DIT 801

Research Report

Food and the future:

Mapping Food Security for Urban Digital Twin

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ARTICLE INFO

Keywords:

'Food security'
'Urban Digital Twins'
'UDT Readiness'
'Mapping'
'Metrics'

Programmes (Tools) used to ArcGIS, Web of Science, Excel, Zotero

ABSTRACT

Urban Digital Twins (UDTs) have huge potential to initiate change but are not yet mature enough to be useable since many aspects of cities, such as social fabric, still need to be integrated within the models. In response to this critique, this study investigates a subset of the social fabric: food security. Food systems are an integral part of the social fabric of cities, influencing community health, culture and identity. This study has a dual aim: firstly, to explore how the social fabric of a city can be mapped and classified to be digital twin ready and ultimately add to the UDT and secondly, to comment on the food security of Hatfield. The study will define food security in a specific taxonomy within Hatfield's context and set the foundation for the research methodology. This report falls within the pragmatic paradigm. Within a pragmatic paradigm, the research design is expansive and uses a mixed methodology that integrates quantitative and qualitative data collection and analysis methods. The research methods include grounded theory, desktop research, GIS mapping, GIS analysis using comparative methodology, case studies and descriptive statistics. To support data analysis, ArcGIS and Web of Science were used as instruments for data collection and analysis. Hatfield is more food secure than initially believed, however, many possibilities exist to increase access. Since food security has four pillars, it is evident that Hatfield is food secure in some regards and food insecure in others. In terms of the availability of food outlets, Hatfield can be deemed food secure, whereas food security decreases in terms of nutrition. From the maps, two main concerns emerged: Lack of connectedness and lack of nutrition. Hatfield can be classified within the nuanced taxonomy as 'non-stable, but physical, and financial access to producer with less nutritional food'. Future research should consider mapping the average income and financial ability of residents to understand the affordability of restaurants in the area. Investigating each pillar of food security in more detail, including the cultural layer, would further enhance the understanding of food security in Hatfield. UDTs have the power to redefine African cities, igniting positive transformations. Through mapping and classifying the food security of Hatfield, profound insights have been gained into the methodology of mapping social fabric and the state of its food security.

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DECLARATION OF ORIGINALITY

I declare that the mini-dissertation, ‘Food and the future: Mapping Food Security for Urban Digital Twin Readiness’ which has been submitted in fulfilment of part 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 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: ……K LOOTS……

Date: …05.06.2023……

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1. Introduction

The rapid emergence of digital twin technology has transformed urban planning and design through data-driven approaches that focus on long-term solutions (Bertelli, 2019). One such solution is the development of Urban Digital Twins (UDTs). While UDTs as models are crucial tools in developing smart cities (Yossef Ravid & Aharon, 2022), it is important to identify their purpose and research goals to ensure their effectiveness. With the ability to address various global issues, including urban sprawl, climate change and housing security, UDT models offer a comprehensive understanding of the complexities of urban space (Saeed et al., 2022). Digital twins are copies of physical reality that exist to test on an exact duplicate of the actual reality object. In 1960, NASA pioneered the concept of digital twins by developing a remarkable exemplar during the Apollo 13 mission, which encountered a critical oxygen tank issue while in space. To overcome the logistical challenges of conducting tests on the actual spacecraft in outer space, scientists resorted to constructing a replica on Earth, referred to as a digital twin. This innovative approach allowed them to explore and validate theories and potential solutions without jeopardising the crew's safety or the mission's success. By creating an exact duplicate of the Apollo 13 spacecraft, the scientific team effectively replicated its operational characteristics, facilitating rigorous experimentation and enhancing the prospects of resolving the predicament in space (NASA, 2021). Urban digital twins offer a similar approach by building a virtual copy of a city to simulate urban theory and planning. This allows for real-life analysis and design testing within the urban world (Bertelli, 2019). Urban Digital Twins are built by mapping and researching real-life urban scenarios and spatial forms. The more data built into a UDT, the more accurately it represents the reality of a city. However, some researchers argue that UDTs do not adequately display the social fabric of cities, highlighting the need for further investigation into their importance within an urban context (Yossef Ravid & Aharon, 2022). While UDTs hold significant potential for initiating change, their current usability is limited due to the incomplete integration of various urban aspects into the models, including the social fabric (Yossef Ravid & Aharon, 2022). The social fabric is not mapped, measured, or analysed adequately to be digital twin ready.

In response to this critique on UDT development, this study will investigate a subset of the social fabric – the food system of Hatfield, Pretoria – to understand how to map and measure the social fabric for digital twin readiness through the lens of food security. Food systems are an integral part of the social fabric of cities, influencing community health, culture and identity (Reese, 2018). By analysing the current state of food production and distribution in Hatfield through a food systems lens, this study has several goals: firstly, to explore how the social fabric of a city can be mapped and classified to be digital twin ready and ultimately add to the UDT and secondly, to comment on the food security of Hatfield. By understanding the complexities of food systems, food security and data landscapes, UDTs could be more effective in addressing the needs and priorities of diverse urban communities regarding food and nutrition. Specifically, this study's findings could help better inform UDT use cases by providing insight into the multifaceted methodology of mapping the social fabric attributes, such as the food security of urban environments.

The lack of social fabric within UDTs is the gap within the discourse contributed to by investigating how social fabric such as food security is mapped and measured. The scarcity of social fabric data in most UDTs has emerged as a prominent research problem, hindering digital twin readiness (Yossef Ravid & Aharon, 2022). The significance of this study lies in its contribution towards obtaining valuable social fabric data essential for an accurate Hatfield digital twin. By investigating the mapping and measurement of the social fabric, particularly in relation to food security, we address a critical gap in the discourse surrounding UDTs. As such, the study provides insight into the methodology of mapping the complexity of the urban social fabric. The findings of the study help inform better digital twins use cases, particularly concerning food security needs

and priorities of diverse urban communities. Finally, the study provides insights into the food security of Hatfield, which could inform policy and decision-making regarding food production and distribution in the city.

The report is structured as follows. The first section will set out the background, aim and purpose of the study. The next section is the scoping literature review setting out the current discourse regarding food security, UDTs, and the mapping of the urban social fabric. Following the literature review, the context and design will contextualise the study and lead to data collection and analysis. Finally, a discussion and reflection on key findings and learnings will answer the research question.

1.1 Background

It is important to define certain terms and core ideas for this study. As such, please refer to TABLE 1.0.

Definition	Description	Source
Urban Digital Twin (UDT)	A UDT is a virtual replica of an urban environment incorporating diverse data, enabling simulation and testing of theories for urban planning, development, and implementation.	(Bibri, 2019; Bertelli, 2019; Marcucci et al., 2020)
Social fabric	Social Fabric encompasses the interconnected web of human relationships and interactions within a network or system, encompassing education quality, poverty rates, and food security.	(Shetty, 2020)
Food security	Food security involves reliable, physical, and economic access and availability to nutritious and affordable food at any given time.	(Bertelli, 2019)
Digital twin readiness	Digital twin readiness refers to digital mapping and classifying urban data to construct a UDT, enabling accurate predictions and informed urban policy-making.	(Author, 2023)
Nutritious food	Nutritious food encompasses a variety of food groups, rich in beneficial nutrients and minimises harmful elements, contributing to growth, overall health and optimal functioning of the human body.	(Hendriks et al., 2021)

Table 1. Table defining core ideas for this study. (Author, 2023)

1.1.1 Core concepts

This section presents a concise definition of five key terms essential to the study's subject matter. A shared conceptual framework is established by clear definitions, fostering a better understanding of the subsequent discussions. These terms have been carefully chosen for their relevance and significant impact on the study's objectives.

Urban Digital Twin (UDT) refers to a virtual replica of an urban environment that includes a broad range of data, such as physical forms, environmental factors, and social characteristics. This virtual model can test theories and simulate changes before implementation in the real city environment, providing a powerful tool for urban planning and development (Bibri, 2019; Bertelli, 2019; Marcucci et al., 2020).

