use typology by linking densities (intensity) and income classes to the specific function of land use.

An innovative 10-class[7] land use typology was developed to include the function of land use, the intensity (density) of use and income. The classification of Table 1 is based on the three principles of: land use functions, density and income. This multi-layered classification is not readily available and various steps were preformed in order to classify the Johannesburg land use accordingly. First step involved grouping all the functional land use classes together; thereafter, the various residential classes were separated based on their densities and income classes. This classification was done utilising data from the GTI 2007 land use classes, the GTI 2007 growth indicators for formal and informal units and using the income classes per suburb obtained from Knowledge Factory and StatsSA 2007 Community surveys. The results of the suggested three-layered typology are represented in Table 2. These 10 land use classes together with their associated residential densities will be used when defining the demand figures for various typologies. Figure 1 shows the spatial representation of the nuanced 10-class typology.

Table 1. Ten-class land use typology development.

Land use class	Data used in classification	Process used for classification	Current land occupation and brief summary of reason for including land use class
Commercial (0)	GTI land use 2007	Select all commercial properties	This class occupies 2.36% of the Johannesburg land area. It is critical when comparing the three scenarios in terms of access to employment
Other (1)	GTI land use 2007 Cadastre 2007 Roads data-set 2011	Select all services, government, unknown, parks, recreation and air transport properties	Includes layers considered static for the simulation. These areas are considered 'undevelopable' land
Industrial mining and manufacturing (2)	GTI land use 2007	Select all Industrial properties and Select all mining properties	Manufacturing occupies 3.37% of the land use and the mining occupies 3.17% of the land area
Vacant, small holdings and open spaces (3)	GTI land use 2007	Select all small holdings and open properties. Roads where excluded from this layer	This will be the primary land available for expansion of the urban environment
Formal residential low rise (4)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Select all formal single dwellings, detached properties. Exclude low-income suburbs and exclude mixed formality area. Schools and community areas were included as part of this land use type	This class is critical in determining the influence of policies on urban sprawl/compactness. The class density is slightly lower than normal due to the inclusion of educational and community services
Formal residential medium density (5)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Select all formal cluster housing properties. Exclude low-income suburbs and exclude mixed formality area. Typically simplex, duplex, security estates or walk-ups. This class fills the gap between extreme low densities of single dwellings and the high densities found in city centres	This higher density land use class includes simplexes, duplexes, duets and walk-ups. The class also contains community services and educational facilities Schools and community areas were included as part of this land use type
Formal residential high rise (6)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Select all formal high-rise properties. Apartments, hostels and flats	Flats and apartment blocks, primarily located in the city's CBD or central economic nodes. Older workers' hostels also fall in this category, although not located near the CBD or economic hubs
Mixed use (7)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Where functional land use class is 'Residential' and where there is a presence of informal structures or backyard structures on the same erf	These areas represent high densities and are a mix between formal and informal housing. These areas are typically characterised by formal residential areas that densify over time by means of informal backyard shacks
Informal residential (8)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Where functional land use class is Informal Areas without a formal structure occupying land illegally	Accommodating an estimated 200 000 households. No formal structure or services put in place
Government low-cost housing (9)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Where Functional land use class is 'Residential', where no backyard shacks or informal dwellings are present and where suburb income levels are below R9500 per household. This is the acceptable limit for state-provided housing according to the Human settlements atlas (2009)	Most of the mixed formality transformed from this class. Mostly single dwellings or walk-ups with smaller dense units and low-income earners (income below R9500p/month)

