Urban Retrofits and Reticulations in the Densification Efforts: Energy, Water, Sanitation and Transport

DICKSON D, MHLANGA, AND SHAMISO HAZEL MAFUKU[1]

Abstract

This article examines energy, sanitation and transport as key flows in urban management systems and how these are critical aspects of the densification efforts. It argues that circulation and flow are what makes the urban area function. Densification and retrofitting in urban settlements have now become a global trend as cities attempt to manage increasing populations and real estate investment. It is thus critical for urban planning to develop strategies that can ensure adequate energy, water, sanitation and transportation. However, in developing these strategies, key insight into urban form, structure, function, infrastructure and city image is required. The objective of this exploration is to propose a theoretical framework upon which the urban retrofitting and densification may be implemented with focus on energy, water sanitation and transportation as current in-demand issues that need addressing.

Keywords: *chaos theory, urban economic activity analysis, informality, geographical information science, geographical information systems*

INTRODUCTION

Zimbabwe's urban areas are currently going through a significant trend shift, especially within the residential sector with densification and the concept of cluster homes becoming popular. This has been necessitated by the demand for residential space in major cities and a surge in urban real

[1]Department of Architecture, University of Zimbabwe

estate investment. This trend in densification can be attributed to "the age of cities" as mentioned by Young and Lieberknecht (2019) where the rate of urbanisation is increasing as larger percentages of the population move to cities. This has now prioritised densification as a new tool in urban development. However, as the rate of urbanisation and densification increases, there is an impact on the essential services required in urban areas, namely water, energy, transportation and sanitation as provision levels become inadequate. Furthermore, phenomena such as informality introduce a complexity that cannot be ignored. Thus, there is a need to analyse and understand the city from a systems perspective and explain into a framework how various "chaotic" urban aspects are related.

The data utilised included a desktop review of key global and local densification and retrofitting literature. Firstly, a background on the densification phenomenon in Harare was explored. This was followed by a literature review of key densification concepts that included global and regional densification case studies. In the development of this exploration, it was important to attempt an understanding of the city itself from an alternative perspective. This was done using the dynamical systems concept and, in particular, the Chaos Theory. This was done with the purpose of explaining into a framework the apparent "chaotic" aspect that occurs within the city. A conceptual densification framework is then presented with a sound scientific densification strategy based on urban planning concepts. A theoretical densification and retrofit model is then illustrated which local authorities in Zimbabwe can utilise. Finally, a discussion which focuses on energy, water, sanitation and transportation densification and retrofit strategies for cities in Zimbabwe concludes the article.

LITERATURE REVIEW

The literature review is divided into two sections. The first section reviews the literature on urban densification, whilst the second section explores strategies being implemented by regional and global cities and how they are attempting to integrate densification into their urban landscape.

THE RISE OF URBAN DENSIFICATION

The advocates of densification suggest that compact cities favour the preservation of the peri-urban and stimulate local economies through clustering and shorter "business distances" which encourage more productivity. (UN-HABITAT 2009; Boyko and Cooper 2011, Glaeser and Joshi-Ghani, 2013). In the case of public transportation, densification creates a positive relationship between higher densities and more effective use of public transportation infrastructure (Newman and Kenworthy, 2000; UN-HABITAT, 2013; Weakley, 2015).Densification may thus be a catalyst for infrastructure improvement programmes but does not necessarily guarantee it and so any densification strategy requires careful urban management and coordinated input by all stakeholders (Boyko and Cooper, 2011; Holman et al., 2015).

Critics of densification argue that it brings with it the challenges of congestion, crime and pollution whilst putting pressure on urban natural resources, especially city "open spaces" (Chen *et al*., 2008; Boyko and Cooper, 2011). They further suggest that densification can be achieved only by highly organised cities with robust infrastructure and competition for available land can lead to low-income groups being disadvantaged (Glaeser and Joshi-Ghani, 2013; Collier and Venables, 2016). Densification restricts the supply of land and has the potential to push up land value, thus prohibiting full access to the city (Bertaud, 2015). It has its pro and cons, and trade-offs need to be made. Both subjective and objective analyses need to be made, in this regard, perceptual and qualitative evaluations are essential but rarely taken into account in the formulation of densification policy (Churchman, 1999; Boyko and Cooper, 2011).

DENSIFICATION, THE URBAN GREEN AND WETLANDS

One of the critical challenges with densification is that it competes with urban green spaces and tends to destroy natural landscapes and indigenous ecosystems (Kamiryo, Sakashita and Matsumoto, 2011). Amid rapid global densification, there is need for multi-functional green spaces that provide multi-layered services that benefit both the environment and community (Kim, Miller and Nowak, 2015; Kim and Coseo, 2018; Kim and Miller, 2019). In this regard, urban green is

viewed as highly restorative to community health and it contributes to the subjective value that a community places on its locality (Kaplan, Kaplan and Ryan, 1998). In developing strategies for sustainable densification, an assessment of existing green infrastructure is critical for planners as they attempt to identify underutilised interstitial spaces as opportunities to provide sustainable amenities for communities (Chanse *et al*., 2017; Nikologianni, Moore and Larkham, 2019).

