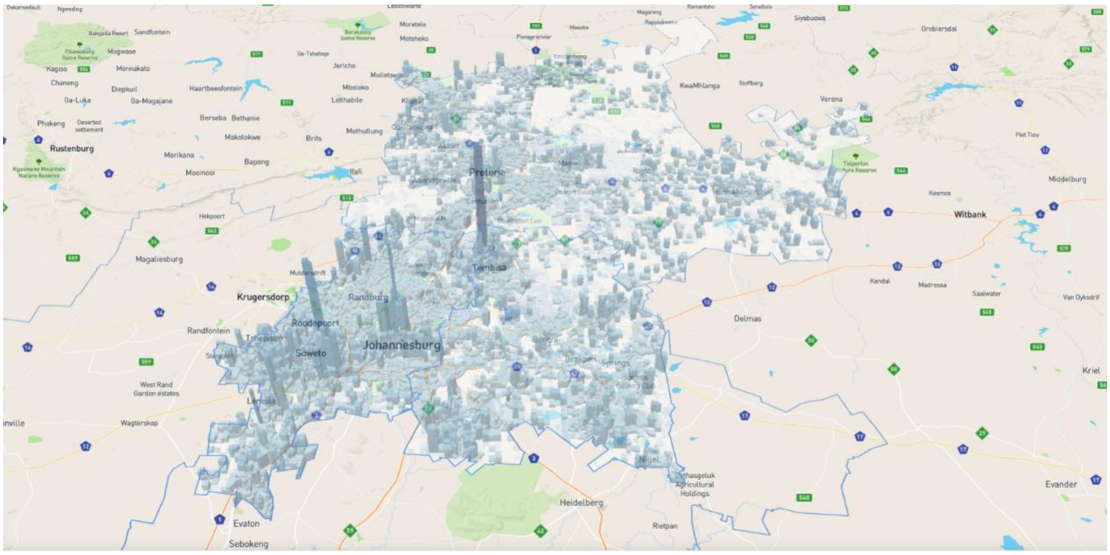

Urban growth modelling and simulation: *Learning from the past, applying in the present and dreaming of the future*

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Learning from the past, applying in the present and dreaming of the future

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When you hear the word “city”, what comes to mind? Built-up areas with skyscrapers? Old buildings with historic and religious meaning? Public transport systems and massive highways? Informal settlements and informal trading?

Our backgrounds and circumstances influence the way we see and experience cities. But one thing remains true of cities: there is always a buzz of interactivity of some sort, be it in business transactions, leisure activities or the process of moving about. Cities are complex systems and governing cities is, unsurprisingly, a complicated matter.

As cities grow, they become increasingly complex in terms of economic systems, social structures and geopolitical considerations. Different role players, acting individually and collectively, give rise to the emergent patterns of the city – traffic congestion, housing shortages, and deficits in service delivery. Factors like natural disasters and climate change add to the dynamic, complex character of cities.

So, how do planners and decision-makers plan cities in a way that will make them sustainable? How do they ensure that the outcomes they intend will be achieved? And how do they test the likely impact of policy interventions?

One of the tools at their disposal is urban modelling, in which the Council for Scientific and Industrial Research (CSIR) has been investing for several years, adapting a simulation model developed in the United States, UrbanSim, and applying it in a local context. Urban growth modelling is essentially a tool to facilitate coordination and prioritisation, taking account of the fact that different role-players in the city make disparate decisions, which influence the major issues that our cities face. The CSIR’s work on urban growth modelling has been from the perspective of various role-players, including government.

The urban challenge in South Africa

Our Constitution clearly sets out the roles of three spheres of government and intends that these authorities should execute their powers and functions in a coordinated fashion and deliver public services effectively and efficiently. Yet, public services appear to be fragmented and government consequently fails to deliver on certain policies.

People’s frustrations at poor service delivery are reflected in the growing number of service delivery protests across the country over the past decade. The social and financial pressures caused by rising unemployment partly drive these protests, as do grievances at the failure of municipalities to create adequate job opportunities (Municipal IQ, 2019).

Where cities manage to create jobs, they face challenges regarding the location of these jobs, which are often distant from where the jobless live. Without adequate public transport systems, households simply cannot afford to access job opportunities. Furthermore, there may be a mismatch between the skills required for available jobs and those that work seekers possess.

[1] Cover image used with permission from UrbanSim Inc.

Questions facing municipal governments include where and when to develop housing, other catalytic projects, and public transport infrastructure to increase access to employment opportunities and improve the wellbeing of communities. Additional factors affecting these decisions include the available budget as well as trade-offs involved in maintaining existing infrastructure, catching up on service backlogs, and undertaking new developments.