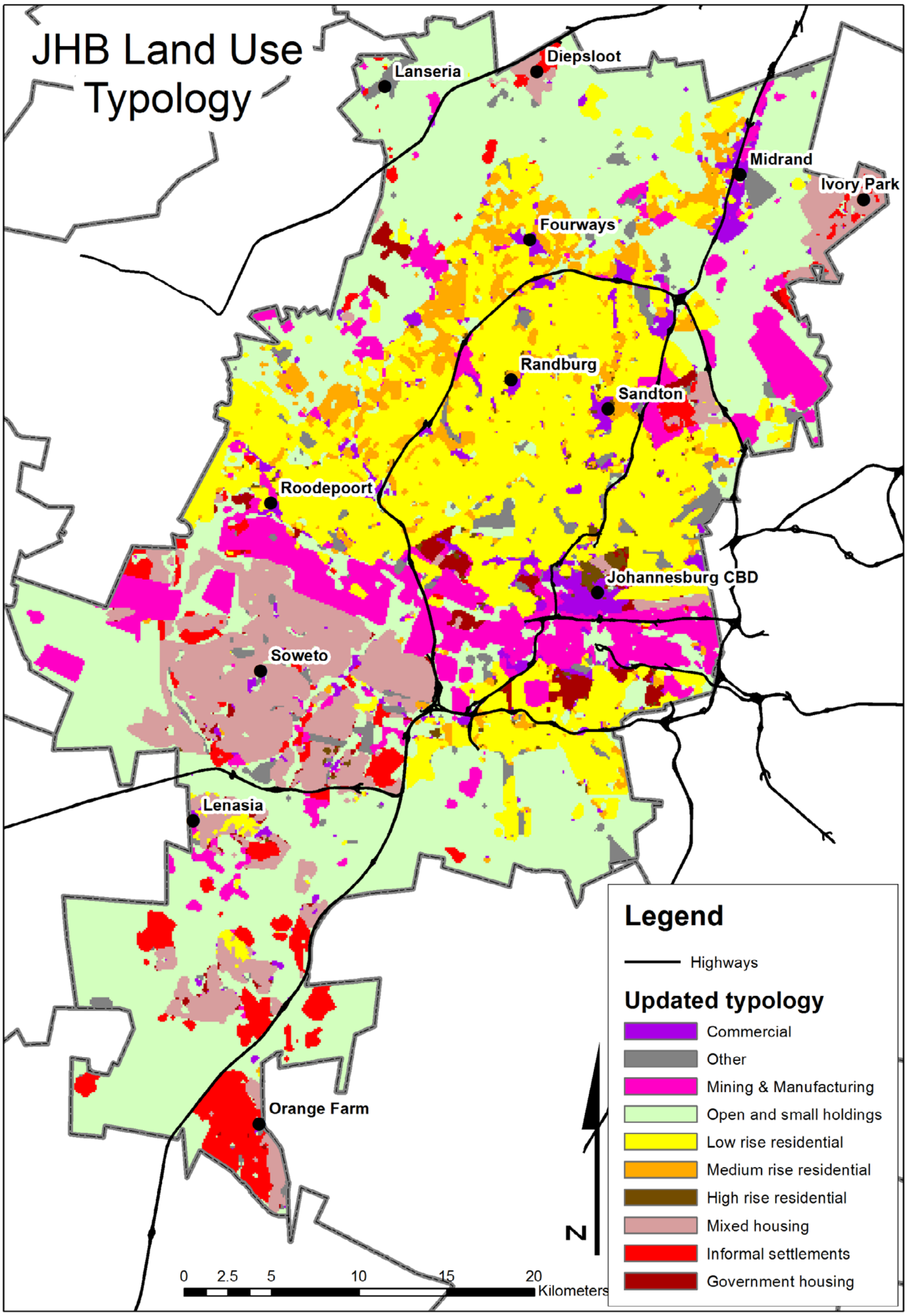

Figure 1. Ten-class land use typology. (source: Author)

4. Simulation paramerisation

In order to run the model (2007–2030), a number of parameters had to be determined and populated within the adapted modelling framework presented in Figure 2.

Thereafter, a visual model validation was done comparing the simulated results of 2010–2012 with aerial photography of 2010–2012. The various modelling inputs will now be discussed in detail.

4.1. Calculating demand figures

Based on the external projected households' figure for 2030 (Global Insight, 2011), the densities per land use type (displayed in Table 2) and the scenarios developed (Section 4.6) the demand figures (Figure 3) were created. Figure 3 represents the input values for the two scenarios and should be read with various scenarios developed in Section 4.6. The model is dependent on these external land use demand figures that specify the amount of hectares per land use class for the projected future simulation years.

4.2. Spatial restriction and preference layers

Two separate restriction layers were created. One allows conversion throughout the metropolitan area, while the second restriction layer is based on the UDB and two potential nature parks as proposed by the Johannesburg metropolitan municipality in their Growth Management Strategy (GMS), 2010 (captured in the Policy-Led scenario).

Preference areas (areas earmarked for certain types of development) are scenario specific and applicable per land use class. Preference areas for the AS-IS scenario are based on past observations, current land use policies and plans that are captured in the municipalities' spatial development plans. Preference areas for the Policy-Led scenario are identified development areas based on the transport and development corridors as well as the densification priority areas as specified in the city's GMS (2010).

4.3. Regional and local drivers of land use change

Developing a realistic land use change model must contain the inclusion of the most important drivers or actors of land use change (Veldkamp & Lambin, 2001). The model should consider the effect that various driving forces and processes will have on different scales of the model. The literature distinguishes between two main scales of driving forces of land use change, those that affect land use from a global/regional perspective and those drivers that have an influence on a local scale.

Table 2. Associated household densities of the three-layered typology

Land use typology and (code)	Dwelling (Household) density per land use type (hh per hectare)
Commercial (0)	n/a
Other (1)	n/a
Industrial (2) mining and manufacturing	n/a
Open (3) vacant and small holdings	0.53
Low-density residential (4)	5.69
Medium-density residential (5)	13.73
High-density residential (6)	46.22
Mixed formality (7)	31.82
Informal settlements (8)	31.02
Government housing (9)	18.35

