NORTH-WEST UNIVERSITY

HONOURS THESIS

A cellular automata approach to model informal settlement growth

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"The main problems in life can only be solved when you know what works, what doesn't and why"

Charlie Munger, American investor and billionaire

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Abstract

Faculty of Natural and Agricultural Sciences
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A cellular automata approach to model informal settlement growth

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Abstract will come here in the future.

Acknowledgements

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List of Abbreviations

CA	**C**ellular **A**utomata
UN	**U**nited **N**ations
StatsSA	**Stat**istic**s** **S**outh **A**frica
GIS	**G**eographic **I**nformation **S**ystem

Dedicated to John Horton Conway (1937-2020)

Chapter 1

Introduction

1.1 Project description

The process of urbanisation has been a double edged sword whereby many a people have benefited from it while a lot more have not. The issue of informal settlements is one that covers areas such socio-economic, governance, climate, politics, healthcare, and resource management to name a few.
One of the few approaches to tackle these issues is through good modelling, and understanding the growth of such informal settlements.
This project will employ a cellular automata technique, specifically John Conway's 'Game of Life' to model informal settlement growth in South Africa.

1.2 Problem description and background

From the 1950s to the early 2000s the rate of urbanisation has increased 20%, however the amount of people living in inadequate housing, informal settlements, and slums globally is still about 1 billion.[23]
According to the United Nations (UN) the definition of an informal settlement is a dwelling with a lack of security, sanitation, water, living area, and housing durability.[9]
The UN also has a list of 17 Sustainable Development Goals of which number 11 is to create 'Sustainable Cities and Communities'. These goals are such that if even a few can be achieved the other will become easier to achieve as well. Discuss Informal settlement framework(what, where, when, how of informal settlements)

Cellular Automata (abbreviated as CA) is a discrete computational model which is studied in automata theory. The basic components of such a model is a grid which contains cells. Each cell can have a finite number of states it can take on. An initial state at time ($t = 0$) is assigned to the grid as a whole. For each time interval thereafter the cells change their states according to a predefined set of rules.[18]

Conway's *Game of Life* also known as *Life* was created by the British Mathematician John H Conway in the 1970s and first appeared in the *Scientific American* magazine.[8]
The states the cells in Life can take on are either alive or dead. The rules that govern the states of Life are as follows:

1. Due to under-population a cell will die if it has less than 2 neighbours[1].
2. If a cell has 3 or 2 neighbours it will remain alive in the next cycle.
3. If a cell has more than 3 neighbours it will die.
4. If a dead cell is surrounded by 3 alive cells it will become alive in the next cycle.

Using such a set of rules this project will embark on creating a model that will accurately predict informal settlement growth in South Africa.
Some limitations have been noted in using CA to model urban growth. These include creating trade-offs between flexibility and simplicity for the transitional rules. At the same time other opportunities in CA models also present themselves for study such as calibration, stochastic components, and cell types.[16]

1.3 Aims and objectives

1.3.1 Aims

- Create a sound mathematical and/or a statistical model
- Apply the model to *Life* to predict growth of informal settlements in the context of South Africa.

1.3.2 Objectives

- Conduct the relevant literature reviews
- Get access to relevant maps needed regarding informal settlements

[1]These are cell which are alive and are located around the current cell

- Get access to additional relevant data on factors influencing the growth of informal settlements
- If above steps fails, create own maps, and data from existing sources.
- Set-up a Geographic Information System (GIS) to load maps and relevant data
- Create a the model stated above to provide an initial state
- Apply initial state to the map in the GIS software
- Iterate and monitor growth output over the generations
- Calculate accuracy of model by comparing maps from different time periods with the actual growth.

Chapter 2

Literature Review

2.1 Cellular Automata and Game of Life

Cellular Automata can be modelled in a number of dimensions including anything from one, two, three, four, or more dimensions.[1] In this project the focus will be on the two dimensional approach using a *n*-dimensional lattice (will be referred to as a grid). The grid can be of infinite size, however will be limited to a finite space i.e. a predetermined set of cells superimposed over a map of an informal settlement.