Urban digital twins require reliable data, and a crucial element of the social fabric that is particularly relevant is food security. Food security reflects the social aspects of a city and serves as a clear indicator of its needs,

behaviours and well-being. By incorporating food security data into UDTs, urban planners can better understand and address the city's requirements. This study focuses on food security to explore how social fabric data can be integrated into UDTs and how a subset of social fabric can be mapped. This understanding is essential for constructing purposeful and effective UDTs.

Social Fabric is what facilitates, consists of and unites human relationships and interaction. Any network or system within a system that directly associates with people is regarded as a social fabric, e.g., quality of education, poverty rate and food security (Shetty, 2020).

The study specifically focuses on the food system as a subset of the social fabric:

Food security involves the reliable, physical and economic access and availability for all people to nutritious and affordable food at any given time (Bertelli, 2019).

Nutrition is a key pillar of food security; therefore, it is important to understand what is meant by nutritious food.

Nutritious food includes all food that provides beneficial nutrients to the human body for growth, overall health and functioning while minimising potentially harmful elements (e.g., excessive sodium, sugars and saturated fats). A nutritious diet/meal includes as many food groups (carbohydrates, proteins, amino acids, fats, vitamins, minerals, dietary fibre and water) as possible (Hendriks et al., 2021).

To enhance the effectiveness of UDTs, it is crucial to appropriately map the data in a digital format, ensuring its readiness for UDT utilisation. This process is referred to as achieving digital twin readiness.

Digital Twin Readiness,
in this report, is assumed as urban data that is successfully mapped and classified digitally, which can be used as accurate information for building a UDT. This UDT is more mature and can aid in making accurate predictions and informing policy-making for urban areas (?, 2023). *I did not get this from a paper. I made this assumption…*

This section has presented concise definitions of key terms essential to the study's subject matter. By establishing clear definitions, subsequent data collection, analysis and discussions can occur. These carefully selected terms, including UDT, social fabric, food security, digital twin readiness and nutritious food, are relevant to the study's objectives, forming the basis for integrating social fabric data into UDTs and mapping a subset of the social fabric. Understanding these terms is vital for constructing purposeful and effective UDTs, which serve as valuable tools for urban planning and development.

1.1.2 Urban Digital Twins around the world.

Urban Digital Twins are crucial in urban planning and management. They aid in creating 3D virtual models that simulate different design scenarios, allowing planners and architects to assess the impact of proposed changes on the urban environment (Bertelli, 2019). Urban Digital Twins also contribute to infrastructure management by monitoring performance, identifying maintenance needs and optimising transportation systems. By analysing traffic patterns, public transportation routes and pedestrian flows, UDTs help identify areas of congestion and improve overall urban mobility (Ketzler et al., 2020). Overall, UDTs provide a comprehensive approach to inform decision-making, enhance infrastructure management and optimise the urban design and transportation systems (Bibri, 2019; Bertelli, 2019; Marcucci et al., 2020).

Building an accurate UDT requires a comprehensive understanding and a multidisciplinary approach towards the physical, environmental and social characteristics of the urban environment (Yossef Ravid & Aharon, 2022; Marcucci et al., 2020). This includes gathering data on the physical infrastructure, environmental factors such as climate and water resources, as well as social characteristics such as population demographics and food systems. This report will not investigate or build digital twins but recognises the importance of social fabric within future UDT studies. A useless UDT is irrelevant. Investing resources into a UDT is only valuable if the UDT can shape real and significant change within a city. If a UDT lacks social fabric, it does not accurately represent the real-world city leading to a skewed UDT. Bridging the gap by investigating how social fabric translates into use cases is valuable for the accuracy and impact of the discourse (Yossef Ravid & Aharon, 2022; Marcucci et al., 2020).

In the study of Hatfield, the aim is to explore the mapping of the social fabric in a city with the goal of constructing a UDT. Presently, conducting comprehensive and basic mapping of the physical and structural aspects of Hatfield, which are digitally twin ready, is relatively straightforward. These tangible elements of the urban landscape are easily replicable and understandable in digital format. However, the social fabric of Hatfield represents an invisible urban landscape characterised by diverse interpretations, complexities and nuances. For instance, examining the social fabric through the lens of food involves various interconnected factors such as access, affordability, cultural practices and community dynamics.

This report contributes to the development of social fabric data in Hatfield, aligning to create a comprehensive and sophisticated UDT for the area. The limited availability of social fabric data in Hatfield currently constrains the full potential of UDTs. However, by addressing these challenges and solutions based on real-life social fabric concerns, UDTs become more valuable to the local community in the future. Moreover, this report establishes a precedent for mapping various subsets of the social fabric in Hatfield and other cities, such as social capital data, spiritual data and poverty, among others. Changes pertaining to food security in urban environments can be tested and simulated by utilising UDTs, incorporating social characteristics and environmental factors. This integration enables digital twins to offer insights into enhancing food access and availability within communities. Furthermore, understanding the diverse components of an accessible and nutritious diet informs the development of sustainable and resilient food systems that foster food security.

In the context of South African cities, implementing needs-driven UDT solutions holds significant promise. By prioritising the unique challenges and requirements, needs-driven UDT solutions can effectively address critical issues and drive sustainable development. These explanations could enhance urban planning, infrastructure management and service delivery, ultimately improving the quality of life for residents and promoting inclusive and equitable urban growth (Bertelli, 2019).

1.1.3 Urban theory with regards to food systems

Urban theory, particularly Farr's (2018) concept of ‘Sustainable Urbanism’, emphasises the importance of a walkable and integrated city where residents can access essential services within a short distance. This theory promotes holistic environmental, economic and social sustainability. The concept of a ‘15-minute city’ or Continuous Productive Urban Landscape Strategy (CPULS) aligns with the need for sustainable and ethical food systems to improve food security and the social fabric of urban communities (Viljoen, Bohn & Howe, 2005; Cardoso et al., 2017). Nutrition, a key aspect of food security, encompasses the consumption of diverse food groups that provide beneficial nutrients for overall health and functioning while minimising harmful elements (Hendriks et al., 2021). The link between food security and urban social fabric is significant, as access to nutritious food positively impacts individuals' physical and mental well-being, contributing to a healthier population and stronger social cohesion (Gamba et al., 2021). Moreover, a reliable and sustainable food system enhances community resilience, fosters local economic development and reduces dependence on external resources. In this context, nutrition is central to addressing food security challenges and improving the social fabric of urban environments. By prioritising nutrition and developing sustainable food systems,

policymakers, urban planners and stakeholders can positively shape the social dynamics of cities and promote overall community well-being.

In this narrative, nutrition is central to promoting food security and improving the urban social fabric. A nutritious diet, consisting of diverse food groups and beneficial nutrients, is essential for supporting individual health and overall community well-being. By understanding and addressing the food security challenges within cities, policymakers, urban planners and stakeholders can develop sustainable and resilient food systems that prioritise nutrition and positively impact the social fabric of urban environments.

1.1.4 Urban Digital Twins for urban food security

As cities expand at an alarming rate worldwide (Farr, 2018), a concerning issue is the emergence of food deserts and the neglect of the importance of urban planning. In South Africa, there are many carelessly designed cities and suburbs. Rapid urbanisation is a reality in South Africa (Habitat Landscape Architects, 2020). Factors such as population growth, rural-urban migration and inadequate infrastructure can lead to ad hoc development patterns, leading to a divide between food supply and demand. The segregation of cities and food creates pressure and dependency on external food sources to feed the urban population. A food desert is an urban area with limited access to affordable and nutritious food, often lacking nearby grocery stores or fresh food markets. This scarcity of accessible options can lead to food insecurity and negative health outcomes, particularly in low-income communities (Gamba et al., 2021).

The impact of urban sprawl on the availability of nutritious food, commonly referred to as the urban food desert discourse, is a significant concern with environmental implications (Cafiero et al., 2014). This report aims to illustrate the reality of food security within a dense, fast-growing, urban environment – specifically focusing on the financial and physical access to fresh, healthy food in cities (Cafiero et al., 2014). In the case of Hatfield, a rapidly expanding precinct with a high demand for food, the flawed food system becomes evident through its reliance on external sources, the presence of food-insecure residents and the prevalence of costly and unhealthy fast-food establishments (Habitat Landscape Architects, 2020).

