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RESEARCH REPORT

DIT 801

How does the mapping of socio-economic security support digital twin readiness?

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ABSTRACT

Smart city development and data-driven urban management consider urban technologies to revolutionise how cities are managed, constructed and developed. This research study considers one such urban technology, namely utilising digital twins in cities. Digital twin city (DTC) technology is investigated to identify the gap in soft infrastructure data inclusion in DTC development. Soft infrastructure data considers the social and economic systems of a city, which leads to the identification of socio-economic security (SES) as the metric of investigation. The research study investigates how GIS mapping of the SES system in the specific context of Hatfield informs a soft infrastructure understanding that contributes to DTC readiness. This research study collected desk-researched secondary data and field-researched primary data in GIS using ArcGIS PRO and the Esri Online Platform using ArcGIS software. To form conclusions, grounded theory qualitative analysis and descriptive statistics analysis of the spatial GIS data schema data sets were performed. Understanding Hatfield's soft infrastructure found that citizen-centric social engagement with the SES systems of Hatfield and the integration of these systems in a cohesive manner create a thriving SES system. This contributed to the identification of the integration requirement of DTC development processes in its data acquisition and application processes. The integration of processes and systems is necessary to incorporate the soft infrastructure of Hatfield into relevant DTC readiness. Understanding the interrelationship between the citizen and its environment is where the success of a DTC lies and should form the focus of further research.

KEYWORDS

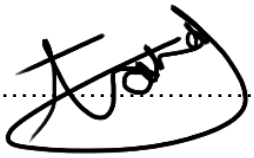
Digital Twin City Development, Soft Infrastructure, Socio-Economic Security, GIS Mapping

DECLARATION OF ORIGINALITY

I declare that the mini-dissertation, *How does the mapping of socio-economic security support digital twin readiness?*, which has been submitted in fulfilment of the requirements for the module of DIT 801 at the University of Pretoria, is my own work and has not previously been submitted by me for any degree at the University of Pretoria or any other tertiary institution.

I declare that I obtained the applicable research ethics approval in order to conduct the research that has been described in this dissertation.

I declare that I have observed the ethical standards required in terms of the University of Pretoria's ethic code for researchers and have followed the policy guidelines for responsible research.

Signature: ……  ……

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ABBREVIATIONS

3D	Three-dimensional
BIM	Building Information Modelling
CAD	Computer-aided Design
DTC	Digital Twin City
GIS	Geographic Information System
POI	Point of Interest
SES	Socio-economic security
SUDT	Social Urban Digital Twin
UDT	Urban Digital Twin
UPS	Urban Public Space

1 Introduction

Population increases, the resultant urbanisation and the simultaneous environmental destruction that we face require us to reconsider and revolutionise the ways in which cities are managed, constructed and developed (Erlström, 2020:1,3,4; Zhou & Hong, 2018:1468).

This research study considers one such urban technology, namely utilising digital twins in cities. Digital twin city (DTC) technology is investigated to identify the gap between soft infrastructure data inclusion as opposed to hard infrastructure data inclusion, which forms the problem to be investigated. Soft infrastructure data considers the social and economic systems of a city, which leads to the identification of socio-economic security (SES) as the metric of investigation. The research study investigates how the mapping of SES in Hatfield informs a soft infrastructure understanding that contributes to DTC readiness.

The report is structured as follows: first, DTC discourse is discussed through a scoping literature review. The literature review identifies key definitions and approaches of DTCs and the socio-economic spatial fabric gap, further defining the concept of SES identifying taxonomies and typologies of SES. The literature review is followed by a section that discusses a theoretical framework regarding socio-economic data for digital twin readiness. This discussion introduces a soft infrastructure framework with socio-economic data as the focal investigation point. Following the theoretical framework, the Methodology section explains the research design, data schema design, data collection and analysis methods. This is followed by the Results section that communicates the findings and, finally, a Discussion section that considers the relevance of this approach and gives commentary on addressing the research question. The Conclusion section discusses and comments on the findings in the Discussion section and how they contribute to the DTC discourse and inform further research.

1.1 Background

After the introduction to the specific research study themes and structure, the Background section further unpacks the background to the discourse. As the research theme is contextualised in terms of the discourse, the research problems and gaps are discussed, which leads to the formation of the research purpose objectives and, consequently, the research questions.

Smart city development and data-driven urban management is an approach that aims to address the negatives of our living and city environments to enhance and conserve the quality

of life, socio-economic development and natural resources in close to real time (Shahat, Hyun & Yeom, 2021:2). Digital twins are cyber-physical-social systems that mirror the life of the corresponding twin in the geographic information system (GIS) domain. Furthermore, DTCs are integrated, multi-scale digital virtual replicas of physical systems and objects that are modelled to simulate urban systems of buildings and entire city life cycles (Ketzler *et al.*, 2020:547,548,554; Shahat *et al.*, 2021:1).

This study defines DTC as shown in Table 1. DTCs are a culmination of several urban digital twins interacting with one another, shared through a data-driven platform. Varying DTC tools have been developed to form multi-dimensional urban analytical platforms. These DTC tools use mathematical modelling, simulation, visualisation and optimisation to aid in the digital planning and management of cities. The aim of DTC development is to create smart cities that conform to citizens' needs or increase liveability, efficiency and resiliency objectives (Ketzler *et al.*, 2020:547,548,554). However, DTC development mainly focuses on modelling and including hard infrastructure data. This approach does not consider a DTC in its local contextual environment and excludes the citizen central to the city. Therefore, the critique on only including hard infrastructure is the lack of social fabric data or soft infrastructure data that needs to be included to be able to develop DTCs to their full inclusive encompassing potential (Shahat *et al.*, 2021:2,10,11).

The soft infrastructure of a city includes the human capital and institutions that deliver services to the population that are vital to the cultivation of the city's economy (Charitonidou, 2022:2). The social fabric of a city is referred to as the socio-economic system interrelationship of interactions and connections that binds a society and/or neighbourhood (Shahat *et al.*, 2021:2,10,11). Consequentially, this study defines soft infrastructure, as shown in Table 1, as the interrelationship of the social capital and economic institutions that interacts and connects through systems services. Cities are complex systems that are further made intricate by the patterns and movements of their citizens. Soft infrastructure renders complex and unstructured data, which is difficult to work with. Complex and unstructured soft infrastructure data is, therefore, a challenging topic, which is ordinarily less investigated. Thus, the inclusion and mapping of social fabric data, which is soft infrastructure as opposed to hard infrastructure, in the DTC development processes is identified as the gap to be investigated and understood further in DTC development (Charitonidou, 2022:5; Shahat *et al.*, 2021:2,10,11).

Reaching DTC readiness refers to the encompassing inclusion of both hard and soft infrastructure data in the modelling of a DTC. Thus, DTC readiness in this research study is described as the phase of having a more conclusive and encompassing picture of the workings and components of a city by forming an understanding of the soft infrastructure. Social beings

and their economics are an integral part of the soft infrastructure of a city. Understanding the soft infrastructure in conjunction with the hard infrastructure leads to gaining the necessary full understanding of the workings of a city to be able to develop a real-time DTC. This study considers the impact of SES as the identified metric for understanding the soft infrastructure of cities. SES is conceptualised as having a feeling of safety and reliability in the absence of danger and threats to values and subjectively having a calm state of mind without the fear of having one's values in harm's way (Fedorenko, Dolynskyi & Zahorodnia, 2022:2). The provision of quality of life is crucial to accomplish SES in an urban environment. SES refers to societal systems, including social capital and economic systems, being able to thrive in states – not only of productive development but also when facing conflicts and risks (Ershova & Orlovskaya, 2020:2).

In this study, SES is defined as shown in Table 1. SES understanding is useful in relation to the social fabric of a city. The cultivation of SES in the city includes extensive amounts of various soft infrastructure or social fabric systems. SES systems that add to the understanding of the social fabric for DTCs include health services, the provision thereof by certain parties, the interrelation with citizens' need, as well as the provision and need for health services in relation to the hard infrastructure and what that interrelationship means for the soft infrastructure of the city.

When developing a comprehensively mirrored digital twin, it is therefore vital to include soft infrastructure data, specifically SES data, by including a bottom-up investigation approach to form an understanding of DTC development (Yossef Ravid & Aharon-Gutman, 2022:4). DTC development and SES investigation embody a vital link in the South African context and the importance of creating South African smart cities.

South Africa is a developing country, which firstly plays a vital role in the need to develop DTCs for improving city living. Secondly, the cultivation of SES renders more facets to be considered. In the South African urban community, the social fabric of cities – with specific reference to the SES thereof – is developed above others by means of the self-security of self-reliant and independent local or regional businesses. This further evolves the SES of local urban communities as they to learn from one another about similar problems and stimulate innovation (Pierre, 2015:2). Both the digital innovation and the development need that are viable in South Africa differ tremendously from other countries that portray examples of innovative development and evolvement. Therefore, the implementation of DTCs in South African urban communities cannot be approached strictly as observed in the rest of the world.

Table 1: Discourse definitions (Author, 2023)

Theme	Abbreviation	Description	Source
Digital twin city	DTC	The virtual replica that represents the life of buildings and city systems	Ketzler *et al.* (2020); Shahat *et al.* (2021)
Soft infrastructure	–	The interrelationship of socio-economic systems in a city	Charitonidou (2022); Shahat *et al.* (2021)
Socio-economic security	SES	Socio-economic systems being in a state of advancement	Ershova and Orlovskaya (2020); Fedorenko *et al.* (2022)

1.2 Research Purpose

This research study contributes to the DTC discourse by exploring how soft infrastructure data, such as SES data, could aid in developing a relevant, localised, and contextual understanding that contributes to DTC readiness. The research study identifies a South African local urban community environment as study context, specifically Hatfield. Contributions are made to the DTC discourse by investigating and mapping the social economic landscape of Hatfield by analysing the basic metric of SES. The SES mapping ultimately informs a viable soft infrastructure understanding for DTC readiness for Hatfield.

1.3 Research Problem

To construct a mature DTC, both hard and soft infrastructure data have to be included. The research problem of this study is defined as a lack of understanding of socio-economic systems being the driver for developing DTCs.

1.4 Research Questions

The research problem regarding the soft infrastructure data to be included in DTC modelling and gaining the further necessary understanding of socio-economic systems is addressed by this study in a South African context as mentioned in the research questions below.

1.4.1 Research Question

How does understanding the SES of Hatfield's soft infrastructure contribute to relevant digital twin use case readiness?

1.4.2 Subquestions

1) What are the useful baseline metrics for measuring SES that contributes to gaining an understanding of the soft infrastructure landscape of Hatfield?

2) What different SES typologies and taxonomies of Hatfield manifest in assessing the nature of Hatfield's soft infrastructure SES system?

3) How can the constructed typologies and taxonomies inform a framework that indicates the function of SES on the soft infrastructure of Hatfield as well as the contributors to an effective SES system of the local urban soft infrastructure of Hatfield?

4) How does the SES typology and taxonomy framework contribute to viable digital twin readiness for Hatfield use cases?

The scoping literature review in the next section further unpacks the discourse on the DTC, soft infrastructure and SES themes stated in the research background and research questions.

2 Literature Review

2.1 Scoping Literature Review

This paper follows a scoping literature review and grounded theory research approach. The paper applies open coding to analyse literature and data and identify and organise concepts, themes and categories (Figure 1).

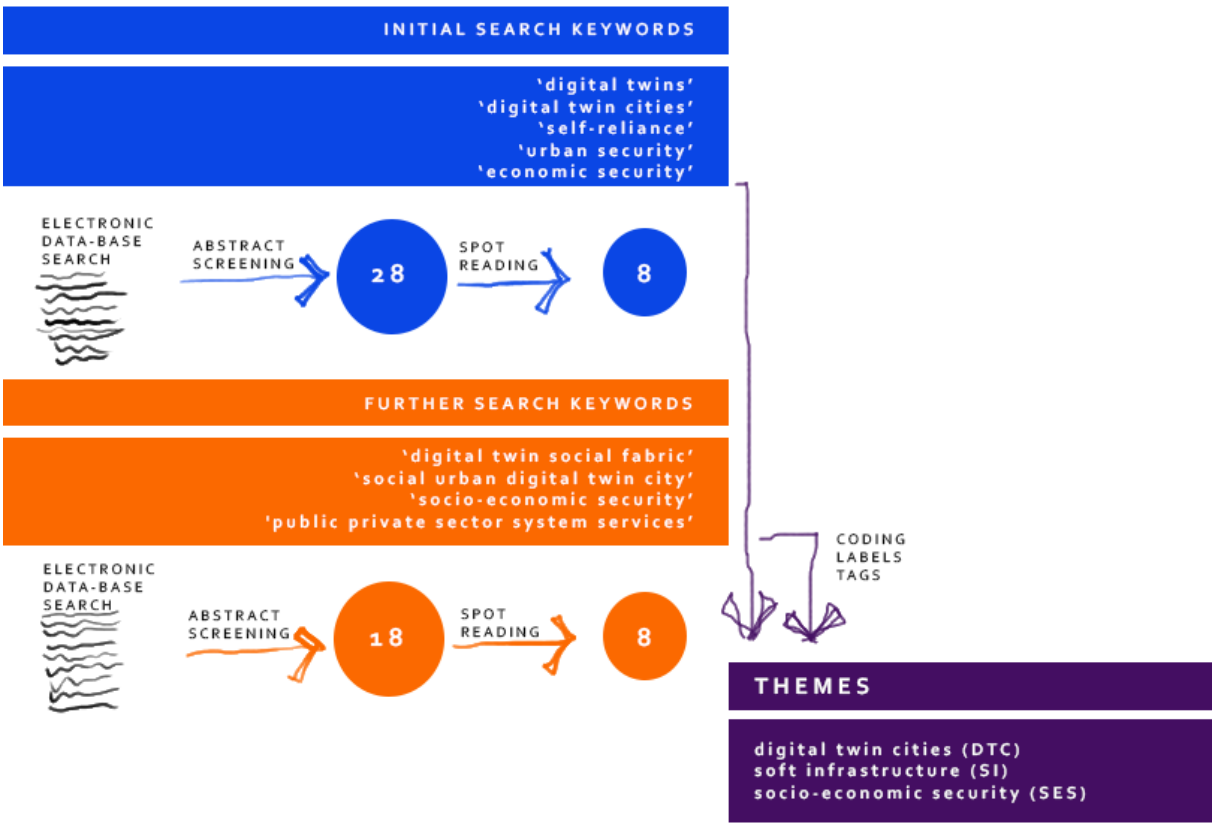

Figure 1: Scoping review coding process (Author, 2023)

Literature was sought from electronic data bases and search engines including Google, Google Scholar, Web of Science and Research Gate. The following initial keywords, namely 'digital twins', 'digital twin cities', 'self-reliance', 'urban security' and 'economic security', were used to collect literature from journal articles, conference proceeding papers, theses and dissertations. The electronic database search results were refined by considering abstracts, whereafter a total of 28 articles and papers were identified based on the relevance of each article to the keywords and their inclusion of relational topics to the other keywords. After spot-reading the 28 articles and papers, six articles and two conference papers were selected for inclusion in the research. The result of this literature review is expressed in Table 2.

Table 2: Articles for inclusion in the literature review (Author, 2023)

Source	**Topic**	**Year**	**Location**	**Type of Publication**
Digital Twins for Cities: A State of the Art Review (Ketzler *et al*., 2020)	Digital twin city	2020	Chalmers	Journal article
Urban Governance in Europe: Competition, Self-reliance, and Innovation (Pierre, 2015)	Urban development	2015	London, UK	Journal article

Source	Topic	Year	Location	Type of Publication
Developing Sustainable Urban Development Models (Haughton, 1997)	Urban development	1997	Leeds, UK	Journal article
An Alternative Approach to Urban Economic Development: Exploring the Dimensions and Prospects of a Self-reliance Strategy (Imbroscio, 1995)	Urban economic development	1995	Louisville, KY	Journal article
An Evolutionary Approach to The Interpretation of The Term «Economic Security of Enterprises» (Fedorenko *et al.*, 2022)	Economic security	2022	Poland	Journal article
Investigating the Impact of Structural Changes: The Socio-economic Security Framework (Pakhucha *et al*., 2023)	Socio-economic security	2023	Ukraine	Journal article
System Performance Indicators of Regional Economic Security (Lysenko & Zelenskaya, 2017)	Socio-economic security	2017	Chelyabinsk, Russia	Conference paper
The Concept of Socio-spatial Development as the Basis of Economic Security of Megalopolises (Ershova & Orlovskaya, 2020)	Socio-economic security	2020	Saint-Petersburg, Russia	Conference paper

Through the open coding process, literature was screened for its capability to define themes and how it supports DTC development. Thereafter, the literature was coded into categories, labels and tags were assigned, and patterns were checked for eligibility. Clear patterns that emerged included the concept of soft infrastructure or social fabric inclusion in urban digital twin development, which meant that the concept of self-reliance played a less significant role than expected in this research context. Whereas the inclusion of the concept of social fabric or soft infrastructure literature searches more frequently talked about the concept of socio-economic systems regarding DTCs.

After the initial search, the focus shifted to include additional keywords and phrases, namely ‘digital twin social fabric’, ‘social urban digital twin city’, ‘socio-economic security’ and ‘public-private sector system services’. The subsequent electronic database search results were screened following the same process, whereafter a further seven articles and one conference paper were included in the literature review. The result of this literature review is expressed in Table 3.