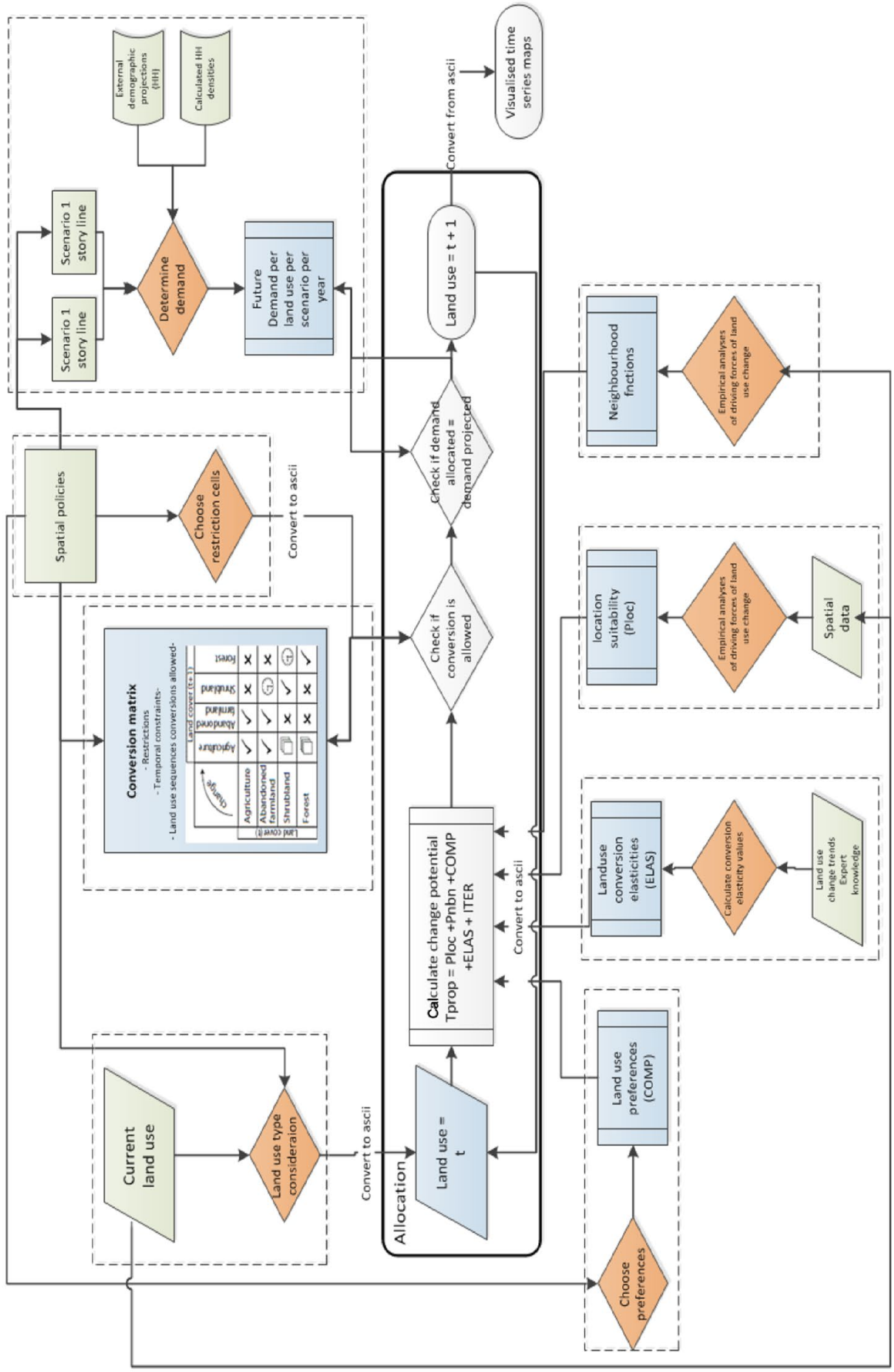

Figure 2. Schematic overview of the Johannesburg model.