Given the demonstrated capabilities of UDTs in theory testing, urban prediction and simulating future scenarios (Bibri, 2019; Bertelli, 2019; Marcucci et al., 2020), it is reasonable to assume that UDTs can also apply to the domain of food security. The hypothesis posits that a UDT incorporating useable food security data, thereby achieving UDT readiness, can effectively capture and represent the current reality of a city, including food security. Consequently, such a UDT can serve as a diagnostic tool for identifying prevailing food security challenges in urban areas and testing potential design solutions to address these issues.

Based on the background information provided, it becomes evident that UDTs have a significant impact, food security holds great importance in shaping the fabric of cities, and UDTs can serve as valuable tools for diagnosing and researching food security within urban areas.

To achieve this, it is essential to accurately map and measure the current state of food security, which brings us to the primary purpose of this study:

1.2 Purpose and aim of the study

The primary objective of this research report is to examine the process of mapping, measuring and categorising the social fabric of a city as valuable social data for UDTs. Specifically, the study aims to enrich the available data for the UDT by effectively mapping and classifying the food security situation in Hatfield. Furthermore, it seeks to explore potential applications of this data in relation to the social fabric of the city. The goal of this investigation is twofold: first, to scrutinise the methodology employed in mapping the social fabric, and second, to classify the food security status of Hatfield with the intention of integrating it into the

UDT, thereby enhancing the model's accuracy. Consequently, the outcome of this research will be a more refined digital representation of the city's social fabric within the UDT framework (Charitonidou, 2022). Therefore, this study demonstrates the feasibility and value of developing UDTs from a social fabric perspective instead of focusing solely on structural aspects.

1.3 Problem Statement

Urban Digital Twins present a large potential to contribute to data-driven design within urban environments. However, most of these models are not mature enough and do not encompass the social fabric of a city (Bibri, 2019). As such, it is necessary to unpack/deconstruct the complexity of the social fabric into subsets of data to feed into a UDT. In response to the critique that UDTs lack social fabric data, it can be concluded that the current UDTs may not be fully effective (Marcucci et al., 2020; Al-Sehrawy et al., 2023; Charitonidou, 2022). The critique regarding the lack of useful social fabric data in current UDTs implies that these may not be effective in addressing real-world needs and challenges. This report contributes to the discourse on UDTs by investigating how social fabric data can be translated and utilised as drivers for UDT use cases, aiming to enhance the effectiveness and applicability of UDTs in addressing urban complexities such as food security (Bibri, 2019; Marcucci et al., 2020; Al-Sehrawy et al., 2023; Charitonidou, 2022).

1.4 Research Framework

1.4.1 Research Questions

This section presents the research question and two sub-questions that guide the investigation and provide a framework for exploring the key aspects of the study's subject matter.

Research Question: How can we effectively measure and classify food security within Hatfield to enhance its readiness for UDT implementation?

Sub-Question: What is the existing state of food security in Hatfield, considering factors such as access to nutritious food, affordability and availability?

Sub-Question: What are the implications and consequences of accurately measuring and classifying food security as a subset of Hatfield's social fabric? How does it impact the community's overall well-being and resilience?

By refining the research question, we can focus on understanding the current state of food security in Hatfield, explore its implications within the context of UDT readiness, and highlight the significance of accurate measurement and classification in fostering community well-being.

1.4.2 Limitations, delineation, and assumptions of the study

This study acts as a baseline for measuring the subset of the social fabric – food security of Hatfield and encourages further data collection and analysis of researched topics. The study has a cross-sectional nature, i.e., the data is captured at a single point in time. This limits the researchers' ability to determine temporal patterns. Longitudinal studies would provide more robust insights into changes in food security over time. Food systems fluctuate seasonally, and such studies are recommended as the next step. Furthermore, the study assumed food security to stand on four pillars: nutrition, availability, accessibility and stability. This study excludes other aspects of food security, such as utilisation, cultural preferences and considerations, quality and safety. This report focuses on *nutrition*, *availability, physical accessibility and financial*

accessibility, and these factors put human livelihood as most important. These factors were mapped and measured to determine food security taxonomies in Hatfield.

The report makes use of desktop studies and grounded theory. Grounded theory is a qualitative research methodology that aims to develop theories or conceptual frameworks from systematically collected data. It is particularly useful when exploring complex phenomena with little existing knowledge or theories. In the context of this report, grounded theory can be applied to gain an in-depth understanding of food security within Hatfield and its implications for UDT readiness. Grounded theory applied to mapping food security allows for a rigorous analysis of spatial data, enabling researchers to uncover meaningful insights, develop theories and contribute to understanding the complex dynamics of food security in a specific geographic context.

The application of grounded theory in exploring research questions involves several key steps. Firstly, data collection is conducted through observations, desktop studies and document analysis, relevant reports, policy documents and local data on food security. Next, open coding begins, wherein collected data, represented in digital maps, is systematically analysed to identify concepts, themes and patterns. Subsequently, axial coding is employed to establish relationships between codes, organising them into subcategories or dimensions, such as physical access, economic barriers, or community support systems within the broader category of food security. Finally, theory development takes place by constructing a conceptual framework or theory that explains the phenomenon based on the core category and subcategories. This theory emerges from the data and remains grounded in the empirical evidence collected during the research process.

2. Literature review

2.1 Review method

The social fabric, such as food security, is a complex issue to explore in order to answer the research question. A broad understanding of food security and UDTs is necessary to effectively map, measure and classify the social fabric of a city. Therefore, a systems approach has been taken to understand the food system, and from that, zooming in on food security can be seen as an outcome/result of the bigger system (Zhang, 2017).