Table 3: Further articles for inclusion in the literature review (Author, 2023)

Source	Topic	Year	Location	Type of publication
City Digital Twin Potentials: A Review and Research Agenda (Shahat *et al.*, 2021)	Digital twin city	2021	Korea	Journal article
A Socio-technical Perspective on Urban Analytics: The Case of City-scale Digital Twins (Nochta *et al*., 2021)	Soft infrastructure DTC development	2021	Cambridge, UK	Journal article
Developing Human-centered Urban Digital Twins for Community Infrastructure Resilience: A Research Agenda (Ye *et al*., 2023)	Soft infrastructure DTC development	2023	Texas, US	Journal article
The "Public-isation" of Private Space: Towards a Charter of Public Space Rights and Responsibilities (Carmona, 2022)	Urban socio-economic development	2022	London, UK	Journal article
Role of Urban Public Space and the Surrounding Environment in Promoting Sustainable Development from the Lens of Social Media (Han, Nguyen & Sahito, 2019)	Urban socio-economic development	2019	China, Vietnam, Pakistan	Journal article
Privatization of Urban Public Spaces and its Impact on Sustainable Cities and Social Inclusion (Ntakana & Mbanga, 2020)	Urban socio-economic development	2020	Johannesburg, South Africa	Conference paper
The Social Digital Twin: The Social Turn in the Field of Smart Cities (Yossef Ravid & Aharon-Gutman, 2022)	Soft infrastructure DTC development	2022	Israel	Journal article
Urban Scale Digital Twins in Data-Driven Society: Challenging Digital Universalism in Urban Planning Decision-Making (Charitonidou, 2022)	Soft infrastructure DTC development	2022	Zurich	Journal article

Patterns and themes emerged, such as the role of the private and public sector in socio-economic systems. Categories were developed to group codes together and some research data was left out as it was not relevant to the refined coding scheme anymore (Ntakana & Mbanga, 2020:3; Shahat *et al.*, 2021:4; Ye *et al.*, 2023:2). After including the concept of soft infrastructure or social fabric in the literature review, a more encompassing investigation was done that had more direct relevance to the specific study.

Finally, three main themes were identified, namely (i) DTC, (ii) soft infrastructure and (iii) SES, all with their subsequent subthemes, which developed the theory describing the current state, research gaps and challenges, and potential further research development opportunities grounded in the data (Shahat *et al.*, 2021:8).

The literature review is structured as follows: first, literature is reviewed for the current discourse on DTCs, specifically focusing on the research gap of developing digital twins from a soft infrastructure perspective. Next, the review defines SES and places it in the context of digital twins for cities. This is followed by investigation on whether and how analysing the social fabric of a digital twin could aid in understanding the SES of urban local communities. The review examines the public-private sector role on the SES of an urban neighbourhood, and vice versa. Finally, SES typologies and taxonomies are categorised to guide the rest of the research study's soft infrastructure mapping DTC readiness.

2.2 The DTC Context

The following section unpacks DTC development as a base, building on the discussion in the previous Introduction and Background sections to enable the formation of informed thinking.

2.2.1 Current Discourse on DTC Development

Digital twinning is made possible by the current digital age; its rapidly emerging advances of cloud-based online technologies; the mapping and analytical capacities of computer-aided design (CAD), building information modelling (BIM) and GIS computational elements; and the increased availability and accessibility of large amounts of data (Ketzler *et al.*, 2020:547,548).

2.2.1.1 DTC composition understood

In these digitally enabling times, the possibility of developing DTCs is easily within reach. DTCs are defined in Table 1 as virtual replicas that represent the life of buildings and city systems. However, DTC composition can be discussed further. According to Ketzler *et al*. (2020), a digital twin is a comprehensive representation that combines a three-dimensional (3D) model comprising geometric data with spatial and contextual information from physical models, such as BIM models. Additionally, a digital twin incorporates geospatial layers derived from aerial photography, satellite imaging, semantic data, real-time sensor data, and simulations. This expanded representation, often referred to as a four-dimensional model, encompasses process data related to cities and their societies (Ketzler *et al*., 2020:547). It is helpful to understand the different data sets included in the development of DTCs to identify where in

the process of DTC development data sets fit in and where they are to be found in the levels of DTC maturity.

Next, DTC maturity levels are explained to orientate the reader regarding this specific study's focus in terms of the maturity level of DTC composition.

2.2.1.2 DTC maturity levels

DTCs vary in terms of maturity and purpose (Figure 2). The first DTC maturity bracket considers the physical infrastructure systems, which is the hard infrastructure of the city and its DTC. Examples of hard infrastructure data components include buildings and wall thermal abilities. The second DTC maturity bracket considers the interrelation of socio-economic systems, which is the soft infrastructure of the city and its DTC. Examples of soft infrastructure data components include people's shopping patterns and transport preferences. Unstructured and complex soft infrastructure data includes, for example, public spaces visited, by whom and how often in relation to certain aspects such as transport accessibility (Charitonidou, 2022:5; Ketzler *et al.*, 2020:548,554; Shahat *et al.*, 2021:2,10,11).

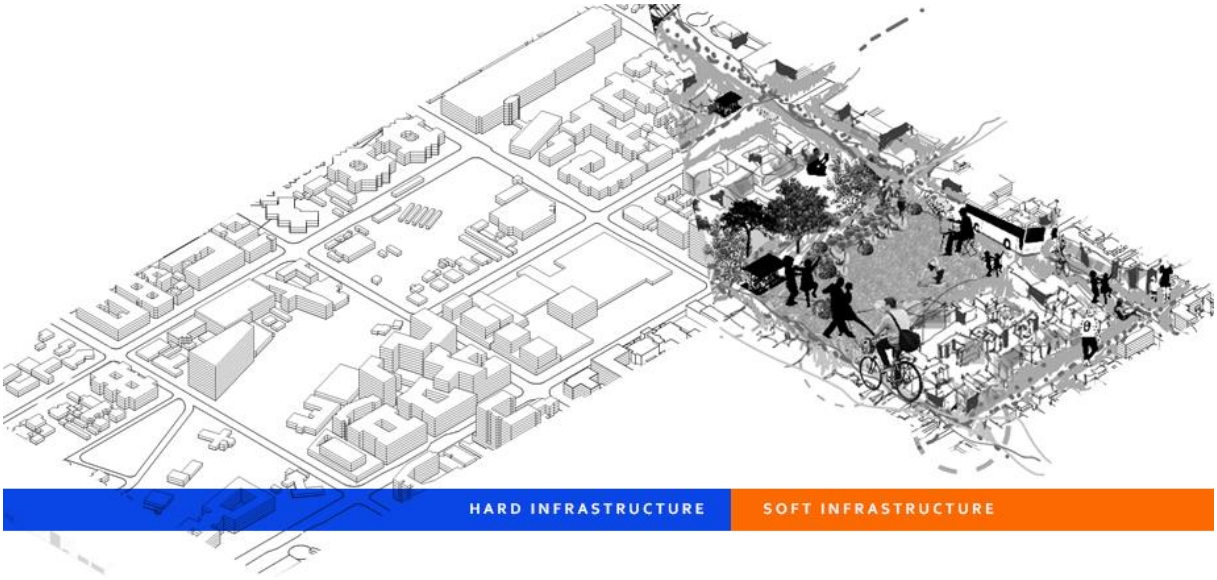

Figure 2: DTC maturity levels (Author, 2023)

As DTC research progresses and develops, so does the understanding of DTC maturity levels. Consequently, as the DTC matures, so does the possibilities of interaction or experience with the DTC, as discussed further in the section that follows.

2.2.1.3 Interaction with the DTC

Non-experts first experienced the 3D modelled DTC urban form when they were exposed to game engines and their quality graphics, user experience and virtual reality (Ketzler *et al.*, 2020:547,548). The second concept of accessibility includes not only experiencing the 3D DTC model but also engaging with it. The virtual analytical experiences of DTCs can be simulated beforehand as digital rehearsals or predictions. Therefore, a DTC creates an experimental platform for practising multiple considerations and iterations of urban solutions and testing scenario-based decisions made without real-life consequences (Ketzler *et al.*, 2020:548,554).

A mature DTC enables the user to experience and interact with the DTC to a possibly higher level. The ultimate utilisation of a DTC is only reached when the physical and virtual space interrelate in near real time. For the digital twin to reach an optimal state, there has to be a corresponding relationship between the physical space and the virtual space where they map and interact with each other in both directions (Charitonidou, 2022:4; Ketzler *et al.*, 2020:548, 554). Consequently, the interrelationship instils a real-time reflection in the virtual space through a parallel comparison of the two and continuous enrichment of the spatial data inventory, which induces self-evolution of the digital twin (Ketzler *et al.*, 2020:548,554). This process guides the formation of DTC readiness understanding.

2.2.2 Gaps in DTC Development

There are several challenges with current DTC development. Most literature investigates the technological aspects and components of DTC development, although certain gaps in this specific sector have also been identified. Literature misses out on investigating the application and implementation of DTC and the components thereof. However, very few literature sources consider the soft infrastructure data to be included in DTC development that contributes to ultimately reaching self-evolution in the digital twin (Ketzler *et al.*, 2020:551; Nochta *et al.*, 2021:1).

2.2.2.1 Technological difficulties

One of the identified research gaps is the intricacy and complexity of data handling, processing, and integration. Although the shear amount of data poses a challenge, the interpretation and integration thereof are even more challenging. The synchronisation and integration of data sets across different scales and data information sources is the origin of this technical challenge (Shahat *et al.*, 2021:3; Yossef Ravid & Aharon-Gutman, 2022:6). The technical challenge of data integration is due to the range and variety of activities and relationships in a city.

2.2.2.2 DTC application considerations

Another identified research gap is the provision of a user-friendly collaborative platform that enables the various stakeholders in the city to co-create and co-develop the DTC. This collaborative platform requires upskilling individuals and instilling organisational collaboration (Nochta *et al.*, 2021:6; Shahat *et al.*, 2021:11).

2.2.2.3 Socio-economic urban fabric DTC development approaches

The main research gap is the inclusion of soft infrastructure in DTC development. One of the primary challenges of developing a comprehensive and enhanced DTC, as highlighted by Charitonidou (2022:3,5) and Yossef Ravid and Aharon-Gutman (2022:4), is visualising and integrating the intricate social and economic processes and systems effectively in the urban environment.

Cities are unpredictable living systems that evolve daily; therefore, in the process of creating a DTC from a soft infrastructure perspective, it is important to not only have a holistic understanding of the physical city form but also of the invisible social and economic layers and systems (Shahat *et al.*, 2021:1). These soft infrastructure layers include transport and commuting patterns, basic functionality, citizens' needs for urban services, communication frameworks connected and developed by overlays of applications and analytical tools of links and, ultimately, the visualisation of the impact, scale and user interaction of interventions (Ketzler *et al.*, 2020:555; Shahat *et al.*, 2021:11).

Thus, it has been established that there is a gap in DTC development research, namely including soft infrastructure data in the development of DTCs. Soft infrastructure data will differ in each city in relation to its context – all the more in the South African context. Before looking at examples of DTCs that focus on soft infrastructure inclusion in Section 2.3, it is important to understand that data is context specific. Therefore, DTC research examples have to be examined to understand methods and stakeholders that have not even been contextualised yet (Section 2.3).

2.2.3 The South African Context: DTC Development

The term 'digital universalism' is used in this research study specifically in relation to the South African context. All data is local owning to its complex attachments to place, interfaces consequently recontextualise data, and data acts as indexes to local knowledge (Charitonidou, 2022:2). Hence, data cannot be accepted universally as one and the same thing. Data is context specific and needs to be localised before application.

In the context of DTCs, the concept of data being context specific carries a twofold implication, particularly when considering the South African context (Figure 3). Firstly, there is a technical challenge in the digital development of DTCs, which is not primarily due to a lack of general capability but rather to the need for sophisticated talent and skills. This challenge arises from a misalignment between creators and developers, as well as the education of end users (Davey *et al.*, 2023:10). Secondly, a specific concern arises regarding the assimilation of cultural diversity, fragile democracies and economies, and the resulting technological developments in countries in the Global South in relation to the principles established by developed nations (Charitonidou, 2022:3).

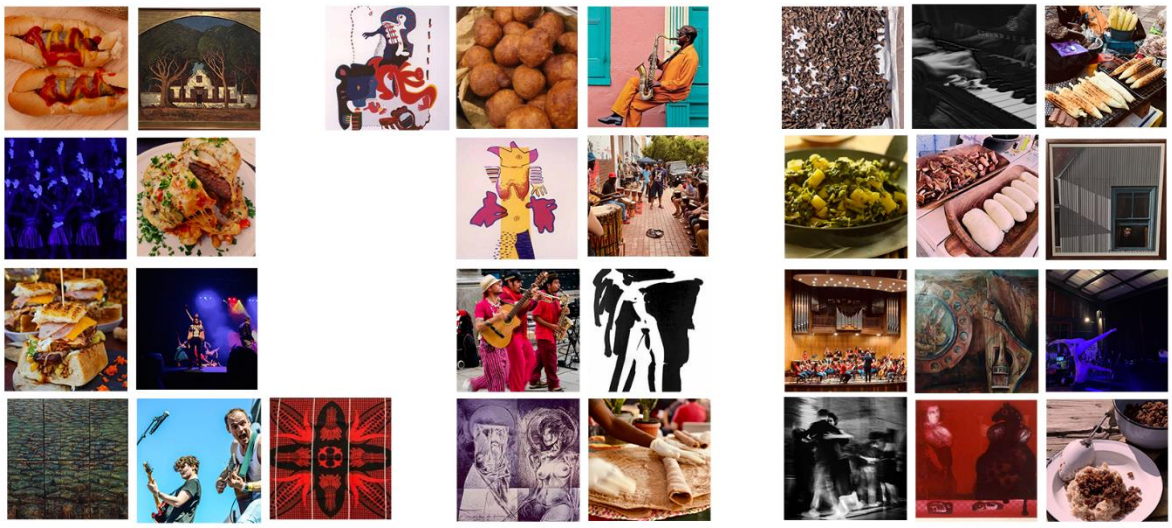

Figure 3: Vignettes depicting the South African context (Author, 2022)

In the South African context, the development of DTCs is directly impacted by socio-economic realities, such as urban infrastructure mismanagement, system failures, and challenges related to spatial and economic inequality (Davey et al., 2023, p.11). According to Davey *et al.* (2023), it is of utmost importance to consider an alternative approach that does not include the socio-technical aspects of involving highly skilled experts and technical investment. Instead, the focus should rather be on utilizing the potential within this context of investigating valuable city use-cases that are driven by the real needs of people and organizations by following a human-centric approach. The approach therefor focusses on creating agency among participants and to allow for various perspectives, needs and practicalities of the local context to emerge (Davey et al., 2023, p.11,14,15).

Combining both the gap in DTC research and the need for soft infrastructure data inclusion in DTC development together with South Africa's distinctive soft infrastructure conditions, the importance of mapping socio-economic systems is reaffirmed.

2.3 Current DTC Development Research on Analysing SES of Cities

In the following section, research studies regarding soft infrastructure investigation of cities for developing DTCs are identified and discussed.

2.3.1 DTC and Social Fabric Use Cases

The first identified studies include an initial range of non-socio-economic specific work to understand how soft infrastructure investigation has been approached in its infancy stages as laid out in Table 4. This is followed by an investigation that focuses more specifically on the socio-economic soft infrastructure understanding of cities.

Table 4: DTC examples (Author, 2023)

DTC development examples focusing on the social fabric of cities				
DTC project	Digital Twin City of Zurich (Shahat *et al.*, 2021:4)	Virtual Singapore (Shahat *et al.*, 2021:14)	Urban Digital Twin (UDT) of Hervanta in Tampere and Kalastama District, Helsinki (Charitonidou, 2022:7,8)	Cambridge Centre for Doctoral Training (CDT) (Nochta *et al.*, 2021:7,8,14,19)
Use case	The DTC use cases of Zurich, Singapore, Hervanta and the Cambridge CDT all share the same vision. Visualisation and simulation for enhanced urban planning decision-making and urban development policy plans are not directly relational to the focus of this study.			
Model composition, data acquisition and integration	The DTC of Zurich's 3D model which visualises street spaces and chosen public spaces corresponds to the focus of this study, where it also contributed to further investigations regarding point-of-interest public space mapping. Their use of open governmental data also informs data collection methods to be included within the theoretical framework.		The Public participation GIS (PPGIS) survey, used in the data acquisition of the UDT of Hervanta, informed further investigations regarding public participation data collection methods by using social media check in data.	The Cambridge CDT used readily available public primary and secondary data sources of local policy documents and municipal publications, and various publicly accessible open data sets and participant responses. These are viable in the context of this study. This further informs the data to be collected as will be discussed in the theoretical framework.

DTC development examples focusing on the social fabric of cities			
DTC application		The DTCs of Singapore, Hervanta and the Cambridge CDT are all in agreement to reach a unified and collaborative application environment that fosters participation and interaction between public agencies, urban citizens, private sector and research institutions. This specific research study's focus might not be exactly related to the application focus. However, the Discussion section will consider instilling accessibility by increasing transparency.	
Further development phases	The DTC of Zurich and Singapore both identified the need to reduce time between data updates and 3D model processing to improve information flow from only being one-way from physical to digital. This is again not this specific study's focus but will be considered further in the Discussion section.		The DTC of Hervanta and Cambridge both considered the need for collecting and sharing data of a diverse set of societal actors that include modelling citizen-centric states. This is directly relational to this research study's focus and will inform the data collection and integration to be included in the theoretical framework.

With the above overview of DTC examples, which include focusing on soft infrastructure inclusion in their development, the exact focus and approach of this study has not yet entirely been shared. The next section discusses the Haifa social urban digital twin (SUDT) to clarify the study focus further.

2.3.2 Case Study: Haifa Social Urban Digital Twin

This section analyses the more context- and focus-related SUDT of the Haifa neighbourhood of Hadar in Israel. The work is specifically reviewed regarding the various socio-economic factors that correspond to this specific research study, including their approach in developing a DTC, socio-economic context, and data inclusion.