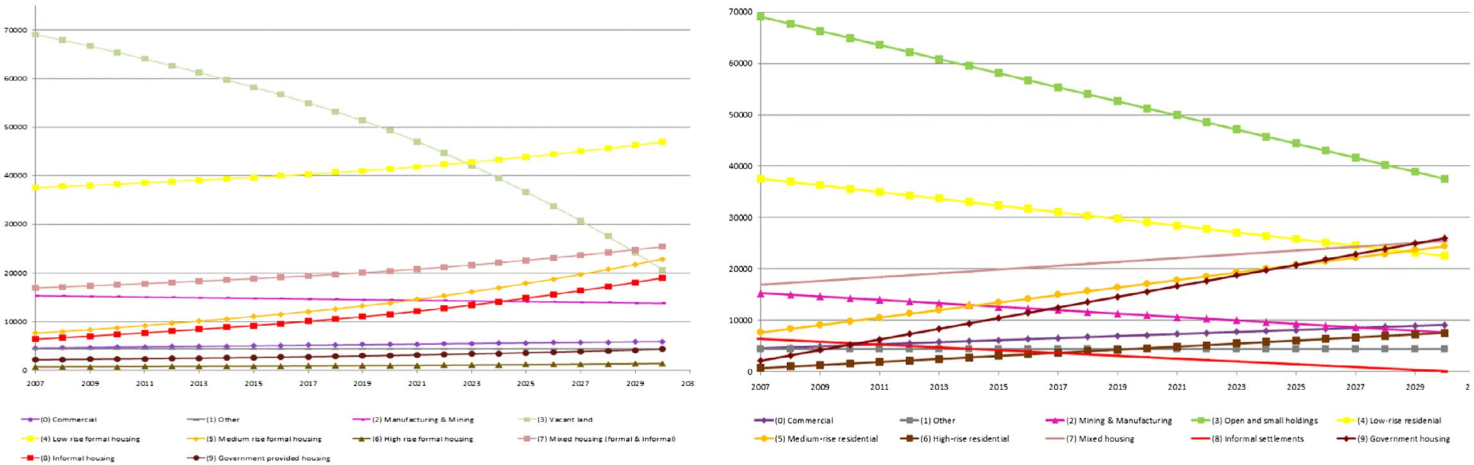

Figure 3. Land use demand figures for the two scenarios (a) AS-IS scenario and (b) Policy-Led scenario.

4.3.1. Regional drivers of change

Zondag and Borsboom-Van Beurden (2009) identified five primary drivers of land use change on a global/regional scale. These are: (1) political, (2) economic, (3) cultural, (4) technological and (5) natural factors. Hersperger et al. (2010) emphasised the role that direct interventions such as policies and laws will have on the land use change of a region. Looking at Johannesburg, the following regional drivers of land use change were identified:

- Demographic growth is projected based on in-migration, urbanisation and natural growth. Population growth and decrease in household size automatically create a new demand for residential space and new areas need to be developed to satisfy this demand.
- A shortage in supply of housing for lower income classes is speculated to be the biggest driver of both informal settlements and backyard shacks.
- Political policies either restrict the development of certain land uses in areas or encourage the development thereof in specific areas (e.g. government strategic investment strategies).
- The economic growth of Johannesburg is a big attracter of new development and investment.

4.3.2. Local drivers of change

Using expert knowledge (obtained through interactions with the municipality), visual interpretation and literature-based research, a series of potential drivers (hypotheses) of change at a local scale were defined. The various hypotheses were tested by means of logistic regression analyses. The logistic regression analyses are used to estimate the coefficients ($\beta_{\text{-values}}$) of the logit model used in creating the location potential of cells to be dedicated to a specific land use type (Verburg et al., 2002). Table 3 shows the results from the step wise regression analyses that were performed to select the most relevant factors. The receiver operating characteristic (ROC) values presented indicate the logistic regression model's performance and the values derived in this case study are an indication that the model has a very good distinguishable ability with all values greater than 0.8.

All land use types were tested for their local drivers of change with the exception of mixed, government and informal housing. Mixed housing is not subjected to local drivers

Table 3. Regression results.

	(0) Commercial	(4) Residential low rise	(5) Residential medium rise	(6) Residential high rise
Driving factors	$\beta_{\text{-values}}$	$\beta_{\text{-values}}$	$\beta_{\text{-values}}$	$\beta_{\text{-values}}$
(1) Main feeder routes	−0.003	−0.0006	−0.0003	−0.001
(2) Highways	−0.00016	−0.00008	−0.0001	-
(3) Gautrain stations	−0.00006	-	0.00003	−0.00009
(4) BRT and feeder routes	−0.00002	−0.00004	−0.00013	−0.0001
(5) Economic hubs	−0.00008	−0.0003	−0.0003	−0.00025
(6) Shopping districts	−0.00002	−0.0002	−0.0002	–
(7) Metrorail	–	–	–	−0.00014
(9) Informal housing	–	+0.0003	+0.00025	–
Constant	−1.218	0.184	−2.398	−2.192
ROC values	0.84	0.88	0.825	0.87 z

as these classes only have the capability to develop on lower income low-rise formal structures or government-built low-cost housing. Government housing is also not subjected to local drivers as these interventions are directly implemented in the city space through policies and direct investment. Informal housing is primarily driven by the availability of vacant land and the effect of neighbourhood factors and is therefore not tested here, but in the following section.

4.4. Neighbourhood factors

Verburg et al. (2002) explain that the conversion of land use classes can be partially explained by the influence of the immediate neighbours of a specific class. Neighbourhood influences are deemed important for commercial facilities due to their clustering characteristics and for residential development due to the attractor role that already put in place services offer. Land use conversion is thus more likely to occur next to already established land uses of the same type. To quantify the influence of neighbourhood cells on land use classes, the enrichment factor, which is a measure of the occurrences of a specific land use class in the neighbourhood of a location relative to the occurrence of this land use type in the study area as a whole, was calculated according to Verburg et al. (2002).

In order to calculate the relationship between the probability of a location and its enrichment factors, a logit model similar to the driving forces' calculation in the previous section is used. The model will be populated with the $\beta_{\text{-values}}$ from the regression equation, the neighbourhood window (sphere of influence) and the relative influence strength of each of the various window cells. Table 4 provides the regression results. The influence of setting the weights was done through an iterative process by visual interpretation of historical growth. Due to the method followed in deriving these weights of neighbourhood setting, a sensitivity analysis (Section 5.1) was performed to test the influences that these weights have on the model.