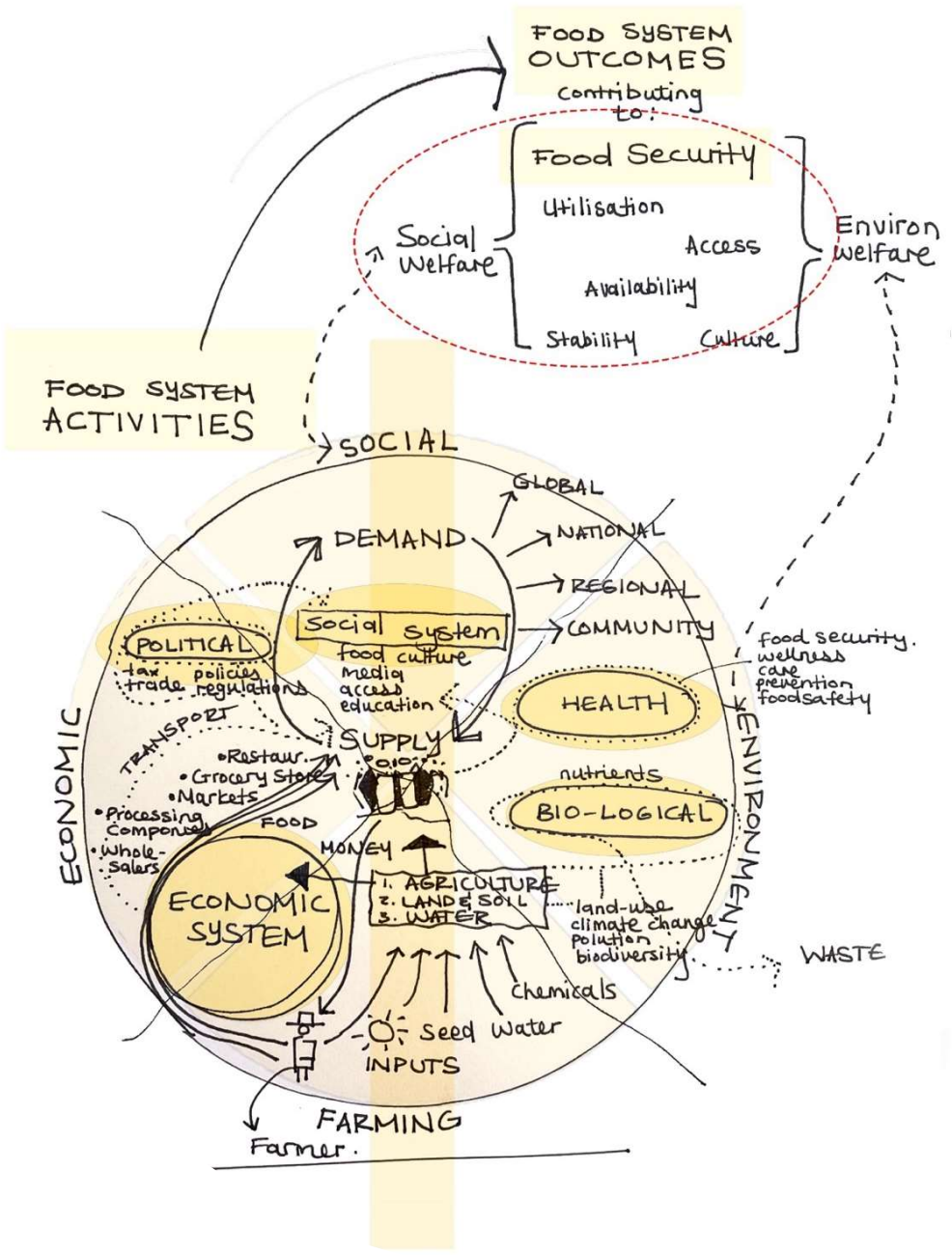


Figure 1. Diagram of general food system and focus area (Author, 2023).

Food system activities have been identified along with food system outcomes that contribute to food security (Zhang, 2017). The food system activities can be divided into four spheres: social, economic, environmental and farming as the base (production). Within these spheres, many smaller complex systems are present. These include economic, political, health, biological and social systems. None of these systems or themes can be studied in isolation, and therefore, before defining a focus area, it is essential to understand it within a larger system. Finally, an important linear aspect of the food system activities directly influences food security: inputs, supply and demand (Zhang, 2017).

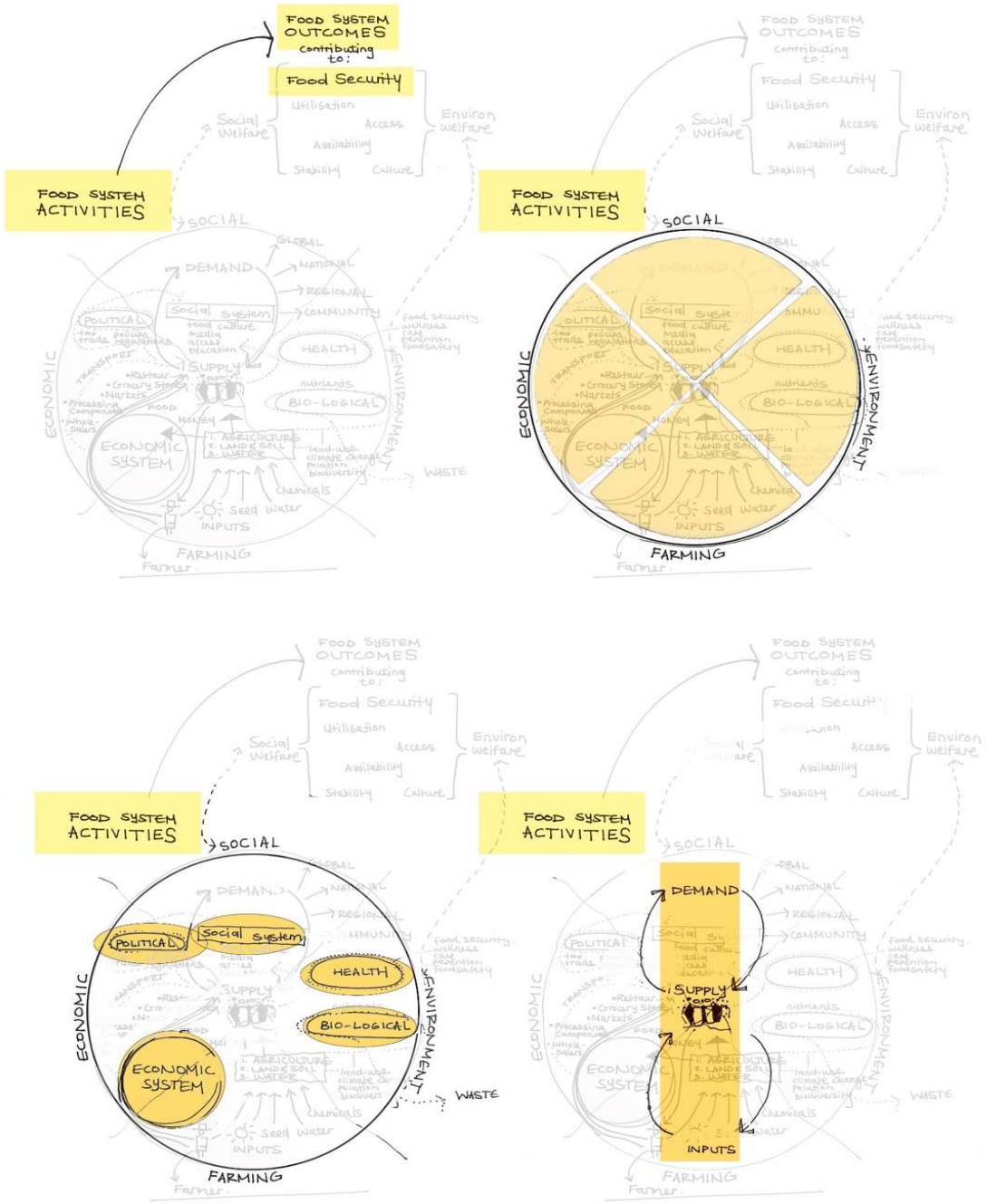
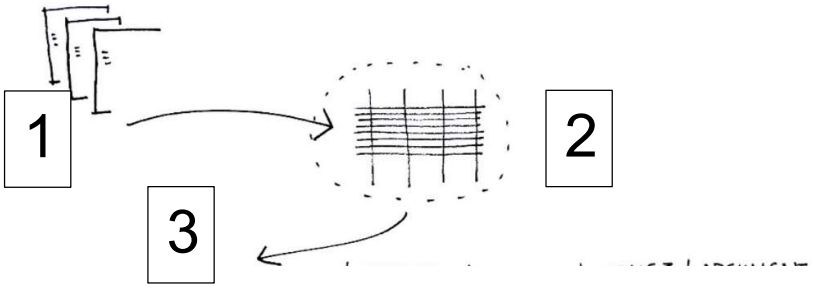


Figure 2. Diagrams of general food system and focus area altered to show certain aspects (Author, 2023).

Next, the literature review takes a systems approach to food security and identifies key themes organised based on individual arguments, research questions and themes from relevant literature. A total of 32 articles, all related to the main keywords in the research question, were included in the scoping review, the research question guided the evaluation, and the articles were classified according to their methodology, argument, or research questions. The review explored themes, cross-overs and contradictions, and the literature was categorised and discussed to inform the research methodology. Tables presented the findings, providing a structured overview of the selected literature and the sorting approach employed. The groups or themes were ‘food security in general’, ‘food security typologies’, ‘understanding and defining UDTs’, ‘measuring urban food systems’ and ‘food security’, and the ‘overlap between UDTs and food security’. The review is written and set out by grouping themes from different authors instead of by the author. This provides an integrated

knowledge set that includes different viewpoints, authors and arguments for each theme. Although there were limited South African examples, the literature offered general knowledge that could be adapted to the current environment of Hatfield. By synthesising the current knowledge and insights, this review contributes to understanding the current discourse and informs the subsequent research in the context of Hatfield.