The Harare Wetlands Trust, a local environmental pressure group, in a 2020 report stated that during the period 2019-2021, over 2000 sites designated as wetlands had been developed within the City of Harare (capital of Zimbabwe) boundary. The organisation warned of the dire medium-to-long-term consequences of developing on these key sites and highlighted that the destruction of headwater wetlands would lead to increased stormwater run-off, increased incidences of flooding, increased siltation in Harare's water sources, reduced groundwater recharging and reduced water quality (Chidakwa, 2022).

THE CITY AS A DYNAMICAL "CHAOTIC" SYSTEM

With the rate of city growth globally, the quest for sustainability, coupled with the need for urban resilience, it has become essential for urban planning and management to analyse cities from as many alternative perspectives to develop a wide array of solutions. In this exploration, one alternative view of city analysis and understanding is the Chaos Theory. The premise of the Chaos Theory focuses on dynamic systems. Dynamical systems are systems with active forces that participate. These systems are constantly in motion (Brin and Stuck, 2002). The principle of dynamical "chaotic" systems is that they operate in phase space (X, Y, Z space) and within this space, data sets are constantly in motion and interacting with each other. This is very similar to the city and the interactions within. The city is defined by physical space and within this space, there are data sets such as energy, transportation, water and sanitation systems which are always in motion and interacting.

Chaos Theory is an inter-disciplinary scientific theory that focuses on unapparent patterns and deterministic laws highly sensitive to initial conditions in dynamic systems (Ekeland, 1998). In dynamical systems,

these unapparent patterns and deterministic laws were initially thought to have completely random states of disorder and irregularity. The theory states that within the apparent "chaotic" complex system, there are always underlying patterns, interconnectivity, repetition, self-similarity, feedback loops, fractals and self-organisation (Thietart and Forgues, 1995). Dynamical systems are essentially predictable for a short period and then begin to appear as random. The duration that a dynamic system is predictable depends on the tolerance of uncertainty, how accurately the current state can be measured and finally the time scale depending on the dynamics of the system (Wisdom and Sussman, 1992). Chaotic dynamical systems have three key attributes which are sensitive to initial conditions, topological mixing and dense periodical orbits.

Sensitivity to initial conditions means that the origin of each data set in the system is arbitrarily closely approximated to other similar data sets that have significantly different future paths or trajectories. Thus, an arbitrarily small change in the current trajectory of one data set may lead to a significantly different future outcome. Topological mixing means that as a system evolves, data sets within a phase space overlap each other, creating intersection zones which are common to the data sets. This is where the term mixing originates. Furthermore, these points of intersection of the data sets create new origin points and trajectories for mixed data sets. The third characteristic of chaotic systems is that it has dense periodic orbits. This means that even though a system is sensitive to initial conditions and mixes with other subsets of data, it still cycles through points of regularity and "unpredictability" along a time scale (Devaney, 2003). This unpredictability is caused by the intersection of original data sets and how they create new mixed data sets which have new trajectories.

INFORMALITY

The majority of the world's urban growth is taking place in the developing world, and within these geographies, informality, once associated with poor informal settlements, is now a generalised form of urbanisation. (Roy, 2005). Roy, defines informality as a condition of exception from conventional methods of urbanisation and involves urbanisation activities that fall outside the control and management of

government. Informality has always presented dualistic views; one perspective views it as problematic, whilst another view gratifies it as the resolve of marginalised groups to achieve social, economic, political and geographic urban inclusion (Banks *et al*., 2019). Cities in Zimbabwe display a high degree of informality as is witnessed in newly developed areas that are characterised by substandard roads, absence of water and sewer reticulation systems and low or non-existent electricity supply systems.

Spatial Analysis Concepts of the City

In developing appropriate strategies regarding densification programmes for cities in Zimbabwe, planners must understand the urban form, urban infrastructure, urban structure and urban function of existing cities. The urban form is how settlements were developed from the beginning and are influenced by social, economic, political, environmental and technological factors (Lynch, 1984). An understanding of how these factors have influenced settlement development has the potential to give insight to planners as to what factors to observe over key periods. Urban infrastructure encompasses the physical structures needed for society to operate. This includes urban energy systems, transportation, water supply, solid waste management, information and communication technologies, cultural and social systems and, finally, green and blue infrastructure. The urban structure of a city describes the arrangement of land uses in an urban settlement. This describes the location and scale of residential, commercial, industrial, institutional and recreational land use zones. The urban function is conceptualised as the core function of the city within the macro-economic and spatial system. It describes how cities are related to each other and how functional economic components contribute to national economic systems. In this regard, cities develop attribute characteristics such as administrative, industrial, tourist or residential core functions.

The Concept of the Good City Image

Lynch (1960), in his book *The Image of the City*, described how urbanites take in information about the city through the use of mental mapping. He describes this mental mapping as crucial in how urbanites navigated through and made sense of the city. Lynch argues that for any given city,

a corresponding set of mental images exists in the minds of the people who experience that city. The mental maps described by Lynch comprised five key elements which were paths, edges, districts, nodes and landmarks. Within the mental mapping experience, paths comprise streets, railroads, waterways and other channels which urbanites use to navigate through the city. Paths are primary in that they arrange city spaces and movement between them. Edges are described as boundaries that are real or perceived and can be in the form of walls, streets, overpasses, underpasses or buildings. Districts are described as two or three-dimensional areas that have common attributes. Nodes are large areas at a city-wide level that serve as focal points and are related to other focal areas through paths. Landmarks are described as points of reference and are in the form of buildings, sculptures and hills. They can carry historic significance.