4.5. Conversion rules

4.5.1. Elasticity conversion

The elasticity conversion is a value between 0 and 1 that indicates the reversibility of a land use type. A value of 0 indicates a land use that is easily reversible, thus it can be deleted and added at the same time in the model where a value of 1 indicates a land use with a high investment cost that will not change easily (Verburg et al., 2002). From the total change in

Table 4. Regression results of the neighbourhood factors.

Land use classes	(0) Commercial	(4) Residential low rise	(5) Residential medium rise	(6) Residential high rise	(8) Informal settlements
(0)Commercial	1.11	–	–	–	–
(4) Residential low rise	–	1.953	–	–	–
(5) Residential medium rise	–	–	1.541	–	–
(6) Residential high rise	–	–	–	0.077	–
(8) Informal settlements	–	–	–	–	.917
Constant	−3.640	−1.839	−3.171	−5.488	−3.303

the Johannesburg metropolitan areas, it was observed that 95% of all land use change that happened between 2001 and 2007 were changes from vacant open land to various other land use types, thus only 5% happened between the non-vacant land use types. The 95% change in vacant land can be attributed to: (1) commercial (7%), (2) other (5%), (3) industrial (9%), (4) residential (71%) and (5) informal (8%). From past development patterns, it can be observed that as long as there is adequate land available, higher investment land is less likely to be converted. As the land use trend data were insufficient to quantify the past development trends, expert knowledge and sensitivity analyses were used to populate the elasticity values presented in Table 5.

4.5.2. Land use conversion matrix

The conversion matrix allows a progressive time step change to take place between land uses. Some of the land uses, e.g. open (3), can be converted into any other land use type while some land uses, e.g. mixed housing (7), have to follow a specific development sequence (informal settlements (8) can be redeveloped to government housing (9) that over time changes into mixed housing (7)).

4.6. Scenario development

Scenario planning provides great benefits to policy-makers. Creating and testing various scenarios allow decision-makers to explore and test the possible implications that various policies might have on the city's landscape. Although the model is capable of experimenting with various policy impacts through the use of different scenarios, only two scenarios were proposed for testing and exploration in the Johannesburg case study area, an 'AS-IS scenario' and a 'Policy-Led scenario'.

4.6.1. AS-IS scenario

This scenario represents unconstrained spontaneous growth. The scenario provides a look into the city of Johannesburg's possible future if the current trends, patterns and investment priorities continue along the same trajectory as the past. The following assumptions will apply in this scenario:

- Government-provided subsidised housing is fixed to the government's land budget; there is thus a limited amount of housing stock being built for the lower income earners.
- Housing backlogs will result in informal dwellings and backyard shacks.

Table 5. Elasticity values.

Land use class	Elasticity values AS-IS scenario	Elasticity values Policy-Led scenario
0 Commercial	0.8	0.8
1 Other	1	1
2 Manufacturing and mining	0.8	0.8
3 Open and small holdings	0.4	0.2
4 Low-rise residential housing	0.7	0.6
5 Medium-rise residential housing	0.7	0.7
6 High-rise residential housing	0.8	0.8
7 Mixed housing	0.5	0.5
8 Informal settlements	0.2	0.1
9 Government housing	0.7	0.7

- Vacant land is primarily considered for government housing delivery due to the price constraints associated with redevelopment of already established areas.
- Informal settlements should be considered for upgrading to government housing before relocation is considered.
- No UDB or large protected areas are implemented.
- Growth continues along the past development patterns specifically the influence of the strong market-led economy in the north.
- Infrastructure investments are constrained to the current large investment projects underway.

4.6.2. Policy-Led scenario

This scenario is based on the Johannesburg city's GMS that is aligned to the National Development Plan (2030) that sets out to create a more dens and compact city, providing sustainable public transport and providing employment opportunities to all its citizens. One of these proposed strategies is called the GMS of 2010. The strategy defines public transport corridors based on the bus rapid transport (BRT) routes, the Gautrain stations and the Metrorail stations and states that densification should take place and is earmarked in support of these areas. The strategy emphasises the fact that low-income housing should be integrated into the city and not further marginalised. The following principles will apply in this scenario:

- Urban sprawl will be limited through the adoption of an UDB of 2002.
- Densifying key priority areas (preferable accessible nodes) through land use policies (zoning) and incentives.
- Densifying transport corridors to ensure a sustainable and efficient transport system.
- Investing in key infrastructure in specified development corridors.
- Investment of housing opportunities specifically for lower income groups should be done in closer proximity to employment and economic nodes, thus providing government low-cost housing in key access areas.
- Investing in residential lower income housing in the northern suburbs in accessible transport corridors by densifying low-rise housing.
- Rehabilitation of old mining land for use in new residential development.
- Encouraging investment in commercial activity in the southern suburbs.
- Protecting large environmentally sensitive key ecological areas.