In summary, the literature review comprehensively analyses applicable articles, including their country and time distribution. It provides valuable insights into key concepts and metrics related to food security and UDTs. The subsequent sections examine the details of each theme, starting with the literature on food security and then exploring UDTs and their relationship to food security, providing a roadmap for the rest of the study.



	RESEARCH QUESTION	ARGUMENT	THEME 1 (Food security in general)	THEME 2 (Understanding UDTs)	THEME 3 (Measurement)
READING 1					
READING 2					
…					
READING 32					

	RESEARCH QUESTION	ARGUMENT	**THEME 1 (Food security in general)**	THEME 2 (Understanding UDTs)	THEME 3 (Measurement)
READING 1					
READING 2					
…					
READING 32					

4

Figure 3. Diagrams to indicate the literature selection and analysis process (Author, 2023).

The literature review proved very helpful in establishing the current knowledge base and status quo of food security, UDTs and the measuring and mapping thereof. It concluded that food security in urban areas refers to the availability, accessibility and utilisation of safe and nutritious food for individuals and communities, a vital component of the social fabric. Economic conditions, infrastructure, distribution systems and government policies influence food security. Food security involves satisfying nutritional recommendations and ensuring access to safe, culturally appropriate, and nutritionally adequate diets. While digital twin technology, such as UDTs, has primarily focused on the physical aspects of cities, there is a need to explore its potential in integrating social dimensions like food security. By mapping and measuring social fabric, including food security, UDTs can enhance urban management, inform policy-making and promote sustainable and equitable food systems. However, challenges exist in defining food security, addressing philosophical assumptions, integrating natural and social worlds, and accessing comprehensive data sets within UDT models. Overcoming these limitations and promoting the integration of mental and physical realities in UDTs can lead to more effective tools for urban planning and management, ultimately improving food security in cities.

2.2 Results of the literature review

- The following keywords were used:
  Urban Complexity, Urbanism, Social Planning, Data-Driven, Smart Sustainable Cities, Big Data, Analytics, Big Data Applications, Datafication, Urban Science, Food Security, Food System, Sustainable Development, Resilience, Circular Economy, Digital Twin, Measurement, GIS Mapping, Social Turn in the Field of Smart Cities, Innovation Labs, Developing Countries.

- The following database was used: *Web of Science, Google Scholar*

- The articles range from being written in 2012–2023

SEE APPENDIX B FOR LITERATURE ANALYSIS AND RELEVANT THEMES (RAW DATA)

2.2.1 Food security in general

Food consumption is a basic human need (Bertelli, 2019; Cardoso, 2017). In simple terms, urban food security refers to the availability, access and utilisation of safe and nutritious food continuously (Bertelli, 2019). Additionally, food security is having reliable access to enough food for an active, healthy life without resorting to emergency measures or going hungry. Food security is part of the larger social fabric, which concerns the availability and accessibility of resources necessary for individuals and communities to maintain their overall well-being. Factors impacting food security include economic conditions, infrastructure, distribution systems and government policies. A focus on food security is essential for promoting healthy and sustainable communities. Food security encompasses four facets: availability, access, utilisation, and stability (Bertelli, 2019). In 2016, Clapp (2016) stated that to increase food security, farmers should use methods and technology to increase productivity; although, ironically, the world produces enough food, most of the world remains malnourished, as Clapp (2016) noted. This highlights the need to shift our attention to *promoting sustainable and equitable food systems* prioritising access to safe and nutritious food for all rather than simply increasing production (Bertelli, 2019).

However, defining food security is a complex and highly debated issue, as it involves considering multiple food systems at different scales. According to Dorward et al. (2017), achieving food security also means

satisfying nutritional recommendations. However, Pothukuchi (2004) and Reese (2018) offer another perspective, defining food security as a situation where a community can access safe, culturally appropriate and nutritionally adequate diets through secure food systems. Jensen (2021) argued that access to food does not mean access to nutrition. It is also worth mentioning that required food/energy consumption differs in every region/country (Bertelli, 2019). Overall, it is not just about feeding those in need but requires more extensive attention to food systems and planning in cities.

Understand food security by its opposite is also helpful – food insecurity. Pothukuchi (2004) and Bertelli (2019) note that food insecurity is defined as a state of being hungry, and/or lacking access to adequate food, and/or worrying about the lack of food. This could mean not having access to a food outlet you can afford, living in a dense city or walking for miles without finding a place to buy food.

Food security also has many qualitative components that highlight the importance of cultural and social access to food (Grewal, 2012). For instance, in a multicultural city like Hatfield, the concept of food security extends beyond mere physical access to food. It encompasses considerations such as the availability of culturally appropriate food options, the preservation of traditional culinary practices and the ability of diverse social groups to maintain their food preferences and dietary customs. Reese (2018) further insists that systemic inequalities regarding food security cannot be solved by gardening. A simple urban farm not considered a part will not necessarily increase food security. Therefore, in terms of urban food security, people (culture), as well as urban space (form), need to be considered (Grewal, 2012; Reese, 2018).

Aspect	Summary
Definition of Food Security	- Food security refers to the availability, access and utilisation of safe and nutritious food always (Bertelli, 2019; Cardoso, 2017)
Factors Affecting Food Security	- Economic conditions, infrastructure, distribution systems, and government policies can impact food security (Bertelli, 2019)
Importance of Food Security	- Promoting healthy and sustainable communities requires a focus on food security (Bertelli, 2019)
Understanding Food Insecurity	- Food insecurity is the state of being hungry, lacking access to adequate food, or worrying about the lack of food (Pothukuchi, 2004; Bertelli, 2019)
Importance of Personal Self-Reliance	- Increasing personal self-reliance and social justice are essential in achieving food security in urban communities. (Grewal, 2012)
Qualitative Components of Food Security	- Food security includes qualitative aspects such as cultural and social access to food (Reese, 2018)
Diagram/Visual Representation of Food Systems	- A visual representation, such as a systems drawing, can help illustrate the concept of food systems and how they relate to food security within the larger social fabric
Importance of Sustainable and Equitable Systems	- Sustainable and equitable food systems should prioritise access to safe and nutritious food for all rather than solely focusing on increasing production (Bertelli, 2019; Clapp, 2016)

Table 2. Table defining core ideas for this study (Author, 2023).

This table connects the statements regarding various aspects of food security with their respective sources, including Bertelli (2019), Cardoso (2017), Pothukuchi (2004), Grewal (2012), Reese (2018) and Clapp (2016).

In conclusion, food security is a vital component of the social fabric, encompassing the availability, access and utilisation of safe and nutritious food. Achieving food security requires sustainable and equitable food systems prioritising access for all populations. Social factors play a crucial role in ensuring inclusive and diverse access to food.

2.2.2 Food security typologies

According to the literature, there are different food security typologies. Research has different food security models, and through the years and development of knowledge, these modules have shifted (Cafiero et al., 2014). The following table summarises the models:

Typology	Description	Reference
Food-first approach to a livelihood approach	Cafiero et al. (2014) propose a paradigm shift in addressing food insecurity by emphasising long-term community-based solutions that ensure sustainable access to food and prioritise equity and social justice. This holistic approach, involving community empowerment and addressing root causes, has the potential to create lasting change and improve the well-being of vulnerable populations.	Cafiero et al. (2014)
Regional food security to/from global food security	The concept of regional food security has gained prominence, highlighting the importance of smaller geographical areas producing, distributing and accessing sufficient nutritious food for their communities. This approach diverges from the emphasis on global food security, which focuses on international trade and enabling countries to engage in food trade. Regional food security represents a niche typology that prioritises the well-being of local communities.	Cafiero et al. (2014)
Urban food security and farmland food security	Urban food security moves away from farmland food security which segregates cities and rural areas. In the farmland food security system, cities import all dietary needs from rural areas, whereas in urban food security, a city can produce, distribute and sell food within the urban environment.	
Seasonal food security	Seasonal food security is a typology where a certain region is food secure for specific periods but depends on other regions for the other times of the year.	

Table 3. Table defining food security typologies (Author, 2023).