FUTURE DIRECTION IN URBAN PLANNING: THE PARADIGM SHIFT

With the global environmental situation in decline and cities being at the centre of the problem, there is need to develop and adopt practical new ways of solving urban challenges and this requires a paradigm shift. This shift entails the melding of technology with the environment to create resilient sustainable communities (Ercoskun, 2012). There is need to completely shift the way we view our cities and the concept of urbanisation. Further, there is need to educate and involve communities by making them understand that they are part of the paradigm shift (Jones, 2016).

CASE STUDY 1: CITY FORM AND INFRASTRUCTURE IN DENSIFICATION - JOHANNESBURG: SOUTH AFRICA

The densification approach in South African cities is characterised by loosening of planning controls, density increases in special areas and greater attention to managing and supporting urban planning processes (Todes *et al.,* 2018). Global south cities are characteristically different in that the majority originated during colonial eras, thus the original city form was influenced by the colonial political agenda. The late apartheid era saw critics arguing for the restructuring of the city towards a more compact and integrative form through policies which encourage densification and mixed-use strategies (Dewar *et al.*,1977). The thrust of this drive was to encourage variety, efficiency, convenience and

accessibility, thus consequently creating wider economic opportunity and social mixing. Such suggestions were then adopted by post-apartheid cities. The City of Johannesburg, for instance, (CoJ, 2016) introduced mixed-use zones, whilst it intensified densification along transportation corridors and nodes. It introduced priority corridors along which infrastructure investment was a priority. It is, however, important to note that in South Africa's case that the city infrastructure is one of the best on the African continent (Todes *et al.,* 2018). It has 9247 km of tarred road with only 1040 km untarred. Further, there is 9500km of water pipes and 9000km of sewer lines. It has two active power stations. The average travel time for commuters is 72 minutes and there is a less than 1km travel distance to access modes of transportation (City of Johannesburg, 2016).

CASE 2: CITY FORM AND COMMUNITY IN DENSIFICATION- TAMELA NEIGHBOURHOOD; CITY OF TAMPERE: FINLAND

In 2008, the City of Tampere initiated a programme to densify using the neighbourhood of Tampere as a pilot case (Wallin *et al.*, 2018). In its vision, the city stated that densification would halt the diffusion of the urban structure which if left unchecked, would lead to additional costs in maintaining the infrastructure and service network (Vision of Tampere, 2012). It further stated that densification would be strategic to attract inhabitants and businesses, new housing projects and jobs without destroying the city's identity, natural boundaries and appeal. Tampere is located in south Finland and in its early days, was a working-class industrial city. However, in the last decades, its economy has been centred on high technology and services (Wallin *et al.*, 2018). Wallin (2018) states that the city has a history of shoemaking and the image of a working-class city.

The modernist approach to urban planning has been criticised for ignoring citizens, thus creating a contradiction between planning processes and past and present citizen experiences (Jacobs, 1961). Leverbve (1991) highlighted how planning reduced social space into abstraction and this resulted in the alienation of citizens' past and present experiences in that space. After this criticism, calls were made to make planning processes participatory (Healey, 2007), but there is still a long

way to realising the citizens' genuine right to the city (Sandercock, 2003). Cities are a composition of subjective and collective stories and these stories are responsible for creating places (Eshuis and Edwards, 2013). From this understanding that cities are "stories of information", it is important for planners to continue these social narratives as they develop strategies for the future (Massey, 2005).

In Tampere, the residents understand their urban landscape as representing stories about the working class and its evolution. Their stories are told through landmarks such as old factories and wooden buildings whose history is enshrined in massive social changes after the Second World War (Wallin *et al.,* 2018). To date, as the city attempts its densification programme, its planners have downplayed the importance of the place's history and the urban stories that revolve around it. Wallin (2018), in the study of the Tamela neighbourhood, concludes by highlighting for planning to gain local support, critically needs an understanding of the local stories of the neighbourhood and integrating them into planning outputs.

CASE 3: INFRASTRUCTURE IN DENSIFICATION – ATHENS: GREECE.

The metropolitan area of Athens is one of the densest worldwide, ahead of London and Los Angeles. This area belongs to the Mediterranean zone. This zone is affected by the heavy Heat Island effect caused by the enthronisation of the surface. Over the last century, several urban plans have been developed to re-form and reorganise the city (Ferrante, 2020). These plans were developed without a clear densification guideline and are characterised by highly densified blocks lacking urban green, vegetation, insufficient public spaces ad increased urban traffic (Tsagkalidou, 2015). To upgrade to the existing urban setting and increase real estate value in degraded areas, new legislation has been introduced that reduces income tax on condition-specific energy renovation are retrofitted onto the building which makes the building more energy-efficient (National Energy Efficiency Action Plan, 2014). This particular case indicates that from a city infrastructure perspective, Athens was inadequately prepared for the task of urban densification.