5. Results and discussion

5.1. Sensitivity analyses

Due to the uncertainty associated with the input layers of the conversion elasticities, conversion matrix and the weights of the neighbourhood functions, it is useful to determine the sensitivity of the model towards variations in these input layers. The one-factor-at-a-time (OAT) method was used in the sensitivity analyses. The OAT method is an iterative process of changing one input factor at a time and observing the results. Only the AS-IS scenario will be tested for its sensitivity, as this method should simulate reality based on past trends and development patterns. The influence of the OAT method will be measured

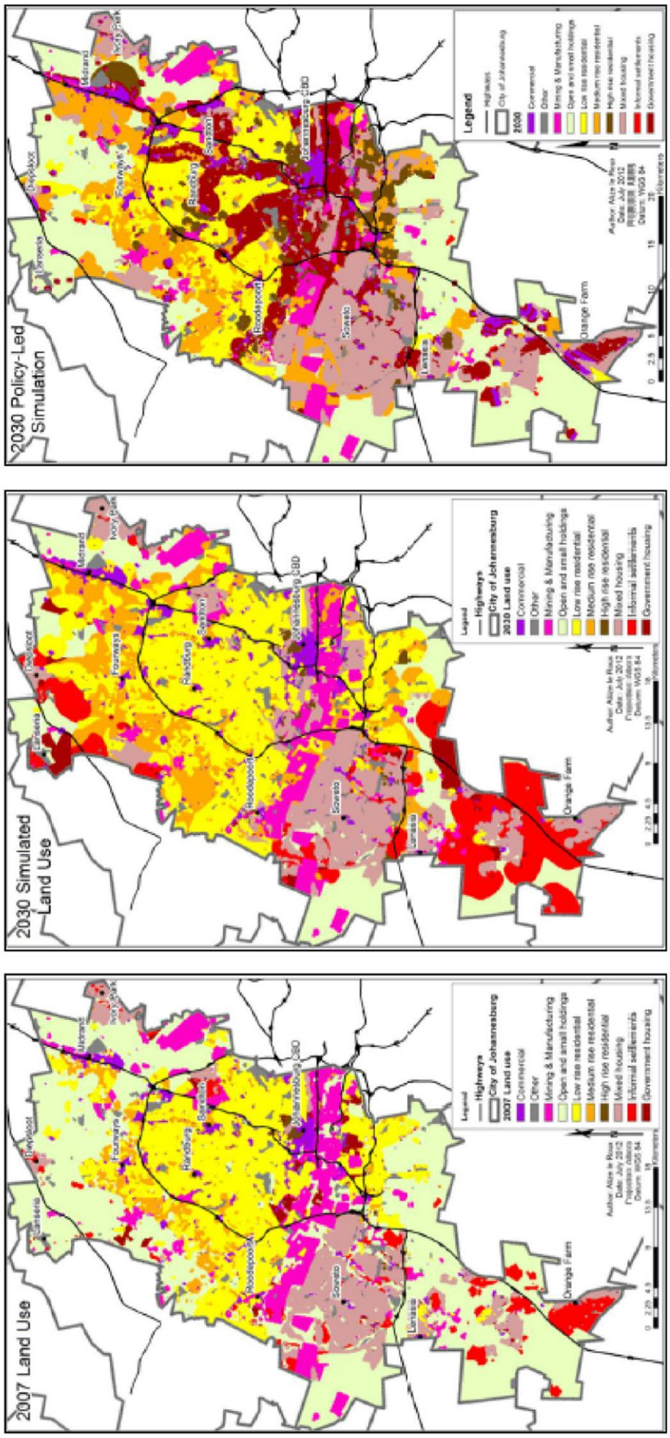

Figure 4. Simulation results for the (a) Situation in the 2007 base year, (b) AS-IS scenario simulated results in 2030 and (c) Policy-Led scenario-simulated results for 2030. (source: Author)

Table 6. Various changes proposed and tested for the OAT sensitivity analyses.

Input setting	Original model	Sensitivity run1	Sensitivity run2
Conversion elasticities	AS-IS scenario	0.1 decrease on all values (10%)	0.1 increase on all values (8%)
Conversion Matrix	AS-IS scenario	All conversions allowed (13%)	–
Neighbourhood weight	AS-IS scenario	Low neighbourhood weights assigned (15%)	High neighbourhood weights assigned (7%)

based on the change percentage observed. The change percentage will be a percentage of change between the normal simulation and the sensitivity run.

$$\text{Change percentage} = \frac{\Delta n}{N} \times 100 \tag{3}$$

where Δn is the total number of changed cells in the study area and N is the total number of cells in the study area.

Table 6 shows the results of the sensitivity analyses. It can be concluded that the model is most sensitive to low neighbourhood weights. The model is not very sensitive to the elasticity values.

5.2. Simulated results

The simulated scenario outcomes (Figure 4) were evaluated based on a set of indicators (based on principles outlined in the city's GMS 2030) to evaluate which scenario produces the best results, given the high rate of urbanisation and migration predicted for the city. The simulated results show the different influences of the two scenarios on the city's northern and southern parts and compares the influences for the year 2030. The simulation starts in 2007 and runs to 2030 (to be comparable to the city's GMS of 2030). The various indicators that were tested include:

(1) Spatial inequality (5.2.1): measured through (1) wealth segregation and (2) distribution and quantity of economic nodes and centres.
(2) Density patterns (5.2.2): measured through (1) amount and location of change (urban sprawl) and (2) densification of transport management nodes (transport sustainability).
(3) Commuting distances (5.2.3): measured through (1) access to public transport.