The development of food delivery services adds a layer to food security in terms of availability and accessibility, both financially and physically. The increasing popularity of restaurant delivery services among college students offers a potential solution to improve the food security status of those experiencing food insecurity (Gamba et al., 2021). These services eliminate the challenges associated with procuring, cooking and storing food, which is often a problem within student housing. Previous research indicates that certain students face difficulties obtaining food due to transportation limitations or disabilities, lack of confidence in their culinary abilities, or lack of cooking equipment. Additionally, limited storage space poses a challenge for some students (Gamba et al., 2021). However, since financial accessibility is equally important to food security as the other aspects, this also needs to be taken into consideration when evaluating food delivery (Bertelli, 2019). Food delivery services like ‘Uber’ and ‘Mr Delivery’ add a delivery fee to the meals they deliver, contributing to the affordability problem among students who are not academically active (Habitat Landscape Architects, 2020).

2.2.3 Understanding Urban Digital Twins

To understand how studying food security could help improve use cases for digital twins, it is helpful to understand UDTs. Digital twin is an emerging technology that has gained attention in recent years due to its potential to revolutionise urban management and design (Marcucci et al., 2020). While digital twins have primarily focused on physical aspects of cities, such as infrastructure, there is a need to explore their potential in integrating social dimensions like food security. By studying existing knowledge of digital twins, we can enhance their effectiveness by effectively mapping and measuring social fabric (in this case, food security) for digital twin readiness.

- Definitions and applications of UDT

A digital twin is a digital entity linked to a physical system, representing its functionalities through real-time data (Marcucci et al., 2020). It consists of three elements: real space, virtual space and the flow between the two worlds (Marcucci et al., 2020). This living innovation lab transforms the city into a data-driven entity through quantification and analysis. Its goals include enhancing urban management, shaping data-driven design, showcasing the potential of data, describing novel architecture and typologies of data-driven smart cities and providing accurate predictions for the future (Bibri, 2019; Bertelli, 2019; Marcucci et al., 2020). An accurate UDT is a complex, fully integrated and multi-scaled product as it is an exact virtual copy of a real-life city (Marcucci et al., 2020).

Digital twin technology can aid in understanding urban data, accurately predict the future and highlight the potential of data.

This table illustrates what other UDTs are doing worldwide: (Ketzler et al., 2020; Saeed et al., 2022).

Country	Problem	Use
Scandinavia, Helsinki	Climate change	Energy and climate atlas to analyse the number of costs and carbon dioxide emission impact scenarios
Scandinavia, Gothenburg	• Increased urbanisation • Segregation of city • Varying socioeconomic conditions • Climate change/sea level • Data management	Used for assessing scenarios and Addressing challenges that the city is facing
Rotterdam, Netherlands	Mobility and electricity issues	• Smart thermal grid • Smart parking and intelligent (electric) mobility solutions • Visualisation • GIS analyses • Citizen participation
Paris, France		• Urban planning and decision-making • Tool to communicate with local people
London, UK		• Viewing of dynamic interactive 3D city models • Add overlays such as sightlines, view management frameworks, transport links, and sunlight paths • Design and testing of the visual impact, scale and massing of urban interventions

		• Eye-level and bird's-eye views, weather and time, and connects 3D and GIS data • Risk management, urban planning and research
North America	Complex planning and development challenges.	• Analysing shadows and evaluating the impact of new zoning and development
China, India, Singapore		• Design proposals can be simulated, and the construction progress will be monitored in real-time • Traffic monitoring and simulation of both mobility and traffic • Digital zoning

Table 4. Table illustrating what UDTs are doing around the world (Author, 2023).

Critiques and limitations exist regarding UDTs, which are still considered an emerging technology. One major criticism is the absence of a clearly defined approach that clarifies the philosophical assumptions and practices adopted by practitioners (Al-Sehrawy, Kumar & Watson, 2023). Since digital twins are unique to each circumstance, studying them requires a nuanced understanding, as worldviews shape their construction and research outcomes. It is crucial to explicitly state the assumed worldview to ensure the reliability and validity of UDT predictions (Al-Sehrawy, Kumar & Watson, 2023).

Another significant critique revolves around the limited data sets within UDT models, particularly the lack of social fabric data. The importance of UDTs has shifted from a purely technical perspective to a socio-technical one, emphasising the integration of natural and social worlds, as highlighted by Charitonidou (2022). Urban Digital Twins should encompass both mental and physical realities to overcome this limitation, as advocated by Al-Sehrawy, Kumar and Watson (2023). Integrating mental and physical realities in UDTs allows for a better understanding of urban dynamics and facilitates more accurate simulations and predictions, aligning with the critical realism paradigm (Al-Sehrawy, Kumar & Watson, 2023). If these critiques are successfully addressed, a UDT is a technology for the greater social good positively informing cities (Liu et al., 2023; Charitonidou, 2022).

In today's fast-paced and constantly evolving environment, it is crucial for city planners and policymakers to have access to suitable tools that enable them to conduct reliable, comprehensive and timely analyses of the potential impacts of
(a) technological changes,
(b) business model evolutions/innovations, and
(c) the spatial-temporal changes that these innovations may produce.
A UDT provides a means to describe, capture and simulate the policy implications (both real and potential) of alternative solutions in order to optimise them for a given objective or set of objectives (Marcucci et al., 2020).
Before a UDT can be utilised for policy-making, it is necessary to thoroughly map and measure datasets to construct an accurate and comprehensive UDT.

- Measuring urban food systems and food security

The goal of measuring food systems is to design effective strategies for achieving food security, as Pothukuchi (2004) highlighted. To effectively improve future food security using a digital twin model, it is crucial to have data that closely reflects the current reality. Food security is a common currency that has evolved from merely being about food supply to a complex and multi-dimensional understanding of utilisation, access and stability to food (Bertelli, 2019). The complexity that food security currently represents is more

accurate, but it is also the reason for the deceleration of policy-making regarding food security (Butaumocho & Chitiyo, 2017).

Measuring is essential in advancing our knowledge, particularly in understanding complex and multi-faceted topics such as the nature of urban food security. Poor measurement leads to poor policy designs; therefore, ensuring food security means measuring food insecurity (Butaumocho & Chitiyo, 2017. Borańtynska & Huseynov, 2017). However, there is limited research on food security measures and investigation of their relationships, which explains the poorly designed food systems in cities (Butaumocho & Chitiyo, 2017). Food security has mostly been studied by environmental or economic departments and rarely by design departments as a national/large-scale problem, neglecting the niched and qualitative nature of food security (Butaumocho & Chitiyo, 2017).

It is important to understand that the complex nature of food security lends itself to different measuring methodologies (Cafiero, 2014; Dorward et al., 2017). As Bertelli (2019) points out, food security has both qualitative and quantitative aspects, and the methodology used for measurement should reflect this. For example, qualitative measures could include assessing: food access and availability, affordability, food utilisation and perceptions of food security. The quantitative measures are listed in the table below, including a more in-depth psychological dimension in urban food security data collection, providing a richer understanding of food security challenges. However, this requires the researcher to be objective and avoid an invalid study because of the subjective nature and bias, which can easily exclude important factors (Kivunja, 2017).

To accurately measure and analyse food security data, it is necessary to define the region under consideration and the appropriate methodology for each aspect of food security (Vicente-Vicente et al., 2021). For example, in considering a national scale versus a neighbourhood scale that allows for niched, community-valued research (Cafiero et al., 2014). The paradigm of food security shifts through time (Cafiero et al., 2014); therefore, defining the paradigm within the specific study context is essential before data collection and analysis.

In the context of food security, it is imperative to consider the social construct of a region and its specific spatial group configuration. A social construct is a concept or category shaped by society through collective agreement and social interactions. This construct can encompass various aspects, such as different neighbourhoods, income classes, or gender groups. To ensure accurate measurement, researchers should define and delimit the region under investigation due to the nuanced nature of food security (Vicente-Vicente et al., 2021). This highlights the shift towards a regional food security paradigm, which prioritises the well-being of local communities (Cafiero et al., 2014; Vicente-Vicente et al., 2021).