The first corresponding factor considers the development driving force that consists of social institutional funding provided by the National Insurance Institute of Israel and the Department of Welfare that does not include the driving agenda of corporate economies. This developing driving force creates a citizen-centric approach that correlates with this research study. The second corresponding factor considers the geographical context of a local urban neighbourhood with a population of not more than 100 000 people of ethnic mixing, low socio-economic ranking, and an uneconomically active middle class population. To understand the neighbourhood configurations, it is vital to understand the social and physical disparities of the context (Yossef Ravid & Aharon-Gutman, 2022:2,4).

2.3.2.1 Model composition, data acquisition and integration

The Haifa model composition consists of a six-phased approach of technological conceptions and sociological contents as seen in Figure 4. The SUDT includes a 3D city model in Phase 1,

whereas the following phases focus on the socio-spatial complexity of the SUDT (Yossef Ravid & Aharon-Gutman, 2022:5).

In Phase 2, the Haifa social data collection method combines micro- and macro-analysis with a multitude of interpretations and worldviews. Success critically relies on data generated from not only top-down institutional data but also bottom-up civic data (Yossef Ravid & Aharon-Gutman, 2022:7).

Phase 3 includes data collection through thick mapping that considers multi-use and multi-dimensional social complexities acquired from both institutional and non-institutional bodies. The institutional database includes shape files of geographical information of land use, blocks and plots obtained from the organisation of the Survey of Israel and shape files of engineering GIS data of community centres or recycling points obtained from the Haifa Municipality. The database for civic bottom-up data includes Excel files with street names and addresses that list food distribution obtained from the Shahaf Foundation (Yossef Ravid & Aharon-Gutman, 2022:8).

Phase of Social Urban Digital Twin Protocol	Technological Conception	Social-Theoretical Content	Description of Phase
Phase 1 3D City Digital Model	3D city visualization	—	3D virtual representation of the urban environment
Phase 2 The Ethics of Social Data	—	The data ethics of digital sociology	Regulatory and legal measures to facilitate social data collection
Phase 3 Data Collection through Thick Mapping	Collection of various datasets	Thick mapping as a tool for utilizing social complexity	Thick description of Institutional and civic data collection
Phase 4 "Small-ness" Data Integration large table	Feature Scaling and integration into one	The "small-ness" urban scale and the household unite	Combination and integration of data into a single array on the household scale
Phase 5 Socio-Spatial Visual Dimension geographical data	Integration of "classical" tabular data into	Social GIS as a link between environment and society	Use of spatial visualization platform for analysis and to generate social insights
Phase 6 Critical Algorithm Correlation	Correlation and algorithm analysis of data	Critical thinking through data analysis by social-spatial visualization	Use of algorithms to integrate information from different sources to generate insights

Figure 4: Phases of the SUDT of Haifa (Yossef Ravid & Aharon-Gutman, 2022:8)

Phase 4 and Phase 5 integrate socio-spatial data of the geographical space, visualise social complexity, and analyse data with examples as shown in Figure 5. The phases consider the

technical deployment through a visual representation of social data elements and transforms social GIS data from tabularised geographical data descriptions into points, lines, and polygons (Yossef Ravid & Aharon-Gutman, 2022:10).

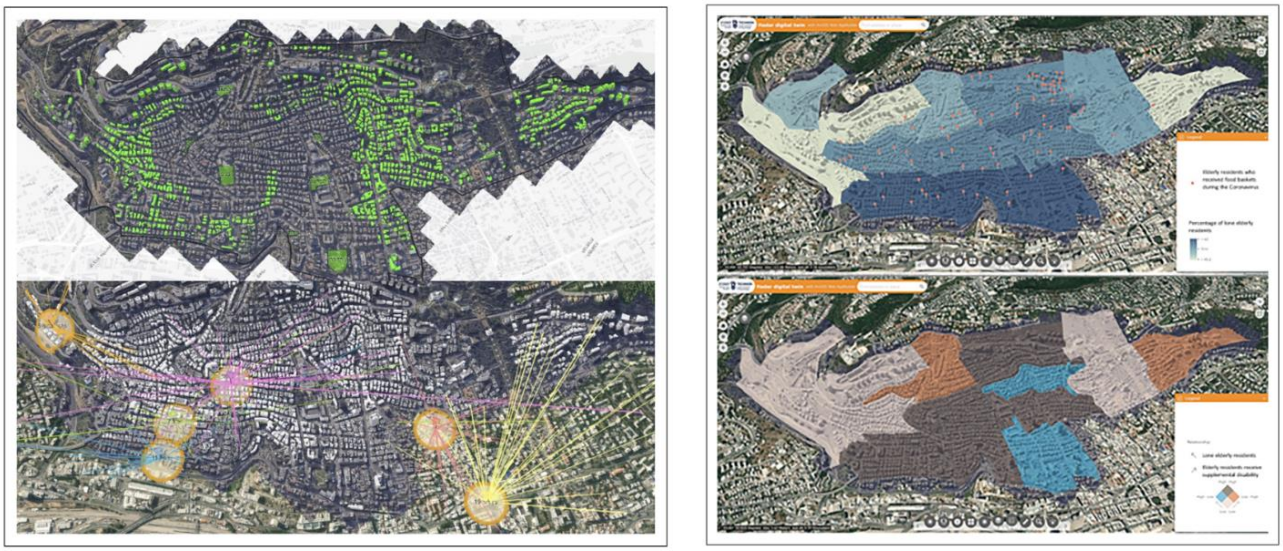

Figure 5: Data visualisation of the Hafai SUDT (Yossef Ravid & Aharon-Gutman, 2022:11)

The Haifa SUDT ultimately integrates data by correlating and coordinating the socio-geospatial layers with the aim of generating social data insights reliant on the logical context created (Yossef Ravid & Aharon-Gutman, 2022:11). The Haifa SUDT case is highly successful in collecting, integrating, analysing and visualising soft infrastructure data. Therefore, it greatly informs the theoretical framework regarding how this research study should approach these processes.

2.4 Current SES Theories

After investigating multiple DTC examples that include soft infrastructure data in their development, the realisation of analysing socio-economic systems became apparent.

2.4.1 Understanding SES in the South African Context

SES is described as a socio-economic system in a state of advancement, which defines thriving in a climate when facing conflicts and risks (Ershova & Orlovskaya, 2020:1). SES is cultivated or maintained through stakeholders on a spectrum that includes individual citizens, private entrepreneurship, state enterprises, the national economy, and the state as a whole (Fedorenko *et al.*, 2022:3,4; Pakhucha *et al.*, 2023:187). Cultivating and upholding SES include not only the population but also elements in direct relation to the economy such as production facilities, infrastructure, and natural and other resources (Lysenko & Zelenskaya,

2017:2). Some organisational sectors in the economy include transport, postal and courier services, public administration, information and telecommunications, and education (Pakhucha *et al.*, 2023:195).

In the current South African urban context (Figure 6) as a developing country, the organisational and associational structural base systems of legislation and regulations that install and regulate socio-economic growth are not fully developed or intelligently and diligently implemented (Lysenko & Zelenskaya, 2017:2,3; Pakhucha *et al.*, 2023:181). Thus, when considering SES in South African cities and neighbourhoods, it is important to consider the whole spectrum of stakeholders and not only its governmental implemented organisational system.

Figure 6: South African urban context collage (Author, 2022)

The following section discusses the possibilities of the nature in which SES is independently maintained and cultivated in cities.

2.4.2 SES and Self-reliance in Cities

South Africa is a developing country with entrepreneurship ingrained in its culture; therefore, local urban citizens engage with innovative process of cultivating new concepts that make entrepreneurs non-reliant on the local government. This innovation does not necessarily imply reinventing the wheel but rather establishing new collaborative systems of SES cultivation that utilise harboured knowledge by delegating roles to non-governmental organisations and businesses, amongst others (Pierre, 2015:2).

In a sustainability context, a self-reliant city does not encompass total self-enclosure but rather internalises indigenous development efforts of economic and environmental activities from within (Haughton, 1997:190; Imbroscio, 1995:841).

Individual citizens and/or private parties play a big role in SES cultivation and maintenance in the South African context. Understanding said systems enables one to identify SES cultivation and maintenance, which is discussed further in the following section. Understanding the relationship between private and public roles in the development of urban SES contributes to understanding the soft infrastructure of local urban communities.

2.4.3 The Private and Public Sector SES Urban Roles

Focusing on the sustainable development of neighbourhood economies and its vital dependency on the integration of public space and privatised systems, the public-private role on the construction of a sustainable urban environment and its facilitation towards SES performance is considered (Han *et al*., 2019:1).

The privatisation of public systems or spaces is implemented through the formation of public-private partnerships such as business improvement districts that focus on arranging security, policing and social control. Privatisation is further distinguished as corporate privatisation, namely privately owned public space that entails management, development and ownership (Carmona, 2022:134; Ntakana & Mbanga, 2020:1,3,4,6). Most commonly, this structured cooperation transfers and contracts managerial responsibilities or ownership from public entities to external organisations in the private sector. This process occurs in cities with inadequate government resources and financial capacity to create, develop and manage government services (Carmona, 2022:140; Ntakana & Mbanga, 2020:1,3,4,6).

In the South African context, developing cities rely heavily on private development to create the urban public realm. The sharing or reallocation of risks, costs, benefits, resources and responsibilities enables the creation of an integrated public space network system by integrating existing isolated hybrid spaces and systems into the city fabric (Ntakana & Mbanga, 2020:3,6).

In the sustainable planning, development, maintenance and management of cities, the common goal is building socially cohesive, economically competitive cities in an environmentally friendly manner. The increase of publicness or upholding social and economic responsibilities related to access and use relies on the intention and interests of what and how the public realm is accessible, developed by either the public city or the private sector, and

how the regulation and management and the resultant development are pursued (Carmona, 2022:138,150,160; Ntakana & Mbanga, 2020:1,6,7).

While investigating the public and private socio-economic service role in the development of SES, it becomes apparent that their relational service systems should be mapped and interpreted to be able to analyse the contribution to SES in the Hatfield context. It is, therefore, necessary to identify the South African governmental public service delivery intentions as a starting point for the SES system services taxonomies and typologies that will form part of the theoretical framework for guidance. This identification guides the investigation regarding how the private sector provides for these public service systems in the Hatfield context specifically.

The objective of the research study is to contribute to soft infrastructure local context data development that aims to contribute to DTC readiness by investigating and analysing system services of SES systems.

2.5 Conclusion on SES Taxonomies and Typologies

The literature review and open coding revealed baseline metrics for understanding the systems servicing the SES system. These metrics together with their SES systems were organised along a taxonomy and typology classification to help establish a GIS data schema. Table 5 explains the classification of the metrics and their conceptual measurables. The classification of baseline metrics are organised in two ways, namely typological and taxonomical. The typological organisation focuses on conceptual structuring and understanding of the interrelationships among metrics based on their characteristics. The taxonomical organisation relies on empirical data to categorise measurables based on observable and measurable attributes.

Table 5: Typological and taxonomical classification of the SES system (Education Training Unit (ETU), n.d.; Ershova & Orlovskaya, 2020:3; Han et al., 2019:2,3; South African Government, n.d.; South African Government, 2006)

Typological classification			
		Public and/or private place and systems provided itself.	Spatial relation of the conditions of the geographic space destination.
	Education	Basic and tertiary, schools, universities, colleges and organisations.	Proximity along the axis of urban security closely connected to axis of socio-economic development. Relevance between proximity, accessibility and use at an intense volume of physical activity.
	Healthcare	Physical, mental and pregnancy clinics and hospitals.	
	Municipal housing infrastructure	Municipal water and waste removal, electricity and gas supply service delivery.	

Typological classification			
	Social welfare security and public administration	Basic services of personal identification, free care and support grants, driver's licence, vehicle registration road worthiness, postal offices vs courier services.	
	Community development	Libraries, cultural institutions and sports creation, parks and recreation, citizen safety of these conditions, such as street lighting and street design.	Vital elements and their intricate interaction, sociability, accessibility, facilities of urban green zones, restricted space and unsafety surrounding environmental factors of noise and air contamination.
		Taxonomical classification	

The categorised baseline metrics and measurables form the base for establishing a data schema for data collection and analysis, which is developed further in the Methodology section (Section 3).

2.6 Theoretical Framework

The literature review established the importance of including soft infrastructure data in DTC development and that analysing SES contributes to gaining a soft infrastructure understanding of cities and neighbourhoods. Thereafter, it identified the specific SES indicators and private and public stakeholder relationships that contribute to SES.

This section places these learnings in a theoretical framework for measuring SES for DTCs at the local neighbourhood level. The framework is applied in the Hatfield context as explained in Section 3: Methodology. A theoretical framework using socio-economic metrics for DTC development involves employing specific indicators and measurements to analyse and assess the socio-economic aspects of a city in the context of implementing a digital twin. The framework involves the following components:

1. **Identification of socio-economic metrics:** firstly, socio-economic indicators, including variables such as population demographics, income distribution, employment rates, educational attainment, healthcare accessibility, housing affordability, environmental sustainability, and social inclusion, must be investigated to establish the socio-economic demographic of the context. The second step is identifying the relevant socio-economic metrics that are crucial for understanding and evaluating the city's development, including the educational, health, housing infrastructure and community development systems.

2. **Data collection and integration:** data collection is crucial for obtaining the necessary information to calculate and analyse the identified socio-economic metrics. Various

sources of data, such as government data, statistics and surveys, sensor networks, and social media platforms, are utilised. The collected data needs to be integrated and structured in a way that facilitates analysis and comparison.

3. **Data analysis and visualisation:** the collected data is analysed using appropriate statistical and data analysis techniques to derive meaningful insights and patterns related to the socio-economic characteristics of the city. Data visualisation techniques, such as charts, graphs, and maps, are often employed to present the findings in an accessible and easily understandable format.

4. **Policy formulation and decision-making:** the insights gained from the analysis of socio-economic metrics provide valuable inputs for policy formulation and decision-making processes. It helps stakeholders to understand the impact of various interventions and strategies on the city's socio-economic fabric and supports evidence-based decision-making.

5. **Monitoring and evaluation:** continuous monitoring and evaluation of the socio-economic metrics are essential for tracking the progress and effectiveness of implemented policies and strategies. It enables policymakers to make adjustments and refine their approaches to achieve the desired socio-economic outcomes.

By employing a theoretical framework that incorporates socio-economic metrics, DTC development can be guided by a comprehensive understanding of the city's socio-economic dynamics. This promotes a holistic approach to urban planning and ensures that digital twin implementations address the socio-economic needs and aspirations of the city's residents.

This study focuses on Step 1 and Step 2 of the theoretical framework in the Methodology section (Section 3) and Step 3 of the theoretical framework in the Data Analysis and Results section (Section 4) using grounded theory for analysis. The Discussion section (Section 5) deliberates on Steps 3 to 5 of the theoretical framework.

3 Methodology

3.1 Research Approach

The literature review and theoretical framework assisted in establishing the mixed-method research methodology for this research study in the context of applied research (Figure 7).

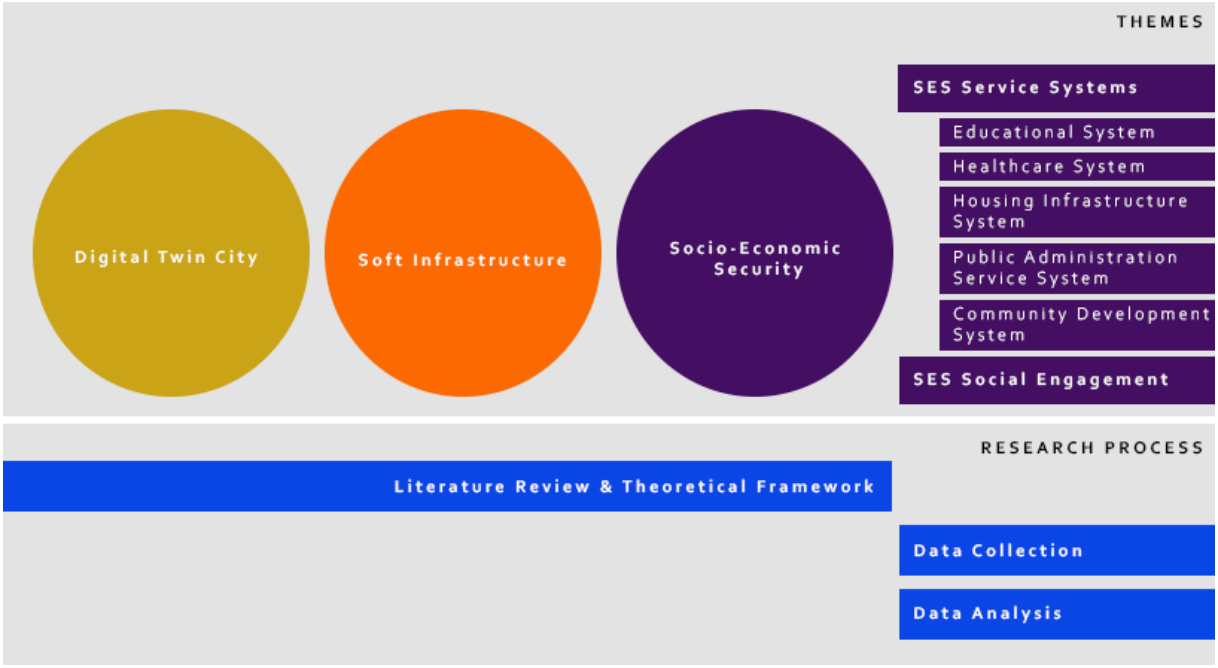

Figure 7: Research approach diagram (Author, 2023)

3.1.1 Research Paradigm

The research study, to be found in the pragmatic paradigm, is set on solving problems in the real world by gaining relevant and useful knowledge that consequently improves the human condition. The success of pragmatic research is measured in the practical application of practical issues.