RESULTS

HARARE: INFRASTRUCTURE ANALYSIS

Morton Jaffray, Harare's sole water treatment plant with a capacity of 700 mega litres a day, has been running at less than half capacity for several years. This declining state of operation has led to many residents in the city resorting to on-site boreholes and wells (Chidhakwa and Mundawarara, 2020). The increase in borehole drilling in new residential areas of Harare is a result of the unavailability of reticulated water and sewer. This has resulted in th7 7e proliferation of pit latrines, poor quality septic tanks and soakaways as the only viable means of disposing of waste, leading to increased levels of groundwater contamination due to the lack of ignoring local geological structures (*The Herald*, 2017). To add to the quandary of water challenges in the city of Harare, the Ministry of Health in 2017 stated that 95% of boreholes in the City had unsafe water for consumption, with a specific case of Mbare where 20 out of 30 boreholes were contaminated (Chipunza, 2017).

Effective and efficient water treatment facilities are critical for functional cities and healthy environments (Okoh *et al.,* 2007). Harare has been facing severe water treatment challenges. It has two primary water treatment plants, Crowborough and Firle. These treatment plants process combined domestic and industrial waste (Mathuthu et al., 1995) (treatment capacity). In Zimbabwe domestic energy is generated mainly by hydropower and coal. Hydropower energy generation constitutes 57%, whilst coal contributes the remaining 43% (Makonese, 2018). In 2020, the Government of Zimbabwe released a statement that the country had enough energy generation capacity due to the finalised refurbishment of the Hwange Power Station which would add 300MW to the national grid (Chingwere and Chikwati, 2020). However, in September 2021, the Zimbabwe Electricity Transmission and Distribution Company (ZETDC) released a power rationing schedule siting generation constraint at Kariba and Hwange stations (*The Herald,* 2021).

In March 2020, the Government of Zimbabwe announced a ban on all private commuter vehicles, citing the need to control the then outbreak of COVID-19. The government further indicated that all private commuters

that wished to continue operating would have to hire out their vehicles and fleets to the government-controlled Zimbabwe United Passenger Company, (ZUPCO) (Dube, 2021). However, the existing transport fleets at ZUPCO's disposal have failed to cope with demand with the company purchasing over 400 new buses from China and partnering with the National Railways of Zimbabwe in introducing commuter railway services from the city centre to Mufakose, Budiriro, Ruwa and Tynwald (Razembe and Muleya, 2021). The commuter train commenced in September 2021 as the demand for public transportation after the hard COVID-19 lockdown was overwhelming, resulting in the rise of unregistered commuter operators commonly known as *Mushikashika* (Zhakata, 2021). Further, the commuting public in Zimbabwe's cities has cited the convenience and flexibility that the informal transport sector as advantageous as its services routes that ZUPCO does not and the fact that they operate late into the night (*The Herald*, 2022).

HARARE: ECONOMIC ACTIVITY ANALYSIS

A study carried out in 2021 by Harare City Council and the United Nations Economic Commission for Africa (ECA) reveals that Harare was responsible for one-third of the country's GDP (Harare City Council and United Nations Economic Commission for Africa, 2021). This study highlighted that the largest share of Harare's GDP contribution (60%) was by the services sector, whilst the informal sector contributed a staggering 40%. Critically, the ECA highlighted that cities in Africa have the potential to drive economic growth, with planned interventions having the ability to create jobs and improve livelihoods.

NATURE OF URBAN SPRAWL PHENOMENON

Urban sprawl is suggested to be counter-intuitive to urban planning as it overruns natural ecosystems depriving the present and future of their environmental rights (sustainable development) (Chiunya, 2015). Banda (2021) attributes urban sprawl to the constant population growth rates on the continent, and high levels of rural to urban migration. This sprawl is manifest in a mainly residential planned and informal settlement (Brains, 2008:4). Therefore, in analysing this phenomenon, it is clear that it is centred on basic human needs (Maslow, 2012) which are shelter and

the services attributed to it such as sanitation, water, transportation and energy.

It is important to note that the majority of urban sprawl has very little to do with industrialisation and production-based expansion. The increase in urban sprawl in Harare has seen a significant increase in commercial centres throughout the city redefining the structure and form of the city (Muhamba, 2021). The sprawl phenomenon has led to the development of high-end office parks in the northern sector of Harare, with these areas now holding the city's top commercial space stock (*The Herald*, 2018). Kamusoko et al (2013) in a study carried out in the Harare Metropolitan Province, observed that from 1984 to 2013, built-up areas had increased from 12.6% to 36,3% of the total land area. This result in urban growth was characterised by infill, extension and leapfrog developments.

SHIFTING PERCEPTIONS IN ZIMBABWE URBAN LANDSCAPE

Currently, the Zimbabwe government is looking into accelerating the urban densification programme to allow the private sector is a major role in urban renewal and development (Musarurwa, 2020). In highlighting this new focus, the Ministry of Local Government is looking at relaxing urban development regulations to allow for more development investment in urban areas. With regards to this new focus, the ministry is looking at new aspects of zoning that will allow for increased levels of densification, both laterally and vertically.