5.2.1. Spatial inequality

5.2.1.1. Wealth segregation. Measuring the effect of the policies on the distribution of wealth is done by subdividing the city into a northern and southern section and calculating the number of households per land use type in each segment. In 2007, the majority (61%) of all households in the city lived within the southern part of Johannesburg and 91% of these southern households are considered lower income earners (mixed (7), informal (8) and government low-cost housing (9)), while the majority of the households in the north (67%) are higher income earners (formal residences).

In the AS-IS scenario (2030), this will stay largely the same with 60% of households residing in the southern parts of the city of which 90% will be in the lower income category.

In the Policy-Led scenario (2030), the results indicate that more people reside in the north (48%) compared to the 39% of 2007. The Policy-Led scenario will lead to almost an equal amount of higher income earners (51%) and lower income earners (49%) present in the north, but the southern part of the city will see slightly more higher income earners (22%) compared to the 10% projected for the AS-IS scenario.

5.2.1.2. Distribution of economic nodes. The effect of the policies on the distribution and quantity of economic activity was evaluated separately for the northern and southern segments of the city. Commercial activity was measured based on the area of commercial activity and the number of households per economic hectare. The inequality and the spatial heritage of the apartheid's planning policies are clearly evident. In 2007, 4.5 times the amount of commercial hectares are available in the northern affluent parts of the city compared to the south. Comparing the quantity of commercial activity with the household distribution emphasises the inequality as 61% of the population are distributed in the southern suburbs of Johannesburg, leaving a ratio of 903 households per commercial hectare versus the 127 households per commercial hectare in the north.

The AS-IS scenario paints a very gloomy picture as both the population distribution (40% north vs. 60% south) and commercial distribution (80% north vs. 20% south) stay largely unchanged from the 2007 situation. The Policy-Led scenario betters this picture as more people are projected to live in the north (48%) as well as more economic activity is projected for the south (33%). Even though commercial activity will slightly increase in the south, this will not keep up with the households' projected growth in the south, leaving the south with a ratio of 489 households per commercial hectare.

5.2.2. Measuring density

5.2.2.1. Urban sprawl. The effect of the policies on urban sprawl can be determined by calculating the total built-up area, the land consumption per households and the percentage of new development in 2030. In 2007, about 95,754 hectares were classified as built-up (58% of the total Johannesburg area) with an average of 15.8 households per hectares.

By implementing a UDB and forcing higher densities in accessible locations, the city's footprint will increase by 14–72% built-up areas. This is a small increase compared to the 86% built-up area (28% increase from the base year) predicted when no development boundary is applied. Densities will also be higher in the Policy-Led scenario resulting in 22.1 households per hectare compared to 18.5 households per hectare if no UDB is applied. Not implementing any restrictions or policies will result in 67% of vacant land being converted to built-up areas where applying restrictions will only see 34% of vacant land converted to built-up areas.

5.2.2.2. Densification of the transport management corridors. This measure looks at the effect of the two scenarios on the sustainability of the government-defined transport management area. Higher densities within the transport management corridors will ensure greater sustainability of the public transport network.

In the AS-IS scenario, the majority of the households are located in mixed housing (42%), indicating that low-rise residential developments will convert into higher densities due to the optimal location of these areas. The Policy-Led scenario indicates a shift towards the majority land being occupied by government-provided low-cost housing (61%) followed by mixed housing (32%). The Policy-Led scenario will host 673,941 households in these preferred corridor areas compared to 514,420 if no policy intervention is made.

5.2.3. Measuring access to public transport

The following section will measure the access to various publicly provided transport systems. The effect of the policies on the access of households to public transport will be calculated by determining the number of people within a set distance from the Gautrain stations, the BRT lines (bus routes) and the Metrorail stations. The access to Gautrain stations is based on a 5-km radius, whereas the access to BRT lines and Metrorail stations is based on a 2.5-km radius. The assumption was made that for both the BRT lines and the Metrorail stations, a walking distance should apply, whereas for the Gautrain stations, a slightly further driving distance can be assumed.

5.2.3.1. Household access to the Gautrain stations. The land area was multiplied by the densities per land use class to derive the number of households per land use class. From the AS-IS scenario, it is evident that the largest land area within the 5-km buffer will be consumed by low-rise and small holdings (cumulatively 68%), whereas the Policy-Led scenario will results in an equal amount of land being occupied by both the higher income classes (44%) and lower income households (44%). Translating these land areas into the number of households gives a slightly different perspective. The AS-IS scenario will see more of the higher income earners (56%) having access to the stations, whereas the Policy-led scenario will see the majority of the government-provided low-cost housing (59%) having access.

5.2.3.2. Household access to the BRT lines. Implementing the various policies in the Policy-Led scenario will see an additional 200,000 households having access to the BRT lines compared to the AS-IS scenario. The majority of the households will fall within the mixed housing class for both scenarios. This can be attributed to the fact that the BRT lines

Table 7. Amount of land (in hectares) in the various land use classes.