In this research study, the classification of a non-singular reality ontology is understood as individuals having their own and unique interpretation of reality. As the focus in the pragmatic paradigm encompasses results, this epistemological approach emphasises the theory that not only is accuracy of value but also the impact of the variety of sources of knowledge obtained and gained. Looking at the pragmatic paradigm, the philosophical approach to decision-making consists of a value-laden axiology focused on conducting research that benefits people, which is further expressed as the knowledge and practice that reciprocally affect one another (Breed, 2022; GradCoach, 2021; Kivunja & Kuyini, 2017:27, 28, 35, 36).

3.1.2 Research Design

The research study consists of a mixed-method research methodology (Figure 8), which consists of quantitative data collection method to measure differences and relationships in a mostly objective and of confirmatory nature. The data collection methods include observational mapping. However, the data analysis method consists of a qualitative data analysis method of a mainly subjective and highly exploratory nature (Breed, 2022; GradCoach, 2021; Kivunja and Kuyini, 2017, p. 35,36).

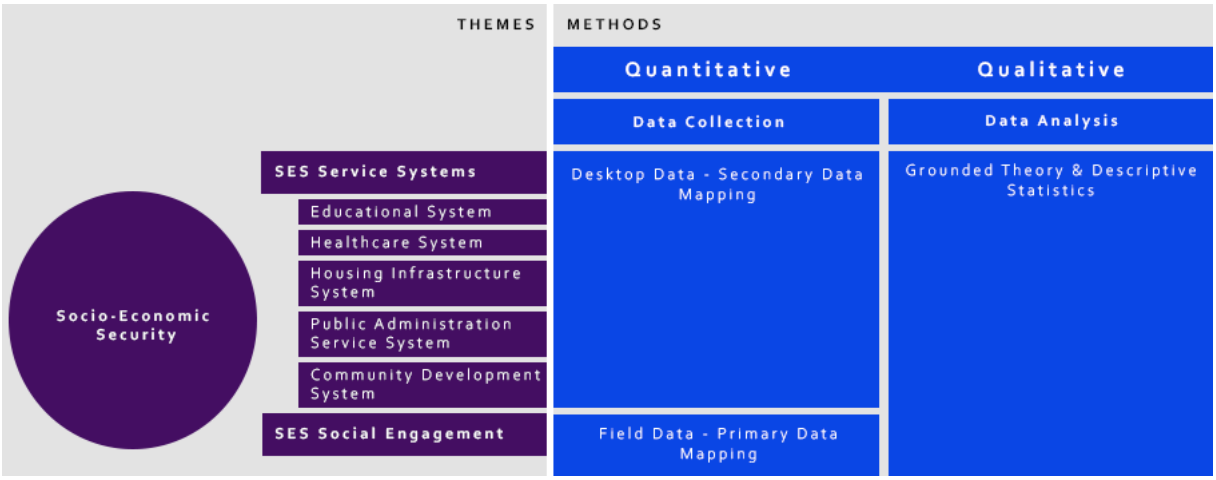

Figure 8: Research design diagram (Author, 2023)

3.2 Study Area and Context

Hatfield as a study area is an extremely important example for investigating the implementation of DTCs in South Arica and looking at urbanisation through a regional lens. The population in the City of Tshwane Metropolitan Municipality is projected to grow by 2.2 million people by 2050. All these people will require adequate infrastructure, including housing, commercial, health, educational, green infrastructure and city services (CSIR, n.d.).

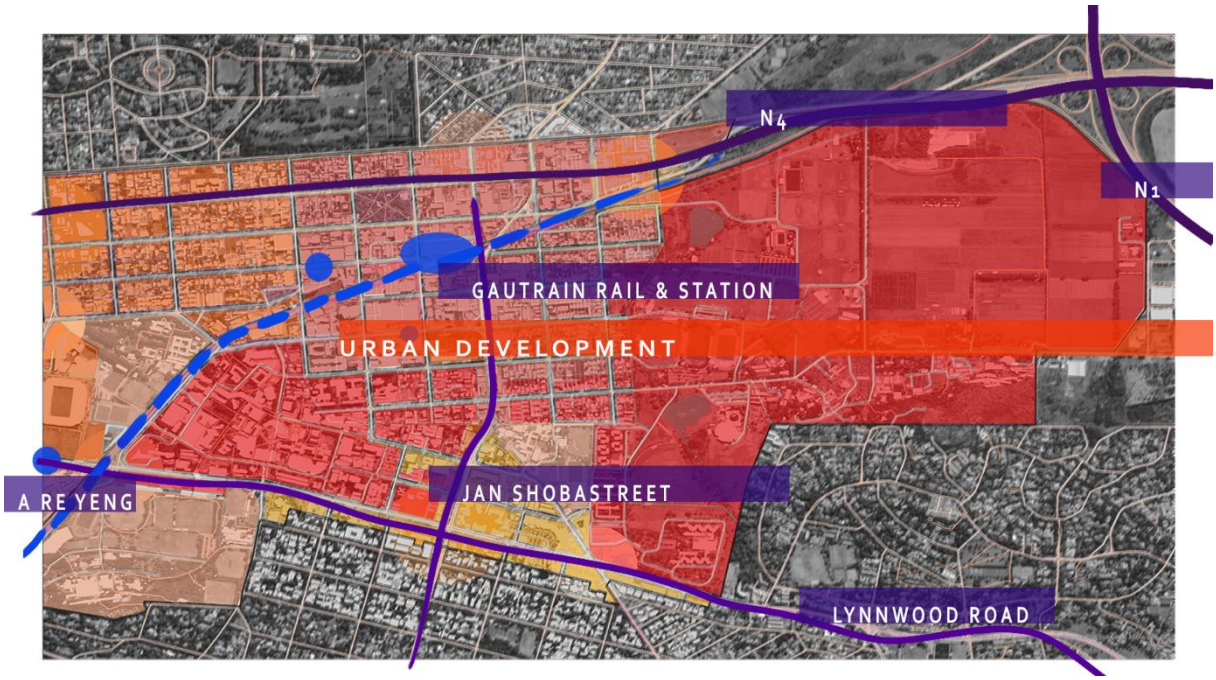

Figure 9: Map showing the Hatfield context (Author, 2023)

Figure 10: Socio-economic demographics of Hatfield (Author, 2023 adapted from Habitat Landscape Architects, 2020)

From a regional perspective, the Hatfield metropolitan node (see Figure 9), situated in the City of Tshwane, is connected to the N4 and N1 main roads, Jan Shoba Street and Lynnwood Road, forming important linkages to the Tshwane inner city, Centurion and Johannesburg (City of Tshwane, 2020; Habitat Landscape Architects, 2020). The characterising zones in Hatfield are defined by corridors of pedestrian and vehicular movement. The university precinct is surrounded by further school and sport zones in the form of high schools and the university's LC Sports Campus. Above the railway line, the mainly residential neighbourhood has been transformed into a precinct of residential typologies that have been repurposed as embassies, offices and business entities. All around the university's Hatfield Campus boundary, residential development has transformed the low-density residential typologies into high-residential student housing of up to ten storeys. East of Jan Shoba

Street, the suburban low-density residential neighbourhood character still persists where the nature of residents has changed over time to house a predominantly student population with a mix of student residential developments of up to five storeys and further student commune housing. The two commercial nodes of Hillcrest Boulevard and Hatfield Plaza act as anchor points in the main Lynnwood Road corridor and the secondary Burnett Street corridor (City of Tshwane, 2020; 2023; Habitat Landscape Architects, 2020).

Hatfield's population of about 100 000 people consists of a mainly student demographic (see Figure 10). This indicates that Hatfield is mainly populated by young non-economically active residents who are students without a monthly income. The residential role shifting from family households to student residential has changed the economic and social functionality in the area. The disposable income spent in Hatfield is unknown but should still consist of sufficient amounts to rate employment opportunities highly. The transient nature of students and the resultant seasonal economy without a doubt has a negative economic impact on the study area. The nine-month temporary period residential population with minimal long-term investment in the economy of Hatfield is concerning to its economic sustainability (Habitat Landscape Architects, 2020).

3.3 Sample of Interest

The research study spanned a duration of four months at the beginning of 2023 and focused on mapping main themes with approximately ten subthemes (see Table 6 and Table 7). These themes were developed from the literature review and theoretical framework to help understand the soft infrastructure of the Hatfield local urban context.

The SES data collection process encompassed gathering metrics from both the public sector service delivery processes and entities, as well as the public sector responsible for assuming these services. Considering that students form the predominant population demographic in Hatfield, the data collection approach was designed to account for the dynamic nature of their behaviour. To capture rapidly changing patterns, the study utilised social media check-in patterns as a valuable source of information. The data collection methods are further unpacked in the sections that follow.

3.4 Limitations and Delineation

The study limitations were as follows: the study was conducted over four months via desktop analysis and GIS data collection. The study was delimited to the boundary of the Hatfield neighbourhood (see Figure 9) and only explored certain metrics, namely secondary data (see

Figure 11) and observable data in the field (see Figure 12). The metrics to be included in the SES system have not been exhausted yet, and the measurable characteristics of the metrics included (see Table 6 and 7) have also not been exploited yet.

3.5 Data Collection Method

Data was collected through a quantitative, self-administered method, which was carried out electronically. This research study collected desk-researched secondary data and field-researched primary data in GIS using ArcGIS PRO and the Esri Online Platform using ArcGIS software.

3.5.1 Desktop Data

The desktop-researched secondary data sources consisted of government publications, the Hatfield Precinct Node Plan, Google maps for location, Boukunde's organisational data previously collected through Eppi-collect, and further prior GIS mapping. The sample database of data collected, as seen in Figure 11, aided in identifying entities in their system service categories and the number of instances of certain system service entities and their distances from one another. The investigation of SES contributed to understanding the socio-economic systems from a more top-down view.

	FID	Shape *	Shape_Leng	Shape_Area	NAME	TYPE	PUBLICNESS	TYPEOFEDU
1	3	Polygon	1494,146262	102611,43072	AFRIKAANSE MEISIES HOE...	EDUCATIONAL	2	SCHOOL
2	4	Polygon	1652,624913	133616,100778	AFRIKAANSE SEUNS HOER...	EDUCATIONAL	2	SCHOOL
3	5	Polygon	3165,493086	505335,519323	PRETORIA BOYS HIGH SCH...	EDUCATIONAL	2	SCHOOL
4	6	Polygon	2080,588287	211044,017364	PRETORIA GIRLS HIGH SC...	EDUCATIONAL	2	SCHOOL
5	7	Polygon	233,006753	1230,221463	EASTERN SUBURBS NURSE...	EDUCATIONAL	2	SCHOOL
6	8	Polygon	164,837727	719,88723	HATFIELD MONTESSORI P...	EDUCATIONAL	2	SCHOOL
7	9	Polygon	86,838224	381,636721	LOFFIELAND CRECHE AND...	EDUCATIONAL	2	SCHOOL
8	0	Polygon	3905,678455	670114,827561	UNIVERSITY OF PRETORIA...	EDUCATIONAL	2	UNIVERSITY

	FID	Shape *	Shape_Leng	Shape_Area	NAME	TYPE	PUBLICNESS
1	0	Polygon	98,68705	413,076525	UNIVERSITY OF PRETO...	HEALTH	PRIVATE
2	1	Polygon	213,555671	1363,088457	AKESO ARCADIA	HEALTH	PRIVATE
3	2	Polygon	39,731005	91,091636	NETCARE WATERFALL C...	HEALTH	PRIVATE
4	3	Polygon	67,896777	188,5907	SITORIA MATERNITY CE...	HEALTH	PRIVATE
5	4	Polygon	633,790419	18508,355717	THE UROLOGY HOSPIT...	HEALTH	PRIVATE
6	5	Polygon	116,132015	674,174703	DENTIST	HEALTH	PRIVATE
7	6	Polygon	130,817897	622,960567	IRSIGLER GB PULMON...	HEALTH	PRIVATE
8	7	Polygon	217,465472	1249,20662	HATMED MEDICAL CE...	HEALTH	PRIVATE

	OBJECTID *	SHAPE *	COURIER_NAME	COURIER_TYPE	PLACE_NAME
1	1	Point	ARAMEX	SHOP	PNP
2	2	Point	PUDO	SHOP	BROOKLYN MALL
3	3	Point	PARGO	SHOP	CLICKS HILLCREST BO...
4	4	Point	PAXI	SHOP	TEKKIE TOWN
5	5	Point	ARAMEX	GARAGE	FRESHSTOP COLBYN
6	6	Point	ARAMEX	SHOP	CHECKERS LOFTUS
7	7	Point	ARAMEX	SHOP	PNP HILLCREST
8	8	Point	ARAMEX	GARAGE	FRESHSTOP A CLUB M...

Figure 11: Desktop data set sample (Author, 2023)

The first part of the data collection was done according to Data Schema 1 as discussed in the Data Schema Design section (see Section 3.5.3).

3.5.2 Primary Data

The second part of the field-researched primary data collection followed POI geo-tagged social media check-in data, using a GIS mapping collection method. This data identified through engagement established a pattern for the rationale of the urban dynamics of urban public spaces (UPSs). The sample database of data collected, as seen in Figure 12, enabled the examination of the rise of new communities and the formation of socio-cultural norms through a socially, visually locative system of public participation, sensing citizen interactions and assemblies. The spatiotemporal models were integrated with the routine activities of citizens who chose to represent their city and places with highly curated content and places of attraction. Thus, associations were uncovered. Investigating the influence that UPSs have on SES through the curated interface of social and cultural contexts contributed to understanding the social security level from the bottom up (Han *et al.*, 2019:6).

	OBJECTID *	SHAPE *	NAME	TYPE_ACTIVITY_CATE...	TYPE	ACTIVITY	ENGAGEMENT	POPULATION_AGE
1	1	Point	PBHS	EDUCATION	EDUCATIONAL_SCHOOL	SPORTS	99	1
2	2	Point	GREEK ORTHODOX CH...	ART_SPIRITUAL_RECREA...	CHURCH	SERVICE _ DANCE	101	12345
3	3	Point	HELLENIC COMMUNIT...	ART_SPIRITUAL_RECREA...	COMMUNITY CLUB	SOCIAL EVENTS	101	234
4	4	Point	FILOS	FOOD_DRINK_ENTERTA...	RESTAURANT	SOCIAL EVENTS	101	234
5	5	Point	BOUKUNDE DEPARTME...	EDUCATION	EDUCATIONAL_UNI	PROJECT PRESENTATIO...	1001	2
6	6	Point	VISUAL ARTS DEPARTM...	EDUCATION	EDUCATIONAL_UNI	PROJECT PRESENTATION	101	2
7	7	Point	ENGINEERING BUILDIN...	EDUCATION	EDUCATIONAL_UNI	MEMES	101	2
8	8	Point	AULA UNIVERSITY OF...	EDUCATION	EDUCATIONAL_UNI	PERFORMANCE	1001	234
9	9	Point	TUKS	EDUCATION	EDUCATIONAL_UNI	GRADUATION _ FORMAL	1001	23
10	10	Point	UNIVERSITY OF PRETO...	EDUCATION	EDUCATIONAL_UNI	GRADUATION	47900	234
11	11	Point	OLD ARTS BUILDING	ART_SPIRITUAL_RECREA...	MUSUEM	BUILDING FACADE	101	234
12	12	Point	UNIVERSITY OF PRETO...	EDUCATION	EDUCATIONAL_UNI	MARKETING	99	23
13	13	Point	ASTERHOF RESIDENCE	RESIDENCE	RESIDENTIAL_UNI	STUDENT SOCIAL EVEN...	1001	2
14	14	Point	MAKWASSI	FOOD_DRINK_ENTERTA...	RESTAURANT	FOOD	101	2
15	15	Point	MZANSI PETROL HEADS	ART_SPIRITUAL_RECREA...	COMMUNITY CLUB	CARS	501	234
16	16	Point	SPRINGBOK BAR	FOOD_DRINK_ENTERTA...	RESTAURANT	SOCIAL EVENT	1001	23
17	17	Point	JUST NAILS HATFIELD	LIFE SERVICE	SALON	NAILS	101	234
18	18	Point	KUNG FU KITCHEN HAT...	FOOD_DRINK_ENTERTA...	RESTAURANT	FOOD	99	23
19	19	Point	NERINA RESIDENCE	RESIDENCE	RESIDENTIAL_UNI	LIVING	101	2
20	20	Point	JJ THERON HALL	EDUCATION	EDUCATIONAL_UNI	PERFORMANCE	99	23

Figure 12: Field data sample data set (Author, 2023)

The second part of the data collection was done according to Data Schema 2 as discussed in the Data Schema Design section (see Section 3.5.3).

3.5.3 Data Schema Design

The measuring instrument utilised in the data collection process encompassed a quantitative approach by constructing basic GIS databases. There were two GIS data schemas for this research paper: Data Schema 1 included the SES service systems from a socio-economic servicing perspective, whereas Data Schema 2 included the SES systems and the public social engagement with these socio-economic system entities.

3.5.3.1 Data Schema 1: Hatfield SES

The literature review and theoretical framework informed the SES system and the factors of interest of their relational measurables and metrics as stipulated in Table 6.