In recent years, substantial allocations have been made in the national budget for infrastructure development. Government has also formulated national plans to stimulate inclusive economic growth, including: the National Development Plan of 2011 (South African Government, 2018a); the National Infrastructure Plan, consisting of 18 strategic integrated projects with an initial budget allocation of R1 trillion (South African Government, 2018b); and the Nine-Point Plan, which aimed to accelerate growth through infrastructural investment (South African Government, 2018c).

At municipal level, Capital Investment Frameworks seek to realise infrastructure projects as part of spatial strategies. The Cities Support Programme of National Treasury enables municipalities to undertake projects that contribute to increased densities and integrated land development (National Treasury, 2019b). Metropolitan municipalities are required to file Built Environment Performance Plans (BEPPs) on the use of infrastructure grants (National Treasury, 2019a). The aim is to align the allocation of resources with development objectives.

With all these plans, strategies and frameworks, the question remains: how does government assess the likely impact they will have on long-term sustainability of cities? How do trade-offs in size and location of development projects affect future densities, access to transport and jobs, and demand for services?

Simulation for safe testing
Decision-making about large infrastructure projects demands a safe environment in which it is possible to test the likely outcomes of interventions and trade-offs. It is costly and impractical to implement infrastructure projects and only observe their outcomes and potential shortcomings well after completion. Simulation modelling is a useful tool to initially determine the probable effects of certain interventions before implementation begins.

The simulation model is developed by observing the real world (user environment) and encoding or translating it into a model environment, which involves preparing a vast amount of data and setting up models or algorithms to represent behaviour in the real world as closely as possible. After the simulation model has been run, the results are decoded and interpreted in real-world terms. This process is repeated by adjusting elements until there is sufficient confidence in the model's accuracy. This model is subsequently used for scenario development.

Figure 1: The modelling process[2]

[2] Icons used in figures in this article are from the following creators on www.flaticon.com*:* Freepik, Good Ware, Vectors Market, Gregor Cresnar, Maxim Basinski.

Data preparation
Modelling at this level requires a vast amount of disaggregated data. The main datasets used in the CSIR's modelling activities were:

- Macrotrends, including household and employment projections.
- A sample of census enumerator forms.
- Cadastral parcels, property boundaries and municipal valuations.
- Buildings data, including building type and other attributes.
- Road networks (OpenStreetMap).
- Transport costs (OpenTripPlanner).
- Rail, bus and taxi routes.
- Other GIS information, including environmentally sensitive, undermined and dolomitic areas.
- Municipal developments in the pipeline.
- Metropolitan boundaries and urban growth boundaries.

These datasets were combined to produce final input datasets that are required for simulation by UrbanSim. The process required a three-way linkage of data on households, employment and buildings to estimate place of work, which was not captured in the census.

UrbanSim's sub-models
UrbanSim (2019a) is a sophisticated real estate modelling and simulation platform. It harnesses the supply and demand dynamics of the housing market, the behaviour of real estate developers and consumer choices regarding the location of home and work, along with other planning tools. It incorporates the interactions among land-use, economic, environmental and transportation domains.

UrbanSim represents various role-players in the city as agents in various sub-models:

- **The Real Estate Price Model** which determines the factors that influence the price of dwelling units in different areas with varying land-use provisions.
- **Transition Models** which use city-wide demographic and macro-economic projections to increase the number of households and employment opportunities in line with projected growth trends.
- **Location Choice Models** which model the likely behaviour of households in terms of choosing a specific dwelling unit (based on a number of household attributes) and the

About UrbanSim

■ UrbanSim started out as a research project and there have been a number of open-source software implementations of the methodology over time, including the Open Platform for Urban Simulation (OPUS). Its development in the US was spearheaded by Paul Waddell and funded by the National Science Foundation.
■ Subsequent versions of UrbanSim improved visualisation and scaling. Constant improvements were introduced and advances in Python facilitated faster runtime and other enhancements.
■ In 2015, a spin-off company, Synthicity, was created to focus on UrbanSim's scaling and visualisation. This company was briefly acquired by Autodesk but ultimately a new start-up, UrbanSim Inc, was created.
■ Since then, the focus has been on web development, making the models more accessible, harnessing the benefits of cloud computing, and software as a service.
■ In 2017, UrbanSim Inc launched the world's first cloud-based urban growth simulation package, UrbanCanvas Modeler.
(Urban Sim, 2019b)

The CSIR began exploring the application of UrbanSim in South Africa around 2006, working initially with OPUS, then with re-engineered versions and eventually UrbanCanvas Modeler. Much of this modelling capability was developed within the Spatial and Temporal Evidence for Planning (StepSA) initiative and subsequently with the Gauteng Department of Roads and Transport. It was only fairly recently that the model was sufficiently mature to utilise it in partnership with clients to develop scenarios. The Department of Science and Technology was an early client as were various metropolitan municipalities.

location of job opportunities (based on jobs available in various sectors and building types with space).
- **Developer Models which** identify a need for development as vacancy diminishes and subsequently determine the best locations for new developments and the number of units per building type to build. As new developments are realised, they are fed as data into the next iteration of the model.