CONCEPTUAL FRAMEWORK

To understand the totality of the dynamics that are taking place in a city, the Chaos Theory becomes the basis of a new innovative way of viewing the city system. This theory affords the urban planner a conceptual overview that includes all key data sets and phenomena that are present in the city. In the initial stage of conceptual analysis, data sets and phenomena placed in a common spatial boundary, the city, can be subjected to the three key conditions of a dynamical system analysis, namely sensitivity to initial conditions, topological mixing and dense periodic cycles. Such an analysis then allows planners to project probable future scenarios of each data set and phenomenon ahead of time, giving the distinct advantage of developing planning management solutions

before anticipated challenges. Figure 1 outlines the conceptual city system analysis framework.

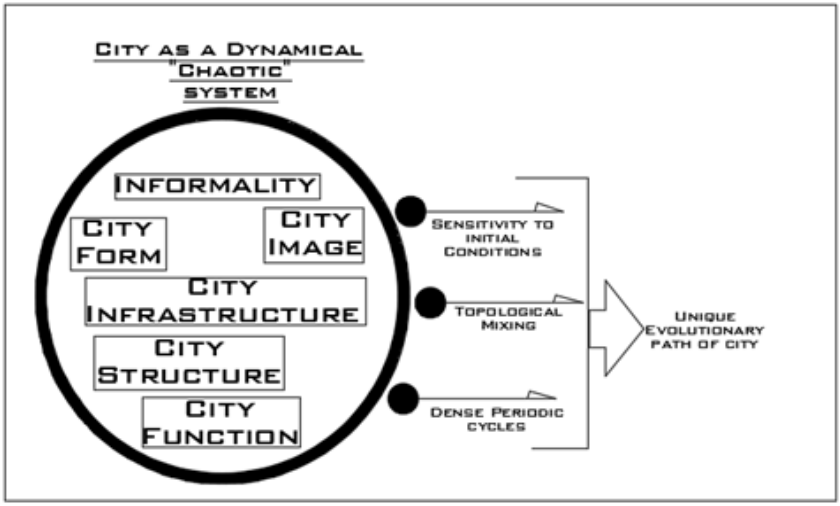

Figure 1: *Understanding the City as a Dynamical System* (Authors, 2021)

THEORETICAL FRAMEWORK: A GEOGRAPHIC INFORMATION SYSTEM FRAMEWORK FOR URBAN RETROFIT AND DENSIFICATION

The data sets and phenomena that constitute the urban system are geographic. Consequently, they can be placed within a spatial context for analysis and interpretation. Geographic information science studies geographic information, phenomena and how society understands and interprets it with Geographic information systems (GIS)subsequently are being the repositories of data, software systems and GIS application professionals (Goodchild, 2010). A geographical information system is an ideal tool for placing urban data sets and phenomena into the spatial context of a city boundary. Therefore, a GIS platform is an ideal platform upon which the urban retrofit and densification framework can be developed. To develop the retrofit and densification framework based on GIS, two key categories are required, namely urban data sets and urban phenomena. Urban data sets will comprise city form, function, infrastructure and structure. The urban phenomena category will include urban sprawl, concepts of city image, informality and the city green.

These two categories, urban spatial concepts and urban phenomenon, are the two components of the GIS-based urban retrofit and densification framework (Tables 1 and 2). Figure 2 illustrates the complete GIS Retrofit and Densification Framework.

Table 1: *Retrofit and Densification Urban Data Category* (Authors, 2021)

Data Category 1: Foundational Urban Data Sets			
Dynamical System Data Set	**Current State**	**Factors to Consider in Densification and retrofitting**	**Geographical Attributes of Data Set (Point, line and polygon location of data sets)**
City Form	City form continues to expand based on historic precedence set by initial conditions	There have been significant changes comparing the pre-independence and post-independence city forms. Further, it is essential to analyse how the city form has continued to evolve, based on political, social, economic and environmental catalysts. To effectively densify, urban planning must anticipate catalytic urban events using facilities such as Urban Observatories. Timeline analysis using Tools such as Google Earth "Historic Imagery" is useful in developing.	Points, lines, polygons

City Structure	Harare, as a city, continues to morph in terms of city structure with increasing intersections between all land uses.	A city follows city form. In densification and retrofitting, it is important for urban planning to constantly observe the dynamic political, economic, social and environmental forces as they influence city form and, consequently, city structure.	Points, lines, polygons
City Function	Currently, the city is predominately service sector (60%) and informal sector (40%).	Within the context of the function, future cities in Zimbabwe need to consider alternative and new industry models which provide niche goods and services locally and internationally.	Points, lines, polygons
City Infrastructure	The city infrastructure is extremely inadequate.	New infrastructure strategies are required as the city continues to expand and densify. Centralised infrastructure systems have failed and alternative decentralised high technology systems can be seen as an alternative.	Points, lines, polygons

Table 2: *Urban Retrofit and Densification Phenomenon Category* (Authors, 2021)