Table 6: Data Schema 1 – SES system services (Author, 2023)

SES systems	Service system elements in SES system	Measurable SES characteristics	Measurement description	Metric
Education	• Basic and tertiary, schools • Universities • Colleges • Organisations (including music, cuisine and language courses)	Educational availability	Number of educational entities per educational system	Numeral ratio (count)
		Educational accessibility	Number of educational entities being private or publicly accessed per educational system	Average ratio (range)
		Available educational area significance	Clusters and proximity of clusters	(Km) (count)
		Accessible educational area significance	Clusters and proximity of clusters	(Km)
Healthcare	• Hospitals • Clinics (including mental and pregnancy) • Doctors' offices • Pharmacies	Healthcare availability	Number of healthcare entities per healthcare system	Numeral ratio (count)
		Healthcare accessibility	Number of healthcare entities being private or publicly accessed per healthcare system	Average ratio (range)
		Available healthcare area significance	Clusters and proximity of clusters	(Km) (count)
		Accessible healthcare area significance	Clusters and proximity of clusters	(Km)
Housing infrastructure	• Waste system service • Water supply	Waste system availability	Proximity of the number of waste systems available	Numeral (count) and (Km)
		Nature of waste system administered	Number of waste systems being private or publicly serviced	Average ratio (range)
Public administration	• Personal identification places	Public administration system availability	Number of public administration services per public administration system	Numeral (count) and (Km)

SES systems	Service system elements in SES system	Measurable SES characteristics	Measurement description	Metric
	• Licencing centres • Courier services	Nature of public administration system administered	Number of waste systems being private or publicly serviced	Average ratio (range)
		Infrastructure entity housing the public administration system	Number of public administration systems serviced per infrastructure entity	Numeral ratio (count)
Community development	• Community development places (including libraries, cultural institutions and sports recreation) • Spiritual places • Citizen safety (including protection services, CCTV and unsafe places according to street design)	Community development place, space availability	Number of community development places per community development system	Numeral ratio (count)
		Available community development area significance	Clusters and proximity of clusters	(Km) (count)

3.5.3.2 Data Schema 2: Public engagement

In the second part, UPSs and further identifying factors of interest of their relational measurables and metrics as stipulated in the Table 7 were identified.

Table 7: Data Schema 2 – Public engagement in the SES system (Author, 2023)

UPS activity category in SES systems	Type of place visited in SES system	Metric	Measurable description	Unit of measurement
Education	Basic and tertiary, schools, universities, colleges, organisations (including music, cuisine, and language courses)	POI usage per UPS	Number of UPS POIs	Numeral (count)
		UPS usage per POI	Number of UPS POIs	Numeral (count)
		POI engagement per UPS	Number POI engagements per UPS engagement	Amount – low, medium, high (value scale)

UPS activity category in SES systems	Type of place visited in SES system	Metric	Measurable description	Unit of measurement
Residence	Residential (including university student and other accommodation), accommodation	Significant POI areas based on UPS engagement	Average number of UPS engagements forming POI clusters and proximity of clusters	(Km)
Art, spiritual, entertainment	Community sports or volunteering club, churches, museums, stadiums and arenas (including sports and other)			
Open space	Area, public square or plaza			
Life service	Salon, physical fitness gym			
Food and drink	Restaurant, takeaway, bar, hotel, events venues			
Retail and commercial	Retail, clothing hire, corporate offices, embassies, car dealerships			

Together, the two data schemas create a targeted representation of the socio-economic systems data of Hatfield and capture the key aspects of the community's engagement and relationships in the precinct.

3.6 Data Analysis Method

This research study used grounded theory for qualitative analysis. To form conclusions, thematic analysis and descriptive statistics analysis of the spatial GIS data schema data sets were performed. Descriptive statistics of average, minimum, maximum, mean, median, and mode were used to describe the data distribution and measure the variability of the data (Han *et al.*, 2019:12). This analysis further examined the relationship of the data schema data sets to relevant critical discourse by following a non-linear process that emphasised the integration of manifesting and latent content.

4 Data Analysis and Results

The Data Analysis and Results section discusses the results of the mapping and data analysis of the research study. This section further explains how the GIS mapping of the identified SES system contributes insight to understand the soft infrastructure landscape of the local urban

community of Hatfield. Data Schema 1: service systems mapping is addressed first, followed by Data Schema 2: socio-economic engagement.

4.1 Data Schema 1: Results

The Data Schema 1 results are unpacked as follows: for each subsection, the results generated from the GIS mapping are stipulated through descriptive statistical analysis of the metrics as laid out in Section 3: Methodology (see Table 6). After the analysis, a short commentary on the subsection is provided on how the SES GIS analysis relates to the research question.

4.1.1 Educational System

After exploring the distribution of the educational SES system (Figure 13), Hatfield emerged as having an active educational servicing system, which confirmed the demographic discussion of Hatfield having a student population (Section 3.2).

For the first measurable of *educational availability*, the ratio 10:3:4:3 of schools: universities: colleges: organisations was found.

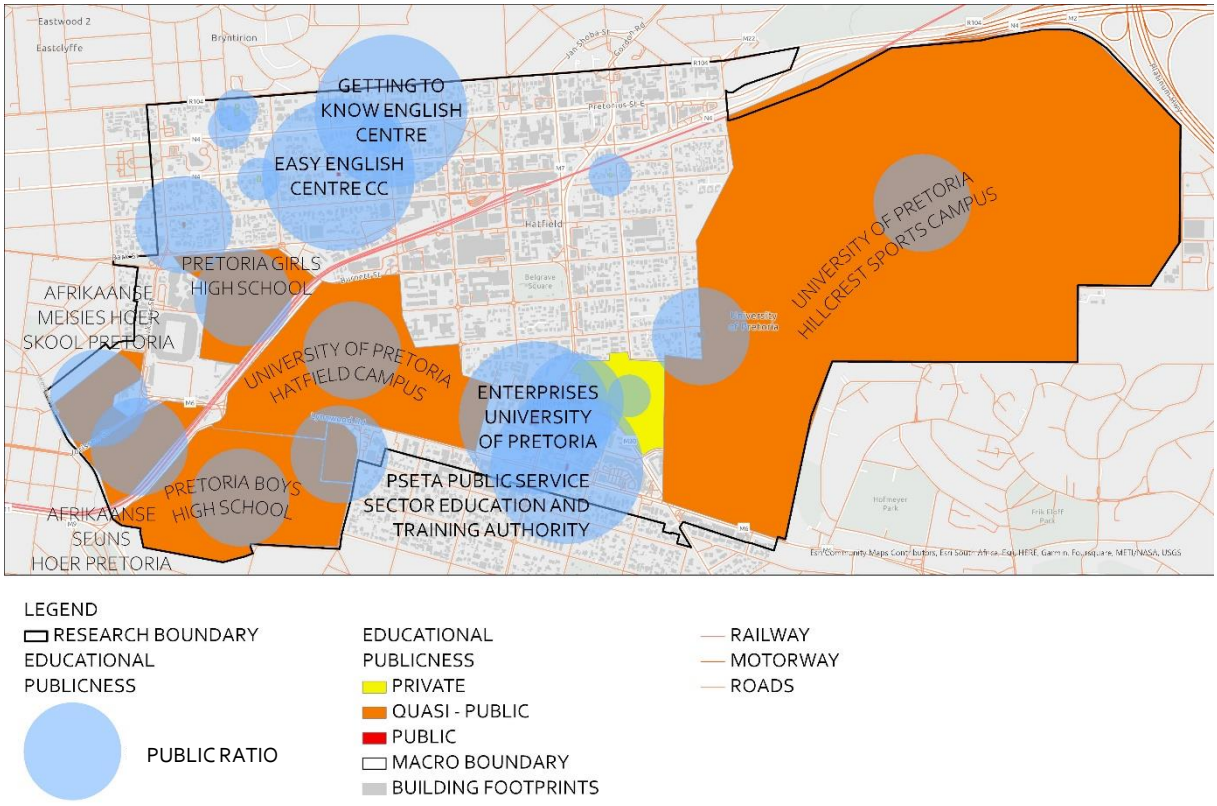

Figure 13: Map of educational services (Author, 2023)

In terms of *educational accessibility* (Figure 14), it becomes evident that of the 20 identified educational entities, six are private educational entities, ten quasi-public entities and four publicly accessed educational entities. Private entities are classified as either privately governed or restricted privately accessible spaces, whereas public entities are classified as state-controlled entities with unrestricted accessibility. However, quasi-public entities include public universities and schools with public ownership in conjunction with private management with restricted accessibility.

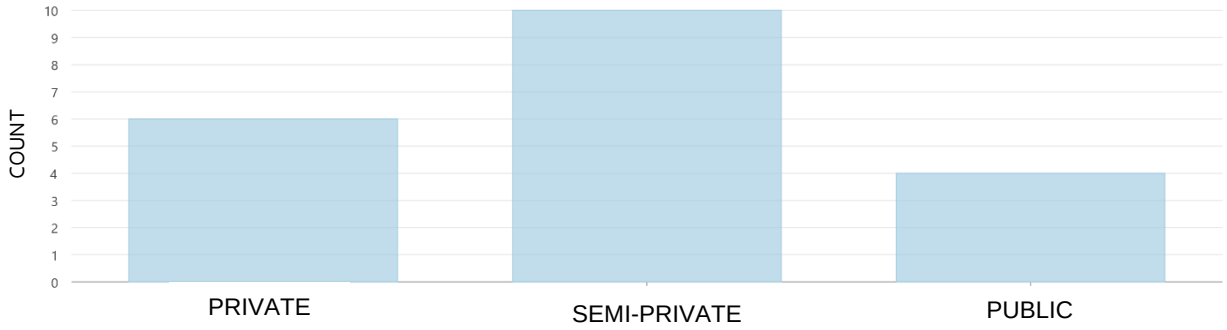

Figure 14: Number of educational entities on the public-private accessibility spectrum (Author, 2023)

The *available educational area significance* measurable was determined by stipulating the sum educational area of 5 466 957,9 km^2 in relation to the total study area of 9 522 953,03 km^2 in Hatfield (Figure 15). It becomes evident that educational service entities in totality cover more than half of the total study area. In more detail, the area per educational system as seen in Figure 16 of ratio of schools, universities, college to organisations, confirms that the university is the main contributor to the educational SES service system in terms of area.

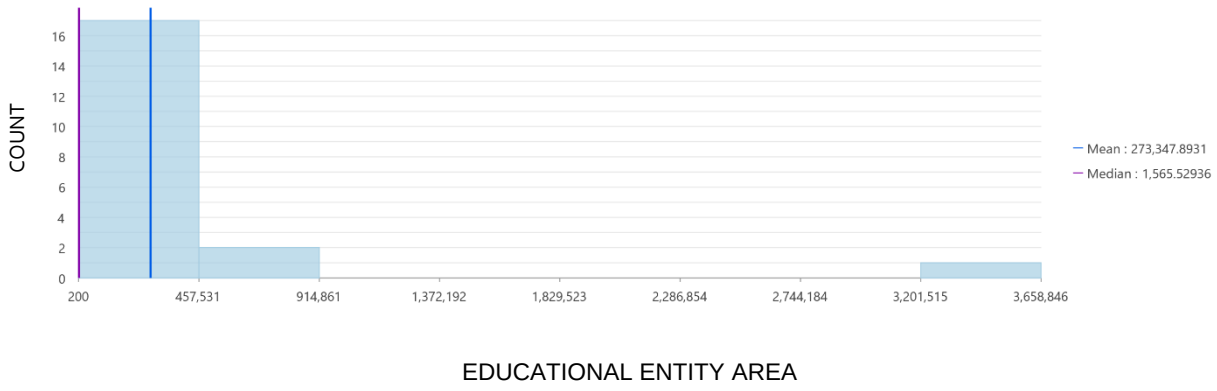

Figure 15: Distribution of educational entity area contribution of 5 466 957,9 km^2 (Author, 2023)

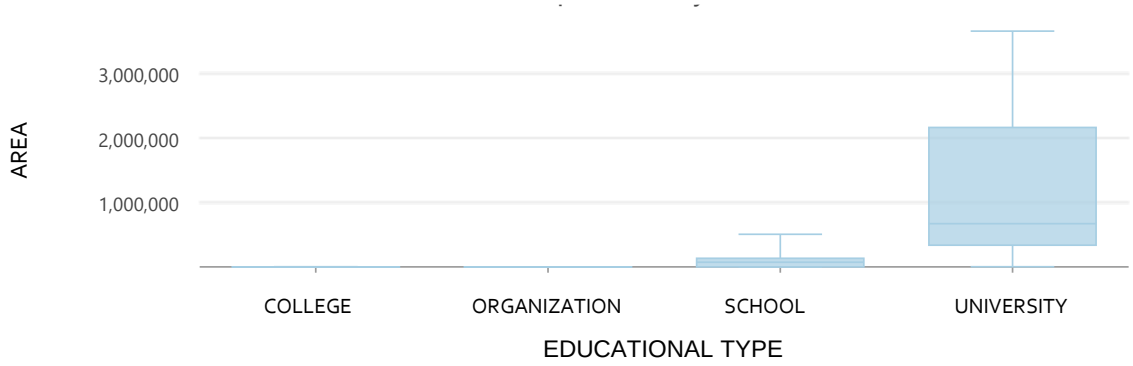

Figure 16: Distribution of shape area per educational type (Author, 2023)

Lastly, the *accessible educational area significance* measurable was determined by assessing the quasi-private educational entities as the maximum area anomalies majorly contributing to the sum educational area (see Figure 17). Consequently, in relation to the number of accessible educational entities, the mode statistic indicates quasi-public accessibility that consists of half of the sum of educational entities being quasi-privately accessible. Together with the area distribution of the quasi-public as major contributor, it is evident that the accessible educational system taking up the most space in Hatfield is only quasi-publicly accessible.

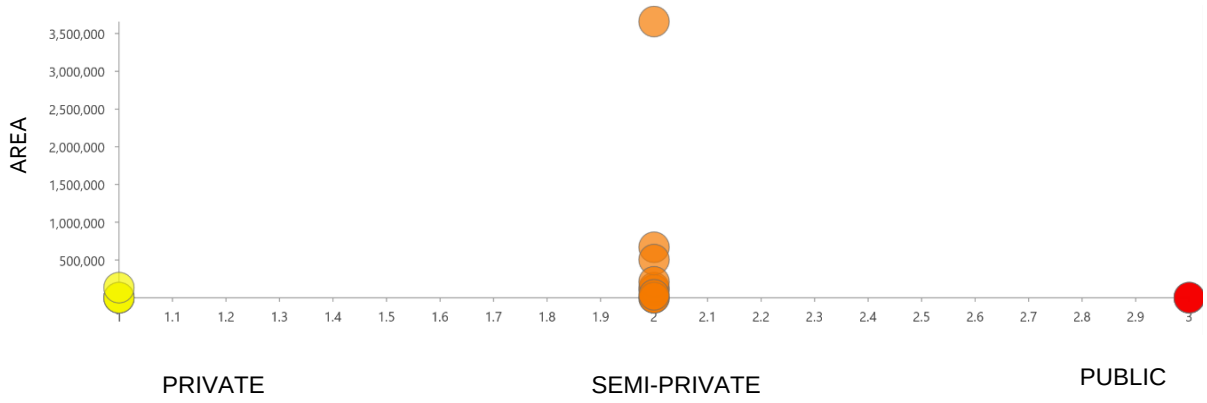

Figure 17: Distribution of educational entity area contribution in relation to the public-private spectrum (Author, 2023)

Considering the nature of the educational system that services the SES system of Hatfield, it becomes evident that although there are mostly schools in the area, the university services the SES system by administering and populating the largest spatial area in the Hatfield context. Additionally, most of Hatfield's educational servicing system is only quasi-publicly accessible, which means that the nature of Hatfield's educational SES systems is not collaborative or integrated but has highly specific restrictions in terms of accessibility.

4.1.2 Healthcare System

The distribution of the healthcare SES system (Figure 18) was explored and it was found that Hatfield does have a healthcare servicing system. However, as with the educational system (Section 4.1.1), by briefly observing the two GIS maps in relation to each other, the healthcare system presence is not found as ample as the educational system.

On the first account of mapping health system entities by the *healthcare availability* measurable, of the 28 healthcare systems in total, a ratio of 2:5:5:16 of hospitals: clinics: doctors' offices: pharmacies was found.

In terms of the second measurable of *healthcare accessibility,* the definitions of public and private healthcare systems correlate to that of the educational system. It becomes evident that the sum of all health entities in the Hatfield study area of 12 health service providers are all privately controlled with restricted accessibility to healthcare systems services. There are only 16 public pharmacies in Hatfield. Fully publicly owned publicly serviced health entities can only be found outside the border of Hatfield.

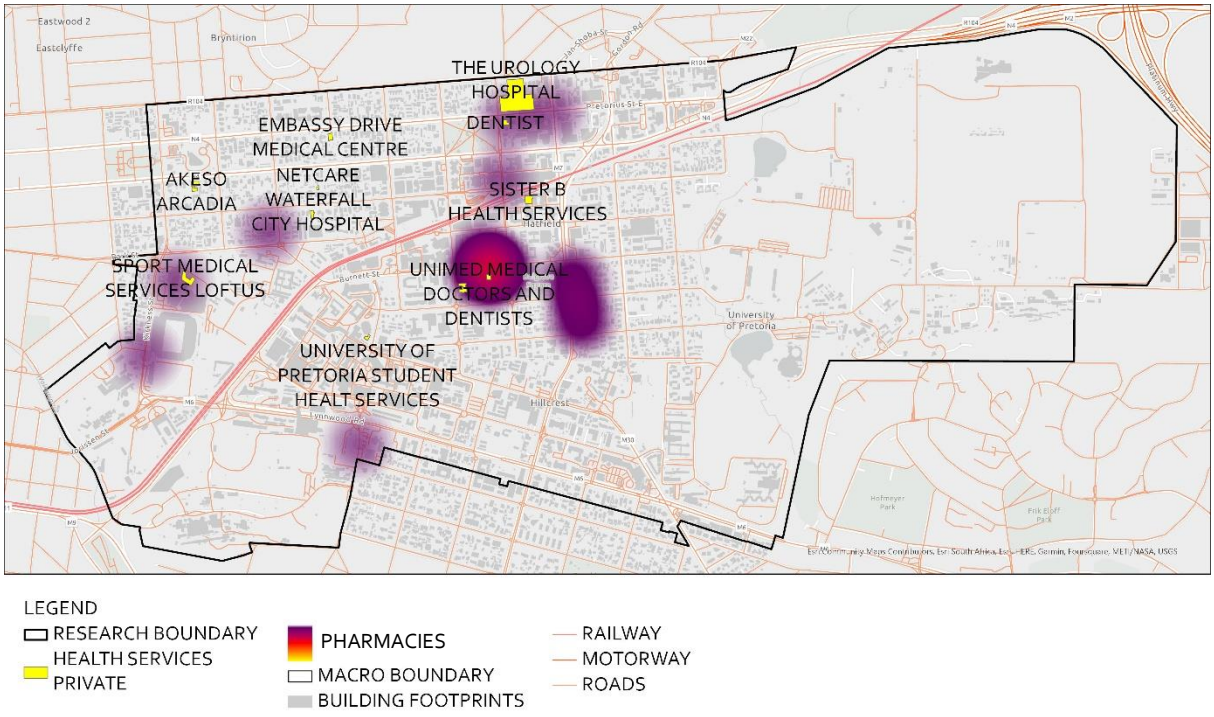

Figure 18: Map indicating health services including hospitals, clinics, private practices and pharmacies (Author, 2023)

Regarding the *available healthcare area significance* measurable, another significant observation is visually identified on the map (see Figure 18), further substantiated by considering the graph (Figure 19) that demonstrates the outlier of the Urology Hospital

consisting of 18 508,36 km^2 of the sum health entity area of 26 354,2 km^2, which identifies this health entity as the major contributor in the study area. Further considering the *accessible healthcare area significance* measurable, the major healthcare service entity of the Urology Hospital is found to be private, which means the major healthcare contributor in Hatfield is inaccessible to the public and highly specialised due to its nature.