It is readily apparent how the model reflects the actions of major role players. Government invests in roads and mass transit networks. Households decide where to live and work, taking into account their income, access to jobs and transport, and proximity of services like daycare, schools and shops. Businesses provide the jobs that attract households. Developers provide housing stock and business space and, in the process, seek to maximise return on investment. Government exercises control on physical development through land-use rights and urban boundaries.

UrbanSim and South African scenarios
In order to envisage the outcomes of various scenarios, a sound base case model must be set up and the simulation must be run for a period in the past in order to validate it. Until recently, the validation period was 2001-2011, since both the start and end years were census years, which provided more data to use. Recently, the CSIR opted to update the base year to 2011 and the validation year to 2018 to ensure that patterns of past planning are not captured in models.

The CSIR developed models and scenarios for the City of Ekurhuleni, Nelson Mandela Bay Metropolitan Municipality and the City of Tshwane. For purposes of illustration, we refer to some Ekurhuleni simulations.

The process of modelling various scenarios usually starts with a trend scenario, which includes all development projects that are certain to be implemented. The aim is to see what the future spatial distribution of households and jobs will be, based on the pattern observed during the validation period as well the assumed realisation of all planned development projects. This process also helps gauge whether the model delivers believable results.

Different scenarios are then juxtaposed to the trend scenario – as illustrated by the Aerotropolis and the Human Settlements Projects scenarios in Ekurhuleni.

The former was based on the *Aerotropolis Master Plan*, which contains three economic development scenarios (City of Ekurhuleni, 2019). The aggressive economic scenario was simulated to show the potential difference it would make to the development of the city.

The simulation related to the Human Settlements Project looked at the outcomes to be expected from two different approaches: the development of housing mega-projects in large open spaces, usually on the outskirts of the city, and smaller housing projects in already built-up areas, located closer to job opportunities.

Further developments in urban growth modelling
The CSIR has made considerable progress in developing its capabilities for urban growth modelling and simulation and has identified areas for further research.

Freight movement
Many urban growth models focus on spatial implications of development for households and transport and they neglect the dimension of supply chains and freight movement. Yet these factors are critical to a city's economic competitiveness. Store locations and sizes, inventory levels and

delivery cycles are all fundamentally influenced by the size and density of a city. Accordingly, the CSIR is developing the capability to show how urban growth modelling could help design resilient supply chains (Karsten et al, 2019).

Climate and health
There is a need to enhance the connection between urban development and climate change models, and the subsequent impact on health. The liveability of African cities is already affected by the continent's rise in surface temperatures, which is double the global average (Engelbrecht et al, 2015). It is also known that a city's form can create localised heat pockets and areas prone to poorer air quality, both of which may have negative effects on health.

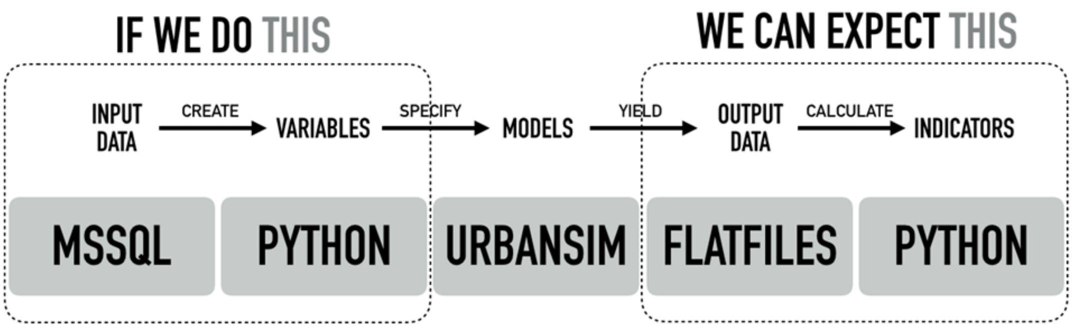
Urban growth may also need to take more account of the protection of high value agricultural land as climate change impacts on crop yields. The nexus between urban growth and climate change is currently being explored.

Enriching the indicators
To date, the CSIR's urban growth modelling efforts have emphasised common indicators in land use planning, such as density and access to transport and employment. However, any indicator that can be calculated from data on household characteristics, land parcels, buildings and zonal datasets could be included in the platform.

Alignment of modelling indicators with reporting to Treasury on BEPPs and relevant aspects of the SDGs would also enhance decision support to municipalities. This integration of reporting indicators would enable cities not only to report on the current state of a specific metric but also to indicate how this could change in future if certain development projects were implemented. Accordingly, the CSIR has started to develop dashboards that include various indicators linked to the BEPPs and SDGs and other thematic areas.