An individual square in the grid (which will be referred to as a cell) can have upto eight neighbours. This is shown in the diagram below.

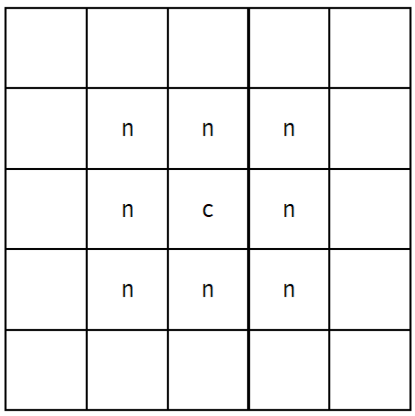


FIGURE 2.1: A cell 'c' and its neighbours 'n'

Source: Own Creation (2021)

A cell can have two discrete states for any given discrete time unit (referred to as generation). These states can be 'alive' or 'dead'. A cell is shown to be alive by having it *shaded* and if it is dead it is left blank.[1] This is shown in the figure below.

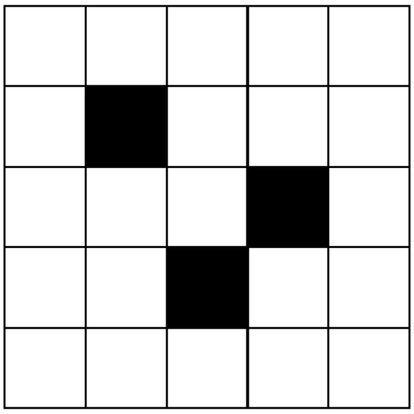
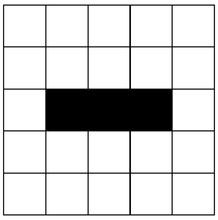


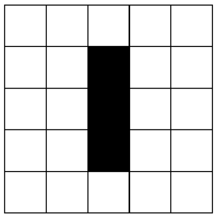
FIGURE 2.2: A grid showing alive and dead cells

Source: Own Creation (2021)

As shown in Figure 2.1 a cell can have either lateral or diagonal neighbours. The rules of *Life* were discussed briefly above in Section 1.2. A graphical representation of these is shown below.



(A) Generation $t = 0$

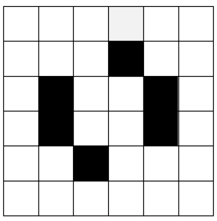


(B) Generation $t = 1$

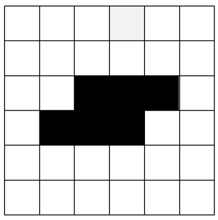
FIGURE 2.3: A simple 2 generation iteration of *Life*

Source: Own Creation (2021)

Another slightly more advanced setup of *Life* is shown below.



(A) Generation $t = 0$



(B) Generation $t = 1$

FIGURE 2.4: An advanced 2 generation iteration of *Life*

Source: Own Creation (2021)

In a seminal paper by Stephen Wolfram, four classes of CA were proposed according to their behaviour given an initial random condition .[22] These four classes are as follows:

- Class 1 - After a finite number of generations a unique homogeneous state is reached i.e. all cells become the same eventually.
- Class 2 - Simple structures are generated which are either periodic, or stable (also called persistent).
- Class 3 - An aperiodic (or chaotic) patterns emerge which carry on indefinitely.
- Class 4 - Capable of universal computations i.e. can exhibit complex behaviour.

Due to the nature of the rules of *Life* certain patterns emerge. This is thanks to the cycles of repeated stated which evolve over certain number of generations. These patterns include still-lifes, period two (or *blinkers*), gliders, oscillators, glider guns, and puffer trains.[1]

The applications of CA and, or *Life* have sparked a number of research papers in fields such as physics, music, complexity, and computation.
Examples in physics include, interaction between a complex system and electromagnetic radiation [4], an implementation of *Life* with quantum features.[7]
Implementations in music include the development of CAMUS (**C**ellular **A**utomata **Mus**ic).[13]
In the fields of complexity, and computation a vast array of work has been done therefore a few examples include; Universal Computer-Constructor in CA [10], and creation of a Turing Machine in *Life*.[14]