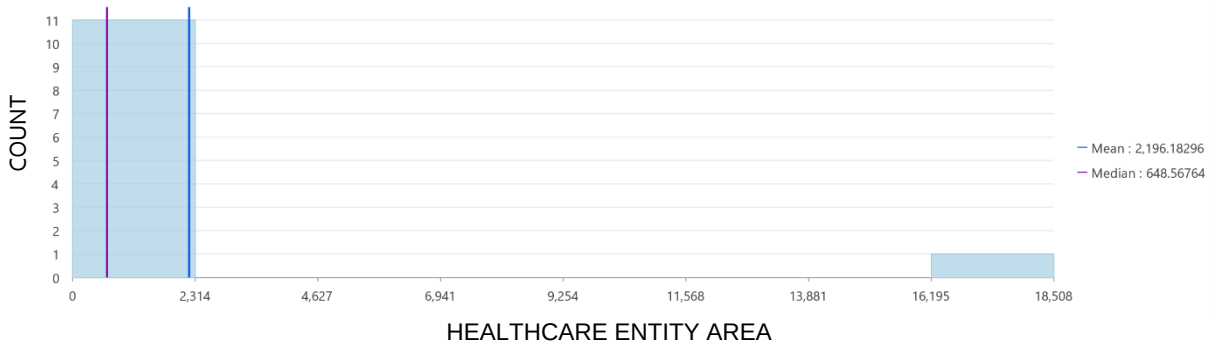

Figure 19: Distribution of health service entity area contribution to the sum health area of 26 354,2 km^2 (Author, 2023)

Considering the healthcare system in Hatfield, its contribution in terms of area administered and populated that services the SES system pales in comparison to the educational system. The accessibility of the healthcare system servicing Hatfield carries the same nature as the educational system by not being collaborative or integrated but by having highly specific restrictions in terms of private accessibility.

4.1.3 Housing Infrastructure System

In exploring the housing infrastructure SES system, the measurables were not applied in the exact same manner as the sections describing the educational (Section 4.1.1) and healthcare systems services (Section 4.1.2). This differentiation was due to the nature of housing infrastructure systems being more integrated in a wider context and in the system itself, with specific reference to waste system services. The waste systems could not be seen as entities; therefore, the entire system was administered as a whole with different points of services that fed into the integrated system. Furthermore, in the case of housing infrastructure, publicly owned and publicly accessed systems were found, with privately managed and controlled systems still being publicly accessible.

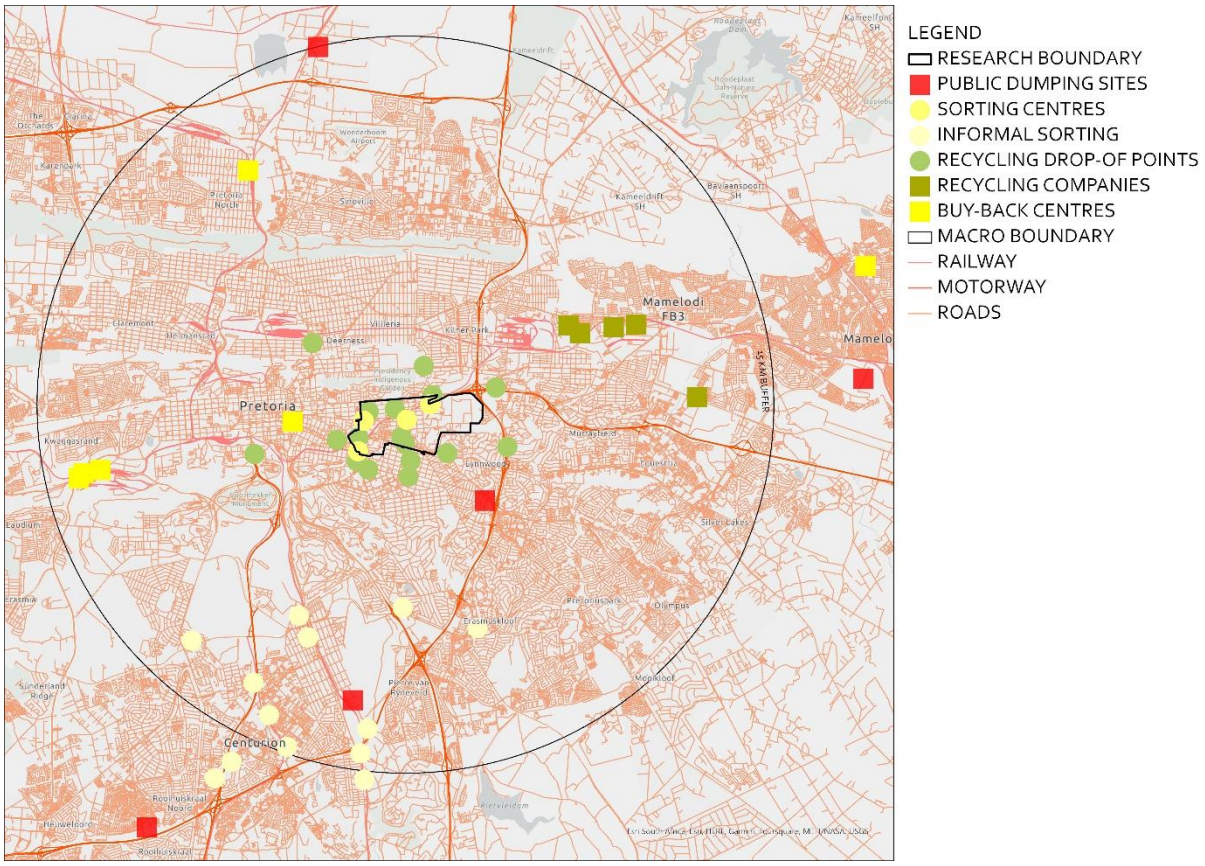

Figure 20: Map including the 15 km context of Hatfield indicating the refuse waste removal service entities (Author, 2023)

Considering the greater context in which Hatfield is found, in terms of the distribution of the housing infrastructure SES system (Figure 20 and Figure 21), the *waste system availability* measurable was considered regarding the proximity of the number of waste systems available. The *nature of waste system administered* measurable was also considered in relation to the number of waste systems being private or publicly serviced.

Regarding the *waste system availability* and *nature of waste system administered* of the public service refuse, five waste dumping sites were found in the greater context of which only two were in the 15 km boundary and none in Hatfield itself. Furthermore, five private recycling companies and five collector centres were found in the 15 km boundary but none in Hatfield itself. Examining the relationship between availability and accessibility, very few waste system services were identified in a close and accessible range of Hatfield. Therefore, it can be argued that waste system services are either a service functioning on a bigger scale or that not enough development has happened in terms of the service delivery provision in sustainable closer proximities in the local urban Hatfield context.

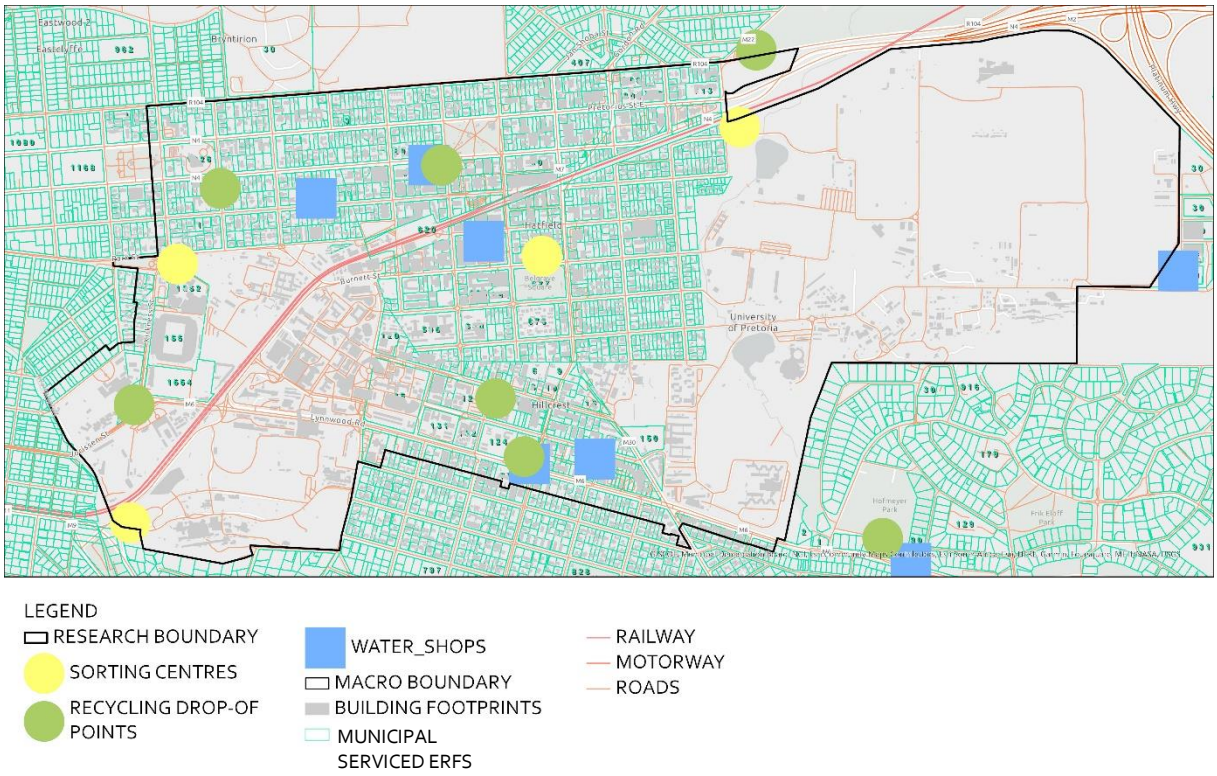

Figure 21: Map indicating the housing infrastructure services in Hatfield (Author, 2023)

South African municipal waste removal services individual erfs regularly – ordinarily weekly. The same nature of water supply is distributed to each erf daily. Scrutinising the measurable of *waste system availability* and the *nature of waste system administered*, the factor that waste system services are individually and regularly available is contrasted when reviewing the availability of the additional waste system entities found. This *waste system availability* and *nature of waste system administered* of additional waste systems found are a general indication that highlight the need for additional service delivery support.

Although in the nature of this research study, it deems to not be possible to conclude whether public housing infrastructure system servicing is sufficient or outperforming private housing infrastructure system servicing as the two sector services do not follow the same administration and patterns of provision. It can be argued that the public housing infrastructure system service in its original intention is servicing the SES system in Hatfield sufficiently, but the changing environmental issues of waste management in need of sustainable development systems may be pressing for alternative ways of considering the servicing of housing infrastructure SES systems. Examples of additional SES systems that would contribute to servicing Hatfield sustainably include either the recycling of waste systems services or the need for cleaner purer drinking water.

4.1.4 Public Administration Service System

In exploring the distribution of the public administration SES service system (Figure 22 and Figure 23), the measurables and analysis were approached in the same manner as the housing infrastructure system (Section 4.1.3) as the nature of integrated systems in a broader context correlates.

Regarding the first measurable of *public administration system availability*, considering the greater Hatfield 15 km context (Figure 22), the number of public administration services per public administration system was found to be 6:65:90 for personal identification places: licencing centres: courier services.

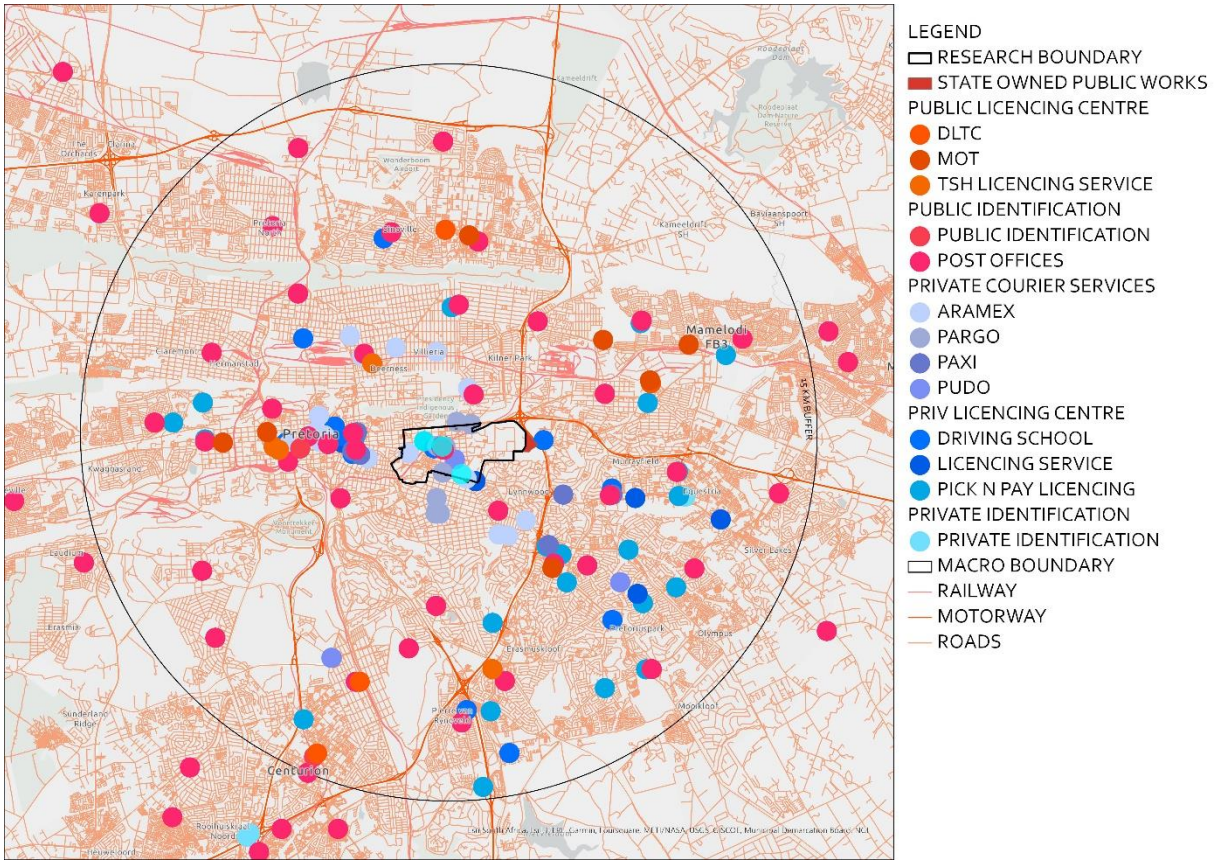

Figure 22: Map including the 15 km context of Hatfield indicating the public administration service system (Author, 2023)

Reviewing the second measurable of the *nature of public administration system administered*, considering the greater Hatfield 15 km context (Figure 22), the number of public administration services per public administration system being publicly to privately administered was found to be 2:4 personal identification places, 15:50 for licencing centres, and 40:50 for courier services. The number of public administration systems being privately administered was 104 of which 50 were private courier services and 57 publicly administered, of which 40 were post offices.

When investigating the *public administration system availability* in the immediate Hatfield boundary, the number of public administration services per public administration system was found to be 0:5:14 for personal identification places: licencing centres: courier services. Further looking at the *nature of public administration system administered* measurable, the number of public administration services per public administration system being publicly to privately administered was found to be 0 for personal identification places, 0:5 for licencing centres and 1:13 for courier services.

It is evident that the private administration of the system services is the main contributor to the public administration SES system servicing in the Hatfield study boundary. For example, only one public post office of the publicly administrated service system was found, yet 18 privately administrated service systems were found within the Hatfield boundary.

Further considering the measurable of *infrastructure entity housing the public administration* system, the number of public administration systems serviced per infrastructure entity was found to be one of eight garages and seven of eight retail centres.