Simulation optimisation
Currently, the CSIR's urban modelling and simulation endeavours are based on a process represented in Figure 2 that is capable of supporting the typical "what if" scenario approach; it indicates that *if we do this*, we can expect *this will happen.*

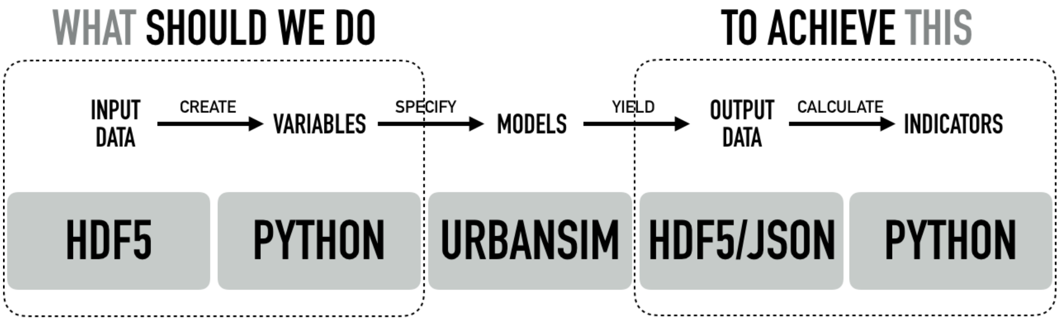
Figure 2: Abstraction of the modelling process



The current approach is useful but limited in the types of questions it can address. It also involves a tedious back-and-forth process of tweaking input data and observing the changes in output data. The CSIR has streamlined the data preparation process by using more efficient data formats and structures. While most data preparation is still done in GIS, many post-processing functions are automated and streamlined in Python. Other innovations include preparing the final database in

HDF5 (an efficient hierarchical data format) and writing output data in multiple formats, as indicated in Figure 3.

Figure 3: Abstraction of the updated modelling process



The other major improvement the CSIR is working on is framing our research questions differently. Instead of asking, "If I do this, what can I expect?" we want to be able to ask, "What should I do to achieve a certain outcome?". This involves developing capability for simulation optimisation. Although this is a fairly new operations research technique, it presents the modeller with newfound capability for enhanced decision-support. Essentially, it makes it possible to run through many simulation models to obtain the desired outcome and provides much-needed decision support on how to achieve targets.

Simulation optimisation could open up a multitude of opportunities for answering new types of questions that are highly relevant in the current political environment. For example:

- How should we structure – spatially and temporally – the rapid release of land for development? In the heated context of the land debate, the release of land in government possession seems the quickest response to pressure for making land available for development. In theory, this could address housing shortages and stimulate local economic growth. However, the location of the land and the timing of its release for development would affect how effective a solution this is. The land's zoning and the resulting permitted land use would further determine what purposes the land could be used for.

- How many social facilities should be built and, importantly, where and when? The availability of social facilities could become a factor that attracts households to live in a particular area. Simulations that varied the date of construction of facilities as well as the location and number of facilities, using an optimisation approach, could result in the optimal timing and location of such developments.

- What should the mix of land use be to obtain certain outcomes, for example, a desired density? Varying land use mixes as an input and adjusting permissible developments of these parcels of land would yield different effects on various metrics related to the city.

Concluding comments
Our concluding observations relate to lessons and dreams.

Learn from the past and apply in the present

The CSIR team has learnt many lessons over the years by using different versions of software and building numerous models.

- We have learnt that patterns of data observed historically do not necessarily hold true for the future – especially in a country undergoing rapid social change.
- We have learnt that collaboration and transparency are key to making progress when working with stakeholders. We have built positive relationships with various departments in municipal and provincial government. Where departments have had conflicting goals or opinions, we have been able to provide tools to test trade-offs and stimulate discussion.

Dream of the future

Our work has greatest value if we are able to dream of different ways in which our cities can evolve and ways in which we can achieve our dreams. South Africa has shortcomings, such as poorer quality data than developed countries, but we have potential, skills and passion to see our country thrive.

- Let us create the systems and processes to collect, maintain and enhance datasets to inform major infrastructure investment decisions.
- Let us continue with our efforts to develop young researchers by working with them on key research questions.
- Let us expand our collaborative effort. The CSIR is building a modularised platform in order to assist more clients and influence planning processes to develop truly world-class cities.

New opportunities continue to present themselves. Recently the Gauteng Department of Roads and Transport commissioned the CSIR to establish a province-wide cloud-based simulation model – the first of its kind on this scale in Africa. In future, we aspire to play a more significant and central role in planning processes. Watch this space!

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