Data Category 2: City Phenomenon			
City Phenomenon	**Current Condition**	**Factors to Consider**	**Geographical Attributes of Data Set (Point, line and polygon location of data sets)**
Urban Sprawl	The expansion of the city continues along major transportation routes. The conversion of peri-urban agricultural land into residential is now a common phenomenon. The traditional concept of peri-urban agricultural and residential-agricultural land uses within the city boundary is now isolated to a few locations within the city boundary.	Can the remaining peri-urban agricultural land be preserved?	Points, lines, polygons
City Image	Perceptions of the city manifested through locations where residential, commercial and industrial investment prefer.	How do citizens, public investors and private investors view the city based on city form, structure, infrastructure and function?	Points, lines, polygons
Informality	Informality in city structure, infrastructure and economic activity.	How can informality be integrated to protect vulnerable groups?	Points, lines, polygons
City Green	City green sites are being overrun by developments.	Inventory of existing city green spaces and development of strategies to safeguard these spaces.	Points, lines, polygons

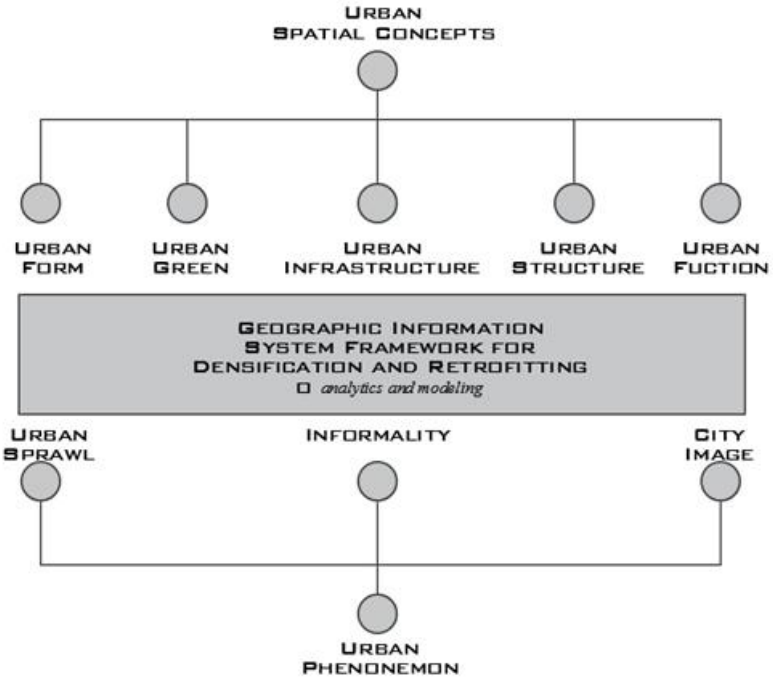

Figure 2: *Geographical Information System Framework for Retrofitting and Densification for Urban Areas in Zimbabwe* (Authors, 2021)

DISCUSSION

In developing a retrofit and densification strategy for urban areas in Zimbabwe, the Chaos Theory offers a scientific approach that integrates the trajectories of various data sets at play within the urban setting. The discussion will focus on developing solutions to the key issues of transportation, sanitation, water and energy.

INTERSECTING URBAN DATASET TRAJECTORIES AND PROBABLE SOLUTIONS

URBAN TRANSPORTATION

Key findings in the study show that public transport providers cannot currently move the whole urban population. This has given rise to two intersecting urban data set trajectories that clash at a "chaos point" (Fig

4). This chaos point in Harare's case is where local planning and enforcement authorities clamp down on the informal activity as witnessed by the announcement by local police to clamp down on illegal transport providers (*The Herald*, 2022). However, this Chaos point can be an opportunity to create new urban transportation models that can mix formal and informal components. This is illustrated in Figure 3 as the "new mixed" dataset solution.

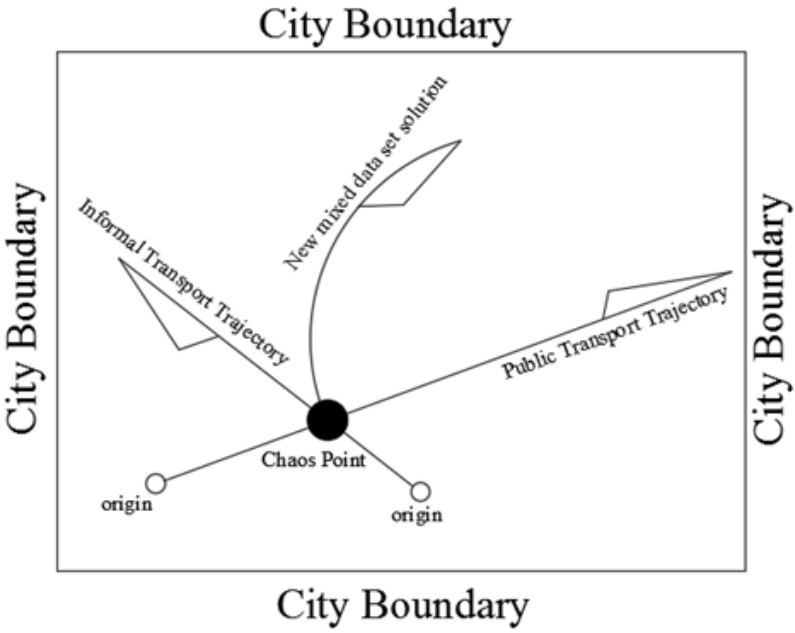

Figure 3: *Urban transport data sets, trajectories and chaos point* (Authors, 2021)

SANITATION AND WATER

Key findings in the study highlight that the City of Harare has inadequate water and sanitation infrastructure to supply urban users. This, again, highlights two intersecting urban data sets which, at their intersection point, create apparent chaos. The two intersecting data sets, in this case, are the city infrastructure provision trajectory and the demand for water and sanitation trajectory. The chaos point of these two datasets manifests itself in the development of informal strategies for access to water. In

Harare's case, this is done through borehole drilling, the digging of shallow wells and the rise of companies selling potable water to households.