Housing type	2007 Base year (Ha)	2030 AS-IS scenario (Ha)	Land area 2030 AS-IS (%)	2030 Policy-Led scenario (Ha)	Land area 2030 Policy-Led (%)
Small Holdings (3)	8514	1098	3.74	2456	7.28
Low rise (4)	7074	6638	22.6	2526	7.49
Medium rise (5)	428	1853	6.31	1486	4.41
High rise (6)	380	763	2.6	1707	5.1
Mixed housing (7)	9766	14,662	49.91	14,521	43.05
Informal settlements (8)	1910	4172	14.20	16	0.05
Government housing (9)	1119	192	0.65	11,022	32.7
Amount of residential land consumption (Ha)	29,191	29,378	–	33,734	–
Amount of households	487,828	740,900	x 1.5 times	825,935	x 1.7 times

run through Soweto that stays largely unchanged throughout the simulation years. So even though 59% of the land in the AS-IS scenario is dedicated to higher income earners, the majority of household access is still obtained by the lower income earners.

5.2.3.3. Household access to the Metrorail stations. From the land consumption of the different land use classes within a walking distance of 2.5-km from the Metrorail stations, it can be observed that in both scenarios the low-rise residential housing will be redeveloped and replaced by lower income classes. A lot of informality (both informal settlements and mixed housing) will be present in the AS-IS scenario, whereas in the Policy-Led scenario, all informal settlements will be replaced by government-provided housing. Table 7 displays the land area consumption per land use class within a 2.5-km distance buffer from the Metrorail stations. It can be observed that the majority of the households fall within the lower income earners (mixed housing, informal settlements and government housing) for both scenarios.

In all three public transport cases, it is clear that both scenarios will lead to an overall increase in the amount of household access to public transport; however, the Policy-Led scenario will allow a greater number of low-income earners to have access to the public transport systems.

6. Conclusions and discussion

In this research, we have shown that it is possible to use an existing land use model (Dyna-CLUE) to simulate land use change for Johannesburg, while taking into account specific elements like informal settlement and backyard shacks. This was achieved by proposing a new three-layered land use class typology including function, density and income. The model was also adapted to simulate the growth of both formal and informal structures as well as policy interventions such as government-provided low-cost housing.

We have tested our model using two scenarios, the AS-IS scenario and the Policy-Led scenario, and by applying an UDB. Outcomes were compared using spatial inequality, density patterns and commuting distance as indicators.

Results for spatial inequality indicate that the AS-IS scenario will not lead to any significant change. The Policy-Led scenario results in more households residing in the north of the city and a greater number of high-income earners in the south, 22% compared to the 10% projected for the AS-IS scenario. It also provides more economic opportunities (33%) in the south for 52% of the households.

The density pattern is influenced by the use of an UDB as it restricts the growth of the city. Implementing the UDB will result in the city being 72% built-up in 2030 compared to the 86% predicted if no boundary is applied. The densities will increase to 22.1 households per hectare in the Policy-Led scenario compared to the 18.5 households per hectare in the AS-IS scenario. However, this increase can also be ascribed to the government-provided low-cost housing and high-rise building implemented in the Policy-Led scenario.

The effect of the policies on the commuter distances indicated that both scenarios will lead to an overall increase in the number of households that have access to public transport, but the Policy-Led scenario will allow a greater number of low-income earners to have access to the public transport systems.

Although this research has proven that it is possible to use an existing land use model to simulate urban growth in South Africa, the current implementation of the model still has some limitations. Land use demand cannot change dynamically based on feedback of land constraints (e.g. if available land runs out, the model should have adjusted to build higher density residences instead of assuming it is not possible). In future implementations, this can be resolved by running multiple scenarios that test the effect of the variations within the household classes. Although a visual validation process was used, it is suggested that a more rigorous statistical validation process be performed that is based on a larger time interval (e.g. year 2001–2011). The insufficient availability of land use trend data has since been overcome by various recent outputs such as the Census 2011 and GTI 2012 growth indicator data-sets.

From the analyses, it became clear that adopting the government policies (as described in the GMS of 2010) on densification and growth restrictions is a good step towards a less segregated and denser Johannesburg. We see great possibilities for using the existing model to simulate land use change in South African cities. The model requires less input data compared to other modelling techniques and with small adjustments and adaptations can prove to be a useful tool for urban planners.

Notes

1. Informal dwellings: 'Makeshift structure not approved by a local authority and not intended as a permanent dwelling. Typically built with found materials (corrugated iron, cardboard, plastic, etc.)' (Census Metadata, 2011).
2. Backyard shacks: 'Makeshift structure not approved by a local authority and not intended as a permanent dwelling. Typically built with found materials (corrugated iron, cardboard, plastic, etc.)' sharing a yard with a formal dwelling (Census Metadata, 2011).
3. In-situ upgrade refers to the upgrade of an informal settlement to a formal settlement on the current location while the residence resides in the area.
4. RDP: Reconstruction and development programme.
5. Social housing: Medium-density housing for rent.
6. Projected figures were used before the official release of the Census 2011 data release.
7. Land use is a general term used to describe how land is being used by humans and the socio-economic activities that take place on the parcel of land.

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