While measuring discrete data through GIS mapping and censuses is crucial, using an index can summarise and compare complex sets of data (Cafiero, 2014). It is helpful to look at Dorward et al. (2017), who identified several dimensions of food security to build such an index. These include food expenditure, caloric availability and food diversity. By incorporating nuanced measurements and understanding the context, it is possible to measure and classify food security effectively and contextually.

Validated (quantitative) food insecurity measures include:

Measurement	Acronym	Unit	Reference
(Living Standards Measurement Study-Integrated Surveys on Agriculture)	LSMS-ISA	The measurement in this study can vary and encompass various indicators, such as income (in local or standardised currency), assets (number or value), agricultural production (e.g., crop yield in kilograms or hectares), and other socioeconomic variables (e.g., education level, employment status)	(Butaumocho & Chitiyo, 2017; Boratyńska, 2016; Bertelli, 2019)
(Household Food Consumption Score)	HFCS	Score index. The score may range from 0 to 100 or have other scaling methods to indicate the level of food consumption and nutritional quality	(Butaumocho & Chitiyo, 2017; Boratyńska, 2016; Bertelli, 2019)
(Household hunger scale)	HHS	Categorical scale with various levels indicating different degrees of hunger or food insecurity, such as 'severe hunger', 'moderate hunger', 'mild hunger', or 'no hunger'	(Butaumocho & Chitiyo, 2017; Boratyńska, 2016; Bertelli, 2019)
(Food consumption score)	FCS	Grams or kilograms	(Butaumocho & Chitiyo, 2017; Boratyńska, 2016; Bertelli, 2019)

Table 5. Table showing qualitative food security measures (Author, 2023).

To conclude, section 2.2.3 on UDTs establishes that UDTs can effectively test for future city design to ensure more appropriate and sustainable cities. However, a UDT needs to be complete and as close to the reality of the complex realities of a city as possible to ensure valid results and findings. Most UDTs lack social fabric that lowers accuracy and, therefore, the accuracy of the predictions and designs. Food security is both a cardinal need of humans and a subset of the social fabric required by any UDT. This report will map and measure the food security of Hatfield, increasing the presence of social fabric data use cases to add to the discourse of the possible UDT for the Hatfield precinct. Without linking contextual reality (spatial form) to behaviour (social fabric), it is impossible to understand the realities of an urban context (Marcucci et al., 2020). This report adopts a systems thinking approach, and the worldview of recognising the importance of social fabric is accepted. Data collection and analysis were derived from the literature. Food security and UDTs are both complex and subtle phenomena – therefore, detailed measurements are needed for an accurate index. There is no perfect index to determine food security, but a holistic multi-dimensional methodology that serves the specific precinct proves the most effective (Al-Sehrawy, Kumar & Watson, 2023; Butaumocho & Chitiyo, 2017).

3. Methodology

3.1 Research paradigm

Defining the research paradigm is important as it sets the study within certain margins to improve research quality and determine methodology. In the pragmatic paradigm, research focuses on addressing practical issues and generates actionable knowledge. It emphasises the application and usefulness of research findings in real-world contexts. When exploring the research question of food security in Hatfield for UDT readiness from a pragmatic perspective, the following mixed methods can be considered (Kivunja, 2017):

Pragmatic research often utilises mixed methods, combining qualitative and quantitative data collection and analysis techniques. In addition to conducting interviews and document analysis as in grounded theory, you may also consider surveys or statistical data to provide a comprehensive understanding of food security in Hatfield.

The research methods for this report include grounded theory, desktop research, GIS mapping, GIS analysis using comparative methodology and descriptive statistics. Open coding is a crucial step in grounded theory research as it helps to identify and organise the research data. To support data analysis, ArcGIS and Web of Science will be used as instruments for primary and secondary collection of literature. GIS mapping presents the opportunity to visually represent the relationships between metric data sets (quantitative) and social/qualitative data (qualitative). The researcher also relied on observational and field research.
Descriptive statistics summarise the findings on GIS maps in the analysis section. These statistics can identify patterns in the data, highlight any outliers or anomalies, and provide a better understanding of the distribution of data. Finally, the resulting maps will define a site-specific taxonomy of food security within Hatfield by using grounded theory.

By adopting a pragmatic perspective, the research on food security in Hatfield for UDT readiness takes a hands-on and problem-solving approach. The focus is on generating knowledge that directly contributes to practical solutions and improves the community's well-being. The research process is driven by the goal of positively impacting food security and urban development in Hatfield.

The following table summarises the key aspects of the research methodology and approach used in the study. It highlights the pragmatic paradigm, mixed methodology, data collection methods, instruments used, ethical considerations, research boundaries, focus areas, the importance of metrics, the four pillars of food security and the primary focus of mapping availability, access and nutrition.

Aspect	**Summary**
Research Paradigm	Pragmatic paradigm
Methodology	Mixed methodology, integrating quantitative and qualitative data collection and analysis methods
Epistemology	
Data Collection Methods	Grounded theory, desktop research, GIS mapping and analysis, case studies, descriptive statistics, observational and field research
Instruments Used	ArcGIS, Web of Science
Ethics	No direct ethical concerns due to the use of spatial and published data
Research Boundaries	Limited to Hatfield as defined in the Hatfield precinct plan
Focus	Spatial, hard data, published journals, precinct plans and case studies
Importance of Metrics	Metrics help define taxonomies and typologies of self-reliance for accurate analysis of food security in Hatfield
Four Pillars of Food Security	Availability, access, utilisation and stability
Primary Focus	Mapping availability, access and nutrition in relation to food security

Table 6. Table showing research design (Author, 2023).

The research is limited to the boundaries of Hatfield as indicated by the Hatfield precinct plan (Habitat Landscape Architects, 2020). Considering limitations and approaching urban mapping and data collection with a critical and nuanced perspective is essential. The importance of defining metrics is to clearly outline the taxonomies and typologies of food security of Hatfield. The table assisted in understanding the research process since it highlights certain aspects of the framework. This study investigates measuring food security in urban areas for UDT readiness, which rests on the four pillars of availability, access, utilisation and stability (Bertelli, 2019). Food security will also decrease if any of these four pillars decrease (Bertelli, 2019).

3.2 Study context

This study focuses on food security in urban areas, and the Hatfield Precinct in Pretoria, a dense urban precinct, has been selected as the study area, which is 197 ha in size. An institutional precinct like Hatfield is ideal for testing and developing emerging ideas and technologies, such as UDT models, because of the predominantly student demographic (Habitat Landscape Architects, 2020). Also, Hatfield has unique characteristics and population, which includes the University of Pretoria and a high concentration of tertiary students, and its location parallel to a tertiary institution. Most of the students are between 18 and 24 years of age. Hatfield is a precinct sandwiched between contrasting precincts resulting in a diverse population regarding income, culture and background. With a population of approximately 50,000 residents, Hatfield is located on the East of Pretoria CBD, Arcadia and Sunnyside and is marked by Kirkness Road (Western boundary), Stanza Bopapa Street (Northern side), Brook Street (Southern boundary), and the LC de Villiers/Experimental farm boundary (N4, Farmers, and Folly Street respectively) (Habitat Landscape Architects, 2020).

Due to the presence of an internationally credited university – the University of Pretoria – most people living in Hatfield study and temporarily live in student housing during their courses. Many people also travel daily to Hatfield from other neighbourhoods. The precinct is vibrant and social, even though the students are mostly not economically active and have low to zero income (Habitat Landscape Architects, 2020). Many social hubs, bars and dance clubs have moved out of Hatfield, decreasing the student spirit. Hatfield has many fast-food restaurants, student-orientated retail shops and restaurants, and a strong informal food trade sphere. Most of Hatfield is privatised and fenced off, with few public spaces. Uniquely, Hatfield has two active urban farms. Within the centre, a relatively small urban farm is open to the public. This site acts as a rehabilitation centre for people with drug addictions. To the east of Hatfield, there is a large experimental farm that belongs to the University and is utilised by students for research and projects. There are livestock as well as food production on site. The experimental farm is an asset to Hatfield that celebrates and researches nature in various forms.