In regards to water and sanitation, the chaos point can be viewed as an opportunity point for developing new water supply and sanitation models. Currently, there are existing technologies that can offer new solution opportunities in terms of urban water and sanitation challenges. There are Free Water- Surface Constructed Wetlands (FW-SCW). These are artificial wetlands that are used for the secondary and tertiary treatment of wastewater. They are designed to mimic the processes of a natural wetland, marsh or swamp (Jinadasa *et al.,* 2006). Secondly, there are high-efficiency aerobic digesters with the capacity to treat residential waste from neighbourhoods with up to 300 residents each. An example of such a product is the Biorock aerobic digester (Ghawi, 2018). This aerobic digester has an output efficiency of 98-99%, meaning that the output water can safely be discharged into surface water bodies. Currently, Harare has centralised water supply and waste treatment models that have been failing to meet requirements, hence a new strategy is required (Figure 4).

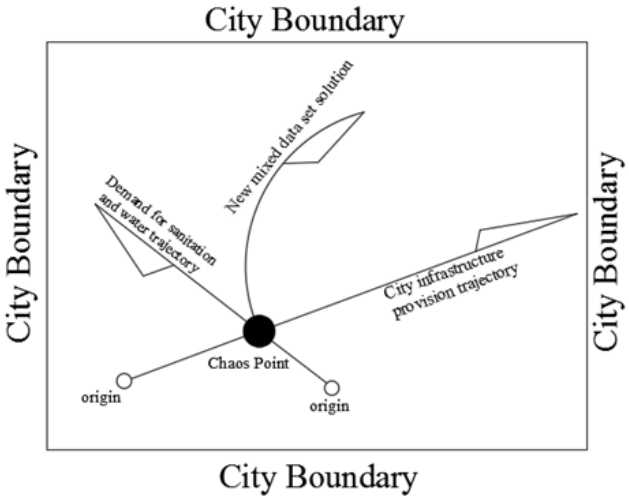

Figure 4: *Urban infrastructure and demand trajectories* (Authors, 2021)

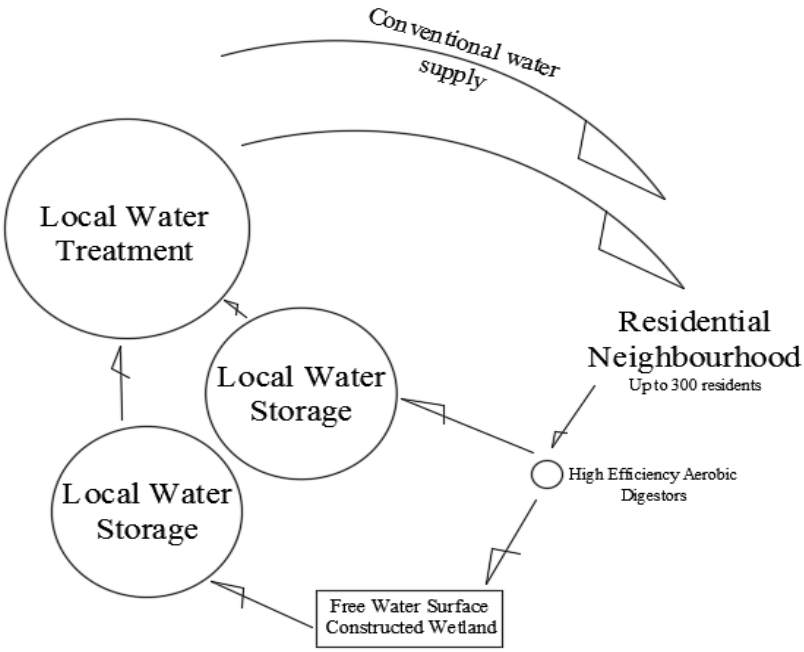

Figure 5: *Retrofit urban water and sanitation model for neighbourhood units* (Authors, 2021)