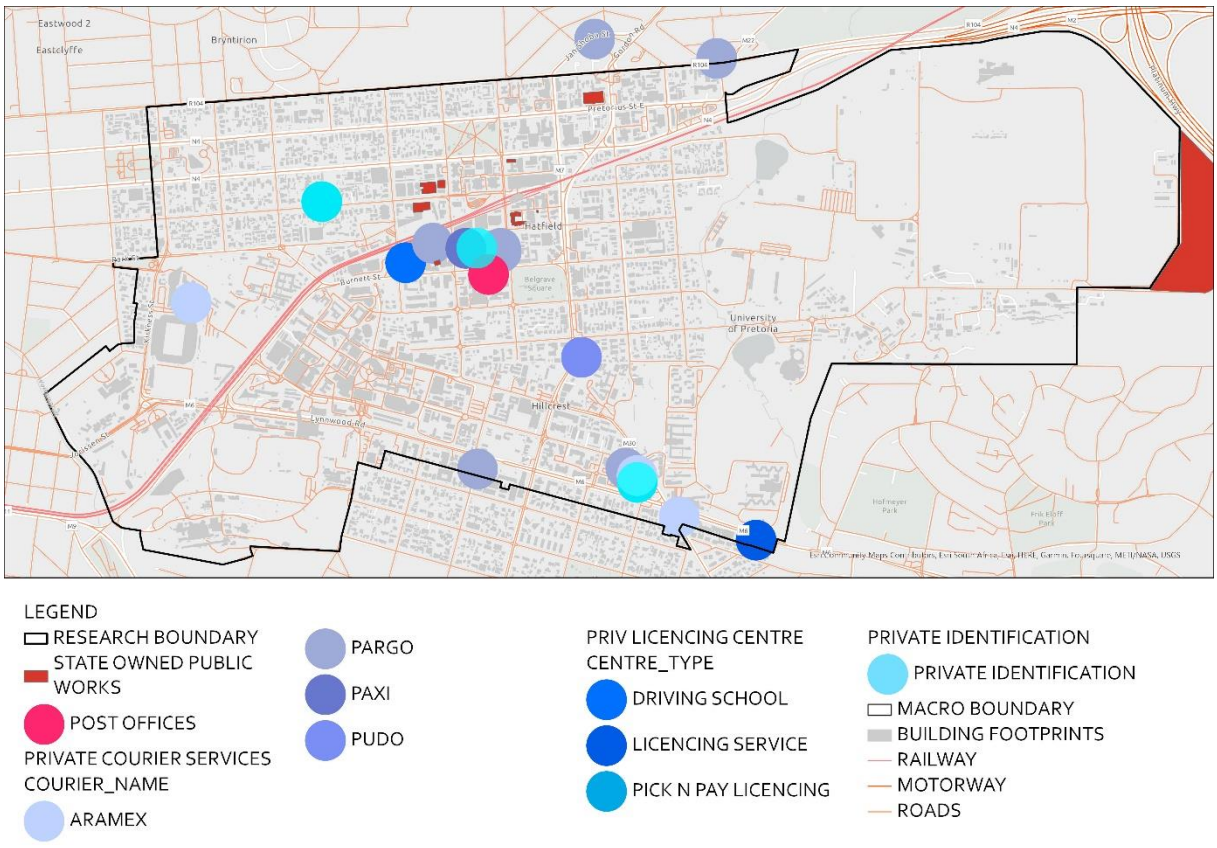

Figure 23: Map indicating public administration service system in Hatfield (Author, 2023)

After analysing the public administration service systems in the greater and immediate Hatfield context (see Figure 23), it became evident that public administration service systems are being privately administered in their contribution to servicing the SES system of Hatfield by utilising existing infrastructure and entities, such as retail supermarkets and garages. This observation indicates a need in the SES system to be serviced in addition to the existing publicly administered systems.

4.1.5 Community Development System

The community development SES system (Figure 24) considered three categories as mentioned in the Database Schema 1 namely, community development places (including libraries, cultural institutions and sports recreation), spiritual places, and citizen safety (including protection services, CCTV surveillance systems and unsafe places according to the street design).

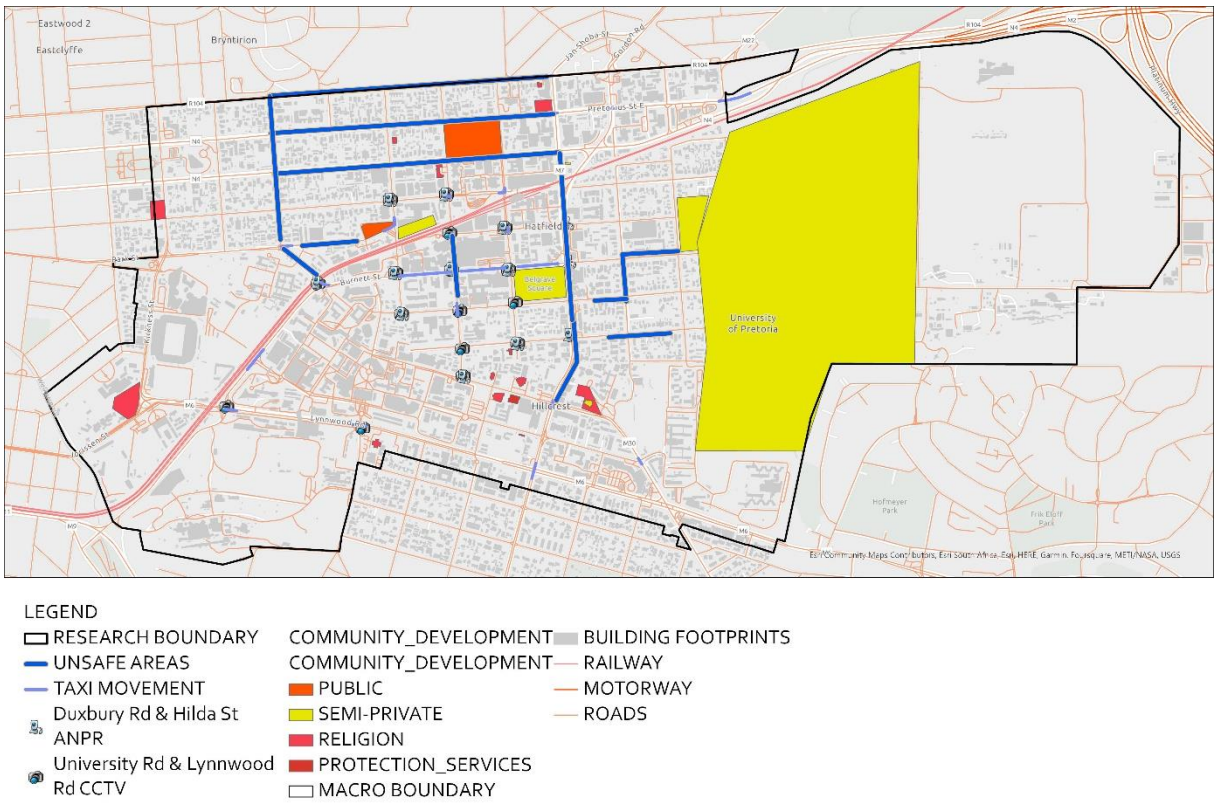

Figure 24: Map indicating community development service provision (Author, 2023)

Regarding the first measurable of *community development place or space availability*, the number of community development places per community development system was found to be 8:14:1 as per community development places: spiritual places: protection services. Looking at the common community development services, there are no public libraries in Hatfield and

eight community centres, recreation spaces and parks – of which only two are fully publicly accessible with no restricted access. There are 14 churches, which are publicly accessible entities.

Another element considered in the SES system is the provision of citizen safety regarding the SES community systems service. In South Africa, as such also in Hatfield, citizen safety is one of the key SES factors to consider. CCTV surveillance positioning indicates where safety is prioritised in the urban core of Hatfield. Furthermore, the identified crime, littering and unsafe areas indicate that citizen safety decreases as security surveillance decreases (Figure 24).

Looking at the second measurable of *available community development area significance*, in terms of the place and space provision, a community development space was not found in the busy Hatfield core but rather around the Hatfield perimeter. Reviewing the citizen safety systems servicing found in the core creates a question of coordination in the community development system servicing the Hatfield SES by not providing safety in community development spaces.

4.1.6 Data Schema 1: Results Conclusion

Considering the healthcare and education in Hatfield's SES system, the educational system is more prominent in its servicing capacity. Further comparing the location of the clustering of health systems with the placement of educational systems, the Hatfield urban dynamic can be described as a mainly educationally serviced system that encapsulates Hatfield's core as the defining perimeter located on the boundary of Hatfield. Furthermore, health services and pharmacies are clustered and distributed in the core of Hatfield.

The housing infrastructure system serviced in Hatfield through identified instances of private administration indicates a need and possibility that could contribute to the advancement of the SES system of Hatfield. The public administration systems mainly serviced through private administration reinforces the possibility of contribution to developing the SES system of Hatfield sustainably. The public administration system serviced is again located in the core around Burnett Street and the north–south axis around Jan Shoba Street, indicated by the retail and commercial utilisation of existing shopping centre and garage infrastructure.

The next section elaborates on the SES system to be serviced in Hatfield by specifically focusing on the social and cultural preferences of Hatfield's inhabitants and how these SES system citizen preferences act as indicators of the success of commonly provided educational, healthcare, social and community development systems and entities for the advancement of the SES system.

4.2 Data Schema 2: Results

The Data Schema 2 results are unpacked as follows: the results generated from the GIS mapping are stipulated through descriptive statistical analysis of the metrics as laid out in Section 3: Methodology (see Table 7). After the analysis, a short commentary on the different categories of diverse urban spaces and their different real-time spatiotemporal patterns and how the SES GIS analysis relates to the research question is provided.

4.2.1 Social POI SES System

The SES system of the POI urban spaces further qualified through their UPS types are shown in Table 8 for reference purposes.

Table 8: POI system (Author, 2023)

POI category in SES systems	**Type of UPS visited in the SES system**
Education	Basic and tertiary, schools, universities, colleges, organisations (including music, cuisine, and language courses)
Residence	Residential (including university student and other accommodation), accommodation
Art, spiritual, entertainment	Community sports or volunteering club, churches, museums, stadiums and arenas (including sports and other)
Open space	Area, public square or plaza
Life service	Salon, physical fitness gym
Food and drink	Restaurant, takeaway, bar, hotel, events venues
Retail and commercial	Retail, clothing hire, corporate offices, embassies, car dealerships

Looking at the first measurable of *UPS usage per POI,* from Figure 25 indicating the number of UPS activity per POI, it becomes clear that the food and drink category was the major POI identified.

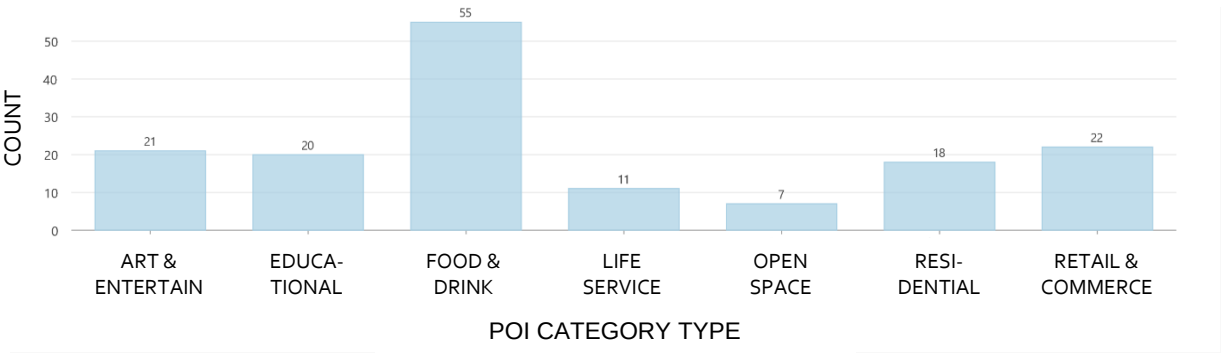

Figure 25: Graph indicating the total number of POIs identified in each activity category type (Author, 2023)

Considering the second measurable of *POI engagement per UPS* in Figure 26, the number of POI engagements per UPS engagement demonstrates educational engagement as the highest activity category, open space second, and food and drink third. This confirms the prior argument that Hatfield is a truly educationally focused precinct concentrated around the University of Pretoria and its two campuses. The first outlier in the open space POI category (Figure 27) of Hatfield as the overarching area UPS with an engagement of 62 600 is identified as a major contributor to the overall engagement number of 213 781. Hatfield as the area UPS explains why the engagement of the open space POI engagement is ranked second.

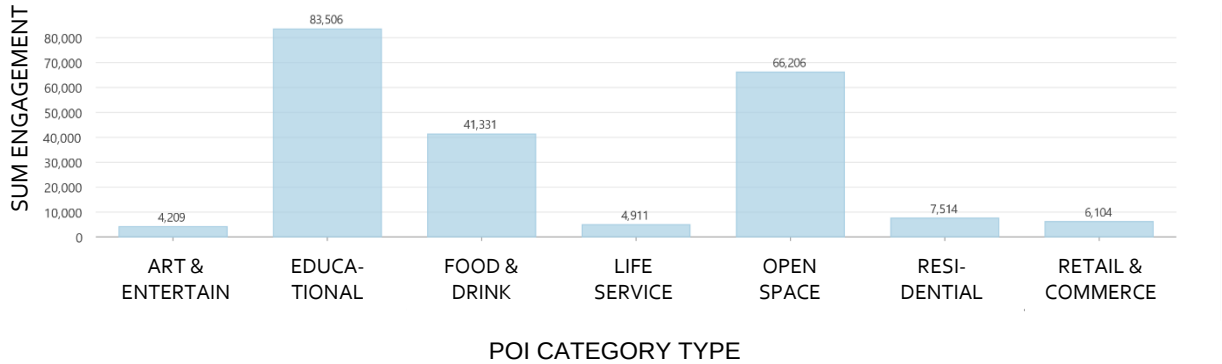

Figure 26: Graph indicating the sum of engagement per POI category type (Author, 2023)

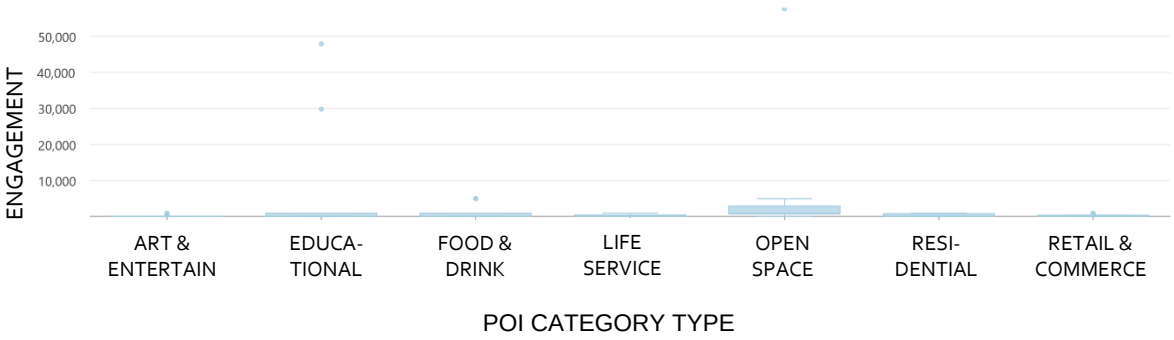

Figure 27: Graph indicating engagement numbers per POI category type showing outliers (Author, 2023)

The third measurable, namely *significant POI areas based on UPS engagement*, considers the POI SES system according to the average number of UPS engagements forming POI clusters and proximity of clusters. The food and drink category had the most POIs and the third-highest engagement number by identifying four majorly preferred POIs as indicated on the map (Figure 28), namely Mustang Sally's Pub and Diner, Blue Room Hatfield, Skyline Pretoria and Fokof Bar all with engagements above 5 000. Clusters of engagement activity form in the retail core of Hatfield, the retail centre of Loftus Park, as well as the social strip in Lynnwood Road.

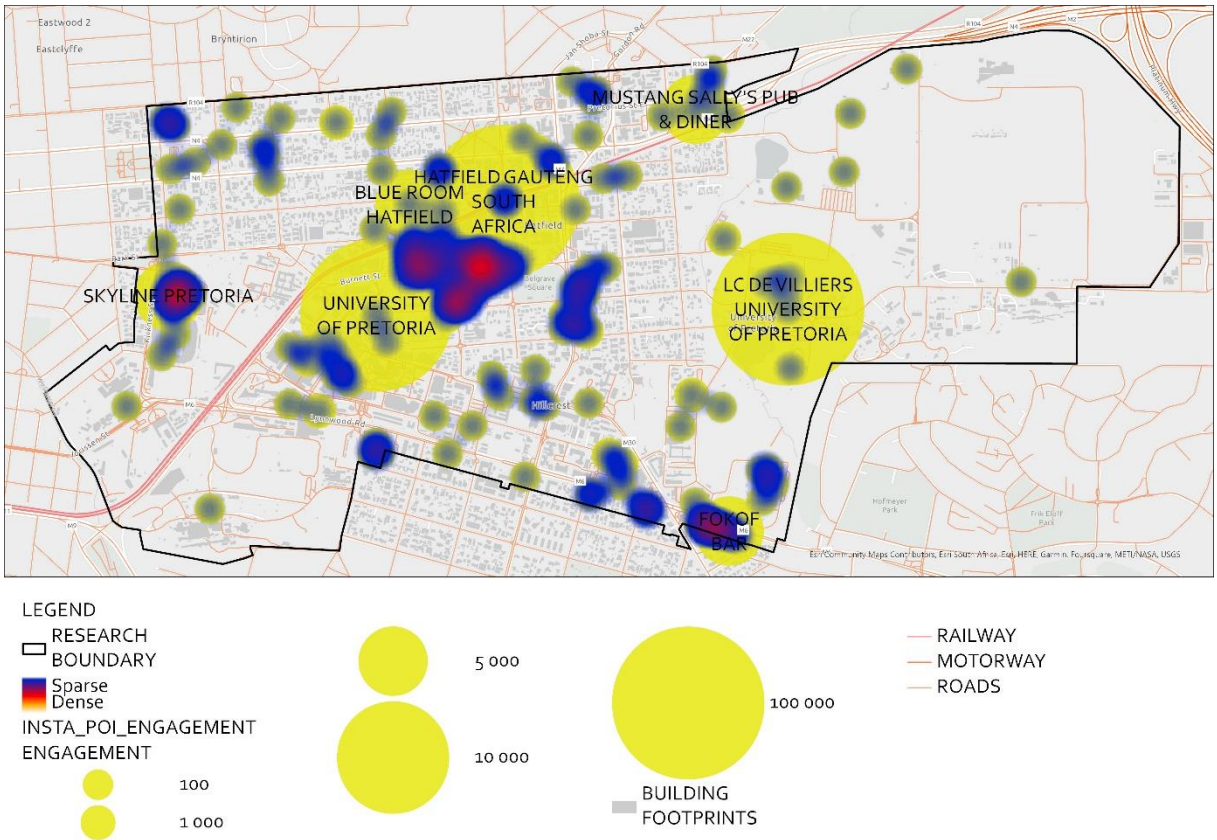

Figure 28: Map indicating POIs in their activity category type clusters and corresponding engagements (Author, 2023)

Looking at the map (Figure 28) that shows the POI number of UPS activity clusters in relation to the UPS engagements, it becomes evident that the highest number of activities forms a cluster of the social hubs in Hatfield's social, restaurant, bar and nightclub core with food and drink as main POI UPS activity contributor. However, the highest number of engagements concentrate on the educational POIs of the educationally serviced SES system.