2.2 Informal settlements

Informal settlements are housing dwellings that are part of urban districts or neighbourhoods that arise and develop without oversight or control from the state. They are synonymous with 'slums' or 'squatters', though are not the same. They form an integral element of urban sustainability whereby developing cities can not develop without them. The connotations with 'informal', 'slums', and 'squatter' have always been seen in a negative light. This is not seen as beneficial as the growth of urbanisation is highly intertwined with

informal settlements.[5]
Across the globe informal settlements are known colloquially by their own variety of terms. [23] In this project the umbrella term informal settlement will be utilised.
The process or principles of informal settlements growth can be grouped into three categories namely;[5]

- *settling* - simply settling down on what is usually unclaimed land
- *inserting* - usually into urban areas that are abandoned, or uninhabited
- *attaching* - informal settlements that grow out of existing urban settlements

In morphological terms, informal settlements can be classified into eight different types. This refers to the urban conditions rather that the process mentioned above, however it is not to say that the two are mutually exclusive. The types are not mutually exclusive from each other either. The types are as follows:[5]

- Districts - most popular where over long periods of time the settlement grows to encompass mixed-use districts with both retail, and industrial functionality.
- Waterfronts - settlements between land and water, whether it is a lake, harbour, river, canal to name a few. Prone to water issues such as flooding if the climate is such.
- Escarpments - settlements on urban topography that is usually too steep to build formal structures. an example location would be an area between a mountain and a city. Can be prone to earthquakes, landslides, and mudslides if the climate is such. Transportation is another key concern.
- Easements - Major infrastructure in urban cities such as roads, railways, pipelines to name a few offer *'buffer'* zones which can become informal settlements.
- Sidewalks - These settlements emerge when public area such as sidewalks have an area where people can set up dwellings, even if for temporary usage.
- Adherences - Related to the principle mentioned above.

- Backstages - Settlements hidden from the public's gaze. Becomes more informal the *'deeper'* one goes from a formal street frontage.
- Enclosures - Settlements where the *'shell'* is contained with in another urban building.

Informal settlement residents just like the residents of formal settlements have a desire for a good quality of life. Factors that influence this quality of life include food storage and preparation, water, sanitation, air quality and pollution, electricity, health risks, access to public facilities and amenities, among other things.[15]
Richards et al. (2007), further sates that everyday problems such as unemployment, and crime also influence the quality of life. The paper further stipulates that the research can be expanded further to look into spatial and temporal factors that influence informal settlements.

The characteristics of informal settlements transcend the physical and are closely knitted with socio-economic as well as political conditions.[21]

2.3 Modelling Urban Development

The phenomenon of urbanisation in the last century has drastically increased from a mere 13% in 1900 to a 49% in 2005. The current projected estimates for the year 2030 in 60%. The majority of this urbanisation is still going to occur in the developing nations.[19]

One of the three factors that is going to influence humans directly in the near future is the land-use/land cover change. This will affect policy makers, geographers, and planners all alike. This is thanks to the socio–environmental consequences of the spatio-temporal process of urban development.[12, 20]