ENERGY INTERSECTION

The Government of Zimbabwe, through the Zimbabwe Energy Regulatory Authority (ZERA), called for interest in research towards reticulated gas systems to service consumers (ZERA, nd). This is in part due to increasing consumption and safety concerns. In 2010, Zimbabwe imported five million kilograms of LP-Gas, in 2016, 24 million, in 2020, the figure was 34 million and, by end of 2021, the figure was expected to be in the range of 50 million (Zenga, 2021). Locally, LP Gas is used only for cooking, heating and lighting and it is becoming the energy source for the majority of the population. With the current decentralised distribution and consumption model of LP-Gas, there is the potential for fatalities arising from poor practices and the use of sub-standard products (Nyamukondiwa, 2019). In the case of LP Gas, it is a case of a decentralised supply which could benefit from centralised distribution

models. Therefore, reticulated gas supply for consumers (residential, commercial and industrial) would ensure greater safety for this energy source that is becoming more and more popular. Figure 4 shows energy infrastructure and energy demand trajectories. The chaos point of these two trajectories manifests as the norm in urban centres through relevant regulating authorities taking measures to control the supply of a product or service, in the case of urban energy supply, following the rise in gas-related accidents in 2013. The Ministry of energy promulgated Statutory Instruments (SI) 57 of 2014 — Petroleum (Liquid Petroleum Gas) Regulations to manage the distribution and retailing of LP-Gas (Kadzere, 2015). Figure 5 shows a possible retrofit water reticulation strategy for residential areas.

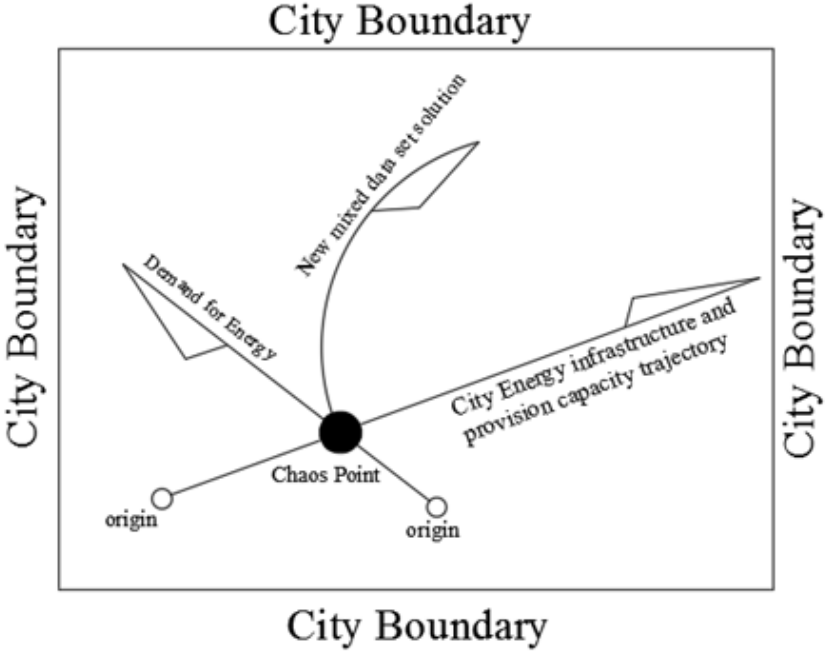

Figure 7: *Urban energy and demand trajectories* (Authors, 2021)

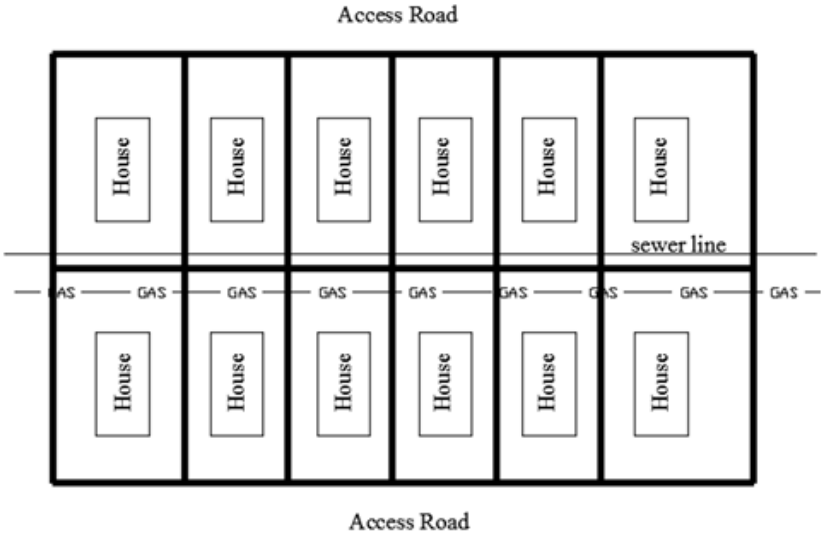

Figure 6: *Theoretical Layout of LP Gas Lines in Residential Block* (Authors, 2021)

CONCLUSION

This exploration of a possible retrofitting and densification strategy for Zimbabwe was unique in that it attempted to utilise key urban planning concepts that aid in the understanding of the continued development of a city. Secondly, to understand the seemingly chaotic dynamics that are taking place in an urban setting, the Chaos Theory was utilised to demonstrate that seemingly chaotic conditions or events are due to the intersection of urban dataset trajectories. This intersection of trajectories creates a chaotic situation where the most usual reaction is the enforcement of existing regulations by relevant authorities. However, the chaos point is the new origin point for an alternative pathway that requires new solutions. The challenges in the supply of energy and services in Zimbabwe's urban areas are partly due to the monopoly model of service and energy provided. This results in greater impacts being felt citywide when the service providers fail to supply required goods and services. This creates a supply-demand gap which is then fulfilled by the emergence of informal service providers.

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