4.2.2 Data Schema 2: Results Conclusion

From the Instagram POI engagement analysis, it is therefore argued that the urban dynamics of Hatfield consist of a predominantly educationally serviced area with a social and cultural dynamic that prefers the curation of a social presence in the urban local context that promotes engagement with restaurants, takeaways, bars, nightclubs, hotels and events venues. This observation contributes to an interesting indication of Hatfield's SES system nature where ordinarily in an educational and student focused demographic context, one would consider the interest in community development focused places and systems that would prefer engagement with community sports or volunteering clubs, churches, museums, sports and other stadiums and arenas to also be highly wanted. This observation starts giving direction to the social preference and nature of the student and young adult demographic of Hatfield of rather contributing to a social events system than contributing to development event systems. This SES observation contributes to understanding the soft infrastructure of Hatfield.

5 Discussion

The Discussion section of the research paper provides insights into the evidence from Section 4: Data Analysis and Results, with these insights further connecting the findings to the theories, concepts and definitions discussed in Section 2: Literature Review. Furthermore, the Discussion section provides insights that connect the findings to the research problem and how said learnings answer the research question. Lastly, the section provides insights regarding gaps and limitations of this research study.

The intention of this research study is to contribute to the DTC discourse of constructing a mature DTC by including soft infrastructure data that aids in developing a relevant, localised, and contextual understanding of a city that contributes to DTC readiness.

The Discussion section is structured as follows: each subsection in relation to the subquestions discuss the contribution of the learnings of the research study in solving the research question, namely, *How does understanding the SES of Hatfield's soft infrastructure contribute to relevant digital twin use case readiness?*

Section 5.1 discusses the order of the findings of the baseline metrics that measured SES and how the findings contribute to understanding the soft infrastructure landscape of Hatfield. Section 5.2 discusses the different SES typologies and taxonomies of Hatfield that manifest in assessing the nature of the soft infrastructure SES system in the study context. Section 5.3 discusses how the typologies and taxonomies inform a framework that indicates the contributors to an effective SES system of the local urban soft infrastructure of Hatfield. Lastly, Section 5.4 discusses how the SES typology and taxonomy framework contributes to viable digital twin readiness for the Hatfield urban context.

5.1 Hatfield SES Systems Findings

Section 5.1.1 discusses the findings of the measured SES and how they contribute to understanding the nature of Hatfield's soft infrastructure SES system.

The GIS-mapped data of Data Schema 1 and 2 was analysed. The descriptive analysis of the availability, accessibility, engagement and activity SES system measurables formed the current status of the nature of the SES system in Hatfield. Patterns emerged by forming an understanding of the interrelation between the mapped SES service systems and the socio-economic engagement. The mapped system services influence the productive development and state of advancement of the social capital and economic systems in the Hatfield urban context (Ershova & Orlovskaya, 2020:2).

5.1.1 Educational System Finding

The first finding considers the educational SES system of Hatfield. It is regarded as a big contributor to advancing and developing Hatfield's SES system due to its prominent servicing capacity. The University of Pretoria acts as the main educational entity administering the servicing of educational SES systems. Over and above the prominent servicing capacity of the educational system, the social engagement in the educational system supports this SES system as playing a major role and contributing to the SES of Hatfield, which is further amplified by the defining student population of Hatfield. However, although the educational system does have an active and prominent role in the SES system in Hatfield, the nature of the educational system is highly secluded and there is minimal collaboration and integration.

5.1.2 Socially Active Preference Finding

The second finding considers the social and cultural dynamic of the urban community of Hatfield that prefers the curation of a socially active environment in their SES system. The social hubs, including restaurants, bars, takeaways, event venues and nightclubs, are

clustered in the core of Hatfield. The young adult population contribute economically towards the social system by specifically supporting the retail and service industry through social event activities that service the SES system of Hatfield.

5.1.3 Retail and Commercial Possibility Finding

The third finding considers the retail and commercial possibility due to the need of the indicated privately administered systems. The housing infrastructure system, such as waste services and public administration services is privately administered, which indicates a need in the SES system of Hatfield to furthermore advance new sustainable developmental ways.

The existing retail and commercial core of Hatfield, already utilised by certain privately administered systems servicing the SES of Hatfield, further creates a space that renders development and advancement possibilities for Hatfield's SES system.

5.1.4 Community Development Need Finding

Considering the community development system that lacks the capacity to service the SES system of Hatfield together with the highly restricted and privately administered healthcare system, the fourth finding includes a gap regarding servicing the SES system of Hatfield. There is a significant lack of social engagement with community development spaces, parks, museums, libraries, or spiritual spaces such as churches. Even though provision has been made for such systems, in certain instances it is not entirely satisfactory. The improvement of community development and healthcare systems and social engagement could contribute to the development and successful advancement of Hatfield's SES system.

The truly representational soft infrastructure understanding that is true to urban dynamics created by the citizens of Hatfield contributes to DTC readiness, which further informs the taxonomies and typologies in the following section (Han *et al.*, 2019:12).

5.2 Hatfield's SES Typology and Taxonomy

The second subsection discusses the different SES typologies and taxonomies of Hatfield that manifest in assessing the nature of Hatfield's soft infrastructure SES system.

The theoretical taxonomy and typology model discussed in the Literature Review section as a base informant is iterated in accordance with the SES systems findings to demonstrate the SES nature that is specific to Hatfield's system. The typological and taxonomical categorisation is shown in Table 9.

Table 9: SES typologies and taxonomies of Hatfield

Typological		
	Vital elements in the system servicing SES	Missing elements in the SES system
Educational system	• University of Pretoria entity • Student population • Educational social engagement	• Collaboration • Integration
Socially active community	• Social hubs including restaurants, bars, takeaways, restaurants and nightclubs • Young adult demographic • Social events and activities • Retail and service industry	• Well-being focused social engagement such as mental and physical health including exercise, nature orientated activities
Retail and commercial servicing system	• Retail and commercial infrastructure • Privately administered systems	• Sustainable way in systems development • Social engagement with development of sustainable systems management including waste management
Community development system	• Community development spaces including libraries, cultural institutions, sport recreation and parks	• Restricted and specialised healthcare accessibility • Community development social engagement
	Taxonomical	

5.2.1 Hatfield Neighbourhood Typology

Considering the urban dynamics of Hatfield's SES system, a top-down categorisation of shared characteristics and relationships guides the curation of the Hatfield soft infrastructure typology. The findings were categorised into key concepts servicing the SES system. These were further divided into two categories indicating, firstly, the existing vital elements and, secondly, the missing vital elements to include.

The aim of constructing SES strategical implementations could include the social and physical configurations of the neighbourhood. The city planning and development processes that promote SES, fulfil the sustainable, socially and economically cohesive design of cities (Carmona, 2022:138; Ntakana & Mbanga, 2020:8). This therefore includes an SES system that correlates with the identified soft infrastructure associated with Hatfield's typology. It is a cohesive system that includes a retail and commercial servicing system on the economic side and its educational system in the specific nature of Hatfield. Furthermore, on the social side,

the SES system could include a community that is engaged socially in a sustainable nature, which includes the development of the community.

5.2.2 Socio-economic Soft Infrastructure Taxonomy

The taxonomical classification of the SES systems elements considers the soft infrastructure nature of Hatfield in relation to its social security, which depends on the economic activation of places and systems. The taxonomical elements to possibly be included therefore require a balance between economic and social elements. In the first instance, the economic activation of SES systems includes stimulating small business development, promoting local ownership, substituting imports by rather promoting local production, and promoting 'buy-local', which in turn stimulates local businesses (Imbroscio, 1995:841).

Together with the economic activation of a comprehensively secure Hatfield neighbourhood typology, the social taxonomy to be considered is informed by the observation of the population demographics. The demographics include a student and young adult neighbourhood that requires exploration and exchange in their daily doings related to the socio-economic system. The social engagement of the citizens centric to the local Hatfield context could promote a narrative of renewal and celebration of the public realm, aimed at being diverse, responsive, democratic and meaningful. The social engagement could ultimately contribute to the benefits of health and well-being that activate and provide for security in relation to the socio-economic soft infrastructure of the urban dynamics of Hatfield (Carmona, 2022:138; Han *et al.*, 2019:2).

5.3 Commentary on the Theoretical Framework for Hatfield SES

The third subsection discusses how the typologies and taxonomies inform a framework that indicates the function of SES on the soft infrastructure of Hatfield as well as the contributors to an effective SES system of the local urban soft infrastructure of Hatfield. This section aims to contribute to the construction of the soft infrastructure nature of Hatfield that informs DTC readiness.

5.3.1 Principles of a Secure Socio-economic Soft Infrastructure of Hatfield

5.3.1.1 Integration

Looking at both the typology and taxonomy of Hatfield, it becomes clear that Hatfield embodies the nature of a disjointed urban dynamic of systems, places and entities operating in isolation. Instances of the disjointed urban dynamics include the educational system with its restricted

accessibility and the healthcare system also with its restricted accessibility and highly specified nature.

This notion of Hatfield's disjoined nature could pursue change through variety partnerships between public, pseudo-private and private entities. The partnerships could advance public interest with the resultant systems having a comprehensive public nature that none could achieve individually (Carmona, 2022:138; Ntakana & Mbanga, 2020:8).

5.3.1.2 Socially focused community development

A further taxonomical observation indicates the need for community development, social engagement and system service provision advancement that could be approached in a collaborative manner. After establishing the vital need for integration in the SES system of Hatfield, the applicable stakeholders and their differentiating roles are considered. The educationally focused Hatfield precinct with its established educational entities could be utilised by integrating Hatfield's social dynamic through ensuring accessibility, activating community recreational places and supporting social restaurants, events and recreation that promote socio-economic sustainability and quality of life.

5.3.1.3 Sustainable systems development

Looking specifically at the retail and commercial typology classification, system servicing collaboration on the provision of SES systems services could be established. The goal should include promoting the sustainable development of economic systems. This is vital to ensure SES as it is a vital determinant of successful economic entity activation and evolvement to ensure the positive processing of sustainable development (Pakhucha *et al.*, 2023:1). Furthermore, the development of SES system strategies aims to conserve resources by limiting consumption, which directly relates to tackling issues in our surrounding environments such as recycling campaigns (Imbroscio, 1995:841).

5.3.2 SES Systems Integration

After establishing the typological and taxonomical need in Hatfield's soft infrastructure, a framework of factors for SES system development is discussed. In the process of DTC readiness, the understanding of soft infrastructure of Hatfield and its need contributes to comprehensive DTC development.

Looking at the publicisation processes, including that of private space, it becomes apparent how integrating systems can offer real benefits and a tremendous net gain to society through

new waves of innovation and entrepreneurial energy. The integration and collaboration between different stakeholders and entities may contribute to the development and management of vibrant, diverse and interconnected contributions to the public realm. These will ultimately contribute to benefits of health, well-being and viability of the SES system (Carmona, 2022:133,135,140,148; Han *et al.*, 2019:1).

The integration of systems in an SES system would contribute to the sustainable development of both the social and economic systems in the soft infrastructure of Hatfield.

5.3.2.1 Conditional integration factors for success

The following principles aim to promote sustainable SES systems development. Partnerships between different stakeholders of publicly or privately administrated systems are only fully advantageous to the development of cities if there is a complete attempt to meet the elements of sustainability. Furthermore, the public realm of communities and citizens could be considered for integration to be fully advantageous, otherwise systems and spaces are created that are labelled as non-local to the society, rendering these underutilised or redundant (Carmona, 2022:135; Ntakana & Mbanga, 2020:3).

Accountability mechanisms have to be designed carefully, and all stakeholders – both the public and private parties involved – have to commit conclusively to prioritise and safeguard their aspirations (Ntakana & Mbanga, 2020:4,6). Accountability measures could include neighbourhood and citywide public participation programmes for promoting the understanding of the stakeholders and rejuvenating the existing city infrastructure (Ntakana & Mbanga, 2020:8).

Again, focus could be on collaborating and integrating the hybrid systems of development between not only the public and private entities but also partnerships between universities, non-governmental organisations and development institutions (Carmona, 2022:138; Ntakana & Mbanga, 2020:8).

5.4 The Contribution of the Framework to DTC Readiness in Hatfield

The fourth subsection lastly discusses how the SES typology and taxonomy framework contributes to viable digital twin readiness for Hatfield use cases. From a socio-economic perspective of understanding the nature of systems of SES, digital twins could be created to service local socio-economic needs.

For example, one clear need is integrating the SES systems into Hatfield. Therefore, a digital twin could be developed to promote the collaboration of the systems servicing the SES of Hatfield by creating an integrated social engagement between sports and recreation parks and restaurants and social events. Another example is the need for collaboration between healthcare servicing systems and social engagement. The added bonus of mental health and well-being will even better service the soft infrastructure SES in Hatfield.

With this research study focus being understanding the SES of Hatfield, it became evident that the specific urban dynamics of Hatfield should be considered when constructing a DTC. This understanding highlighted the importance of integrating systems and services to support SES development. The parallel importance of integration in the development processes and application considerations for DTCs with the same goal of supporting SES development will be unpacked further below.

With the first step of addressing the technological difficulties of digital twin development, the initiation of DTC construction could address the transparency in which data and resources are documented and communicated (Charitonidou, 2022:7). Consequently, the challenge lies in the fusion of GIS and BIM to analyse, integrate and visualise city-scale multi-source data challenges (Shahat *et al.*, 2021:10). This fusion and transparency of data sharing in the public-private sector is of utmost importance if a common goal of a socio-economically secure Hatfield is to be reached. In the built environment of DTC creation, dispersed asset and data ownership and the lack of data sharing frameworks complicate the data integration challenge even further (Nochta *et al.*, 2021:3).

The principle of transparent data sharing and integration between DTC development processes is to be supported further by the transparent data sharing and integration of processes of development of the end user. In this case, it includes the socio-economically active citizen in Hatfield who requires public entities, spaces and systems to contribute to the socio-economically secure social fabric of Hatfield. This DTC development process considers the inclusion of participatory human-centred behavioural analysis by the citizens who use them for decision-making processes in urban planning, including geo-design and agent-based simulations (Charitonidou, 2022:2,7; Nochta *et al.*, 2021:5,6; Ye *et al.*, 2023:6).

6 Conclusion

This study contributes to DTC readiness of soft infrastructure understanding by specifically investigating the Hatfield context as an example of South African local urban environments for the advancement of socio-economic systems understanding as a driver for developing DTCs.

Through GIS mapping of the SES system of Hatfield, a soft infrastructure understanding of Hatfield's social and economic urban dynamic was constructed in the ArcGIS online world. This contributes to gaining an understanding of the factors, informants and data sets to be included in the comprehensive development of a DTC.

In conclusion, this research study answered the research question of how understanding the SES of Hatfield's soft infrastructure contributes to relevant digital twin use case readiness as follows: the understanding of Hatfield's soft infrastructure indicated that citizen-centric social engagement with the SES systems of Hatfield and the integration of these systems in a cohesive manner create a thriving SES system. This contributed to the identification of the integration requirement of DTC development processes in its data acquisition and application processes. The integration of processes and systems is necessary to incorporate the soft infrastructure of Hatfield into relevant DTC use cases.

Understanding soft infrastructure is complex because of the intricate workings of a city – specifically the moving patterns and preferences of citizens. The unstructured and complex data sets of the soft infrastructure of the city opposed to common hard infrastructure data sets such as BIM modelling define the success of a DTC. Without including the social and economic systems in the development of a fully matured and comprehensive DTC, informed urban management and development policies and decisions will not happen. It simply would not be possible to measure the success of a DTC applied in the physical world if the encompassing social and economic systems in relation to the infrastructure systems are not included in the development of the DTC model.

The context of South Africa as a developing country, and specifically Hatfield's urban context as in this research study, acts as valuable context for investigating and understanding soft infrastructure. The changing nature of the socio-economic system of Hatfield with its great number of variables creates a complex system of informants. This together with the variability of informants lead the research findings to start grasping the complexity of the composition of soft infrastructure data. The complex set of soft infrastructure data further demonstrates that all the variables have a different influence on the nature of the urban system.

Due to the limitations of the research study, a more in-depth investigation of Hatfield's SES system has not been exploited yet. Further discussions on the complex system of informants and variables and further investigation of variables and elements of the soft infrastructure system of a local urban context are recommendations to be investigated. The complexity of investigating soft infrastructure data has been established, which could furthermore be seen as a highly challenging or motivating challenge.

The principle of social and economic integration of systems and citizens leads to the recommendation of adopting the point of interaction of systems in a city or rather integrated systems including the citizens in an urban context as the initiator for further research. Understanding the interrelationship between the citizen and its environment is where the success of a DTC lies.

In building cities for the people, by the people, a socially, economically and sustainably content city could be the environment we are now only aiming to create.

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