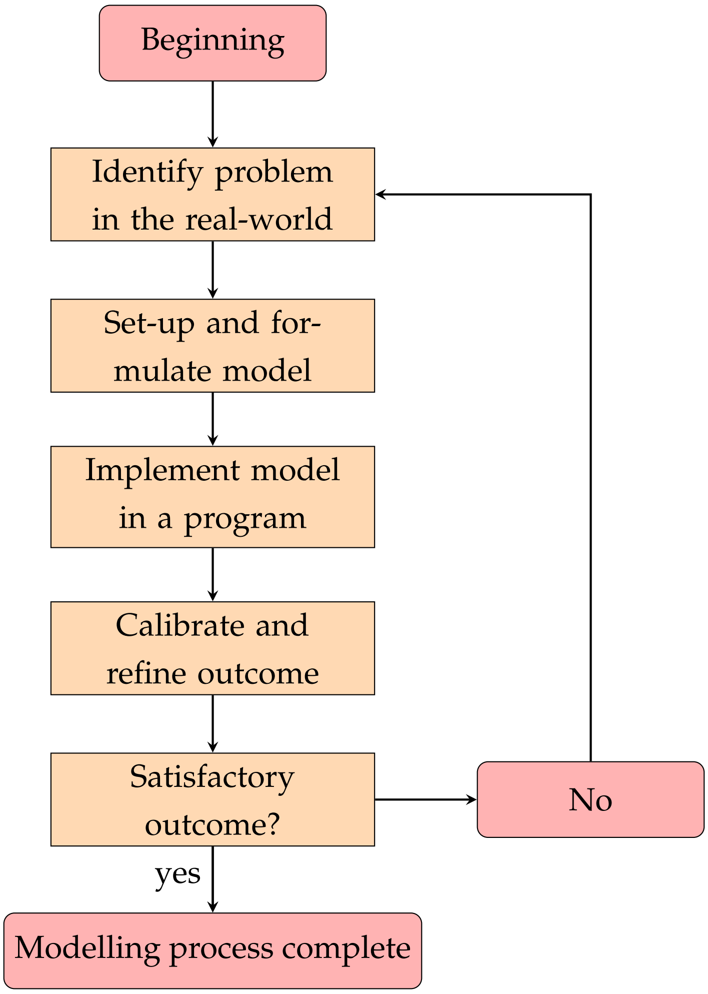
When it comes to geographic models they can be categorised into three categories of increasing abstraction.[17] The models are as follows:

- Scale
  - Iconic
  - Analogue
- Conceptual or Diagrammatical

- Mathematical
  - Probability
  - Deterministic

The mathematical models are therefore the highest level of abstraction. Scale models mimic reality but are miniaturised copies of the real world. The main difference between Iconic and Analogue is the later besides being replicas they tend to transform certain properties of the real world system, e.g. using wool for clouds. Conceptual models are concerned with the relationships that exist between components in the system e.g. a sewage system can be denoted with arrows and boxes on a diagram. Mathematical models if in their purest form translate a conceptual model in to pure, formal, and symbolic logic of mathematics.[17]

The flow chart of the modelling process is shown below.



Source: Own Creation (2021) adapted from [12]

Before continuing it should be noted that one of the major pitfalls of models are they are a simplified view of reality, hence they can tend to leave certain facts behind of reality.[12]

One of the earliest models created in geography and urban modelling dates back to the 1800s where Johann Heinrich von Thünen in his book titled *Der isolierte Staat* translated to mean *The Isolated State* discussed maximising agricultural production.[3]
Other seminal research included the like of Alfred Weber in the early 1900s published the title *Über den Standort der Industrien* which translates to *Theory of the Location of Industries* This work created models based on real-world conditions.[6]

The seminal work on the three classical models of urban structure, growth, and urban land usage patterns was done by a number of authors. The models include Concentric Zone Theory, Sector model, and the Multiple nuclei model.[12]
These models laid the foundations for later computer based models to emerge in the field of urban modelling. The early works include tecniques on simulation, linear analysis, and mathematical programming.[11] Among the first studies carried out on simulations of real-world cases using urban CA was done by [2].

The meta-analysis carried out by Sante et al. (2010) showed that a number of characteristics are utilised in each of the studies that resulted in a varied range of accuracy for the models implemented in CA for urban growth.[16]
A few characteristics are:

- Cell space
- States
- CA relaxations (Neighbourhood, Transition rules, Constraints)
- Calibration
- Validation

Additional factors were also implemented which also helped in creating a varied range of accuracies. Some of these factors include:

- Accessibility of transport

- Distance to railways, airports, and urban centres
- Social services
- Slope & Elevation
- Environmental factors
- Hazard lands
- Agricultural value
- Urban suitability
- Zoning
- Population density
- Land value
- Construction year
- Water supply
- Social housing

All of the above with a combination of additional research will now help the project move to the next step which is the development of the artefact, which in this project's case is a model.

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