There is currently much research being done regarding a potential UDT of Hatfield. This academic momentum is useful for research regarding the development of UDTs. There is a wide range of economic privileges vs disadvantages in Hatfield, and many students are food insecure. Since Hatfield mostly consists of students, there is a strong seasonal difference in food security since there are periods where there is no student activity in the holiday months; January, June and December. This counters a risk to the stability of food security, one of the four main components of food security (Bertelli, 2019).

Figure 4. Photo showcasing formal food outlets in Burnette Street, Hatfield (Author, 2023).

Figure 5. Photo showcasing aerial view of the University of Pretoria, Hatfield (University of Pretoria, 2023).

Figure 6. Photo showcasing street view of informal trade on Festival Street, Hatfield (Google Earth, 2023).

Figure 7. Photo showing Urban Farm, Modja Gebeni, in Hatfield on Festival Street, Hatfield (University of Pretoria, 2023).

Figure 8. Photo showing Experimental Farm in Hatfield (Habitat Landscape Architects, 2020).

Figure 9. Photo showing Old Arts Building and students on the University of Pretoria Campus (University of Pretoria, 2023).

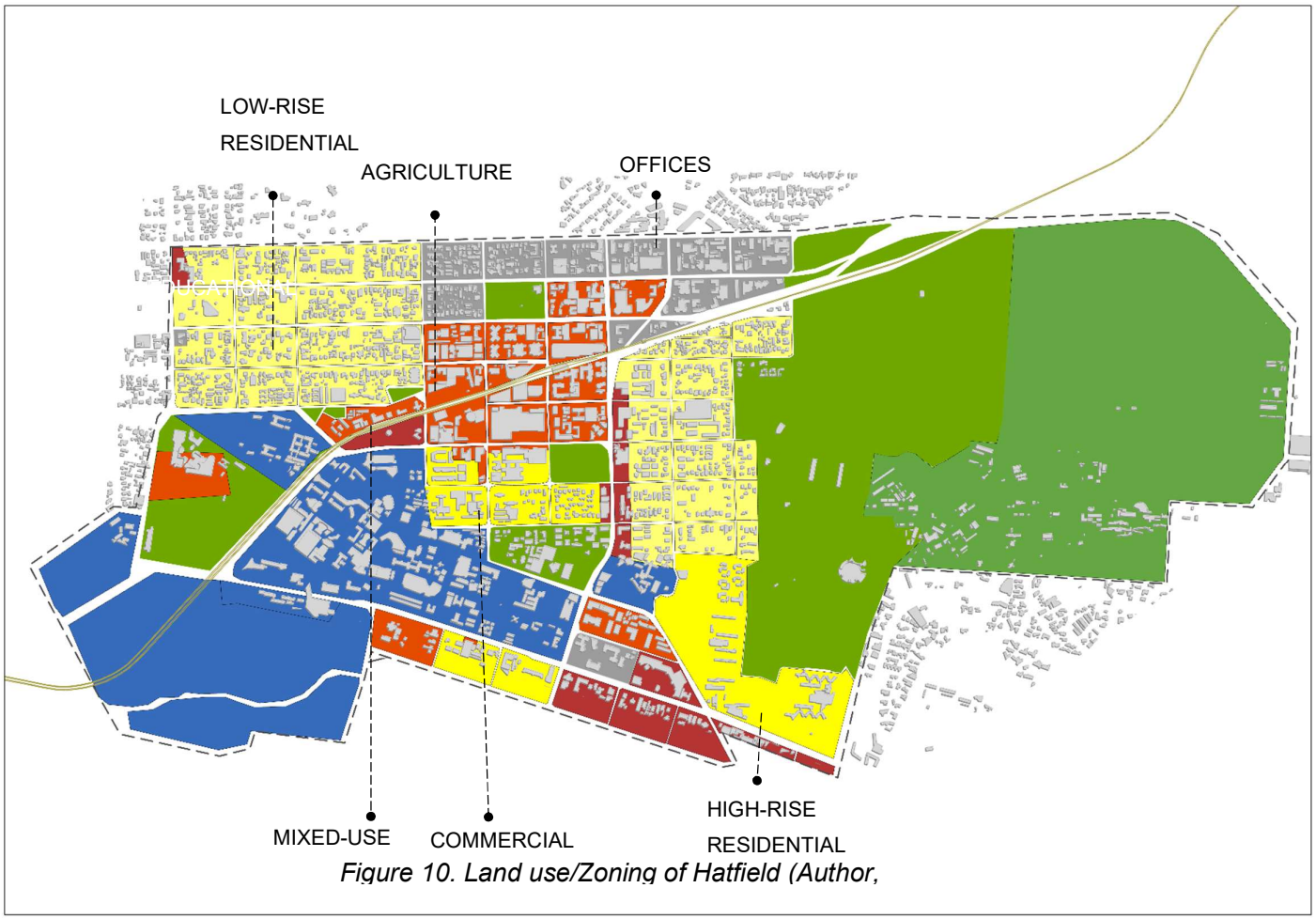


Figure 10. Land use/Zoning of Hatfield (Author,

Hatfield has educational, sport, agricultural, mixed-use, high- and low-rise residential, and commercial zoning and is regarded as a high-density city (Habitat Landscape Architects, 2020). How a city is zoned can shape the physical environment and determine the availability and accessibility of various resources and amenities. For example, the location and distribution of residential zones can affect the housing options and neighbourhoods available to different socioeconomic groups, influencing social segregation or integration (Habitat Landscape Architects, 2020). Zoning can also impact access to essential services, such as schools, healthcare facilities and recreational spaces, further contributing to social disparities.

Moreover, zoning policies can influence the development of public spaces, transportation infrastructure and community facilities. The design and layout of Hatfield allow for social interaction within the inner core that increases connectivity and a sense of belonging, whereas some of the single-use zones could contribute to social isolation and fragmentation. The zoning of agricultural land is also significant regarding food security. In residential areas, single use can also lead to food insecurity because of low production or the presence of food outlets. Hatfield is home to a Gautrain station and a public railway station within the centre of Hatfield, resulting in a double railway line cutting Hatfield diagonally into two parts. There are many bus stops and an active taxi/public transport network providing a layered transport system due to the student population and the university as a destination.

Universities are regarded as a civilisation nucleus and a cultural centre. The connection between the communities and the university is central to achieving a holistic approach to local problems such as food security (Ngo & Trinh, 2016).

Considering the factors discussed above, the Hatfield precinct serves as a case study to explore and evaluate the food security situation within the city. Through mapping, measuring and understanding the various aspects of food security, such as access, availability and affordability of nutritious food, the study aims to assess the extent to which Hatfield can ensure its population's food security and thereby gain an understanding of the mapping and measuring of the social fabric for digital twin readiness.

Gamba et al. (2021) demonstrate that individuals who face food insecurity to various degrees tend to experience significantly worse physical and mental health outcomes compared to those who do not face food challenges. Among college students, marginal food security has been correlated with lower grade point averages, diminished cooking skills and food agency, poorer perceived health, higher body mass index and increased prevalence of depression (Gamba et al., 2021). This emphasises the importance of understanding food security in an environment with a high student population. Food insecurity potentially negatively impacts a student's future (Gamba et al., 2021). This emphasises the importance of the Hatfield precinct as a case study.

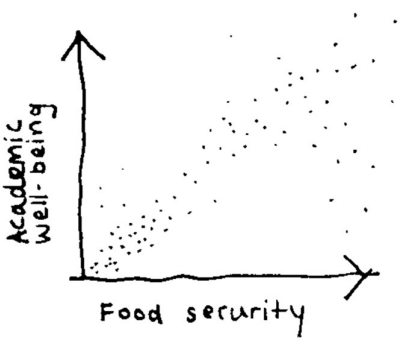


Figure 11. Diagrammatic graph showing relationship between academic well-being and food security (Author, 2023; Gamba et al., 2021).

3.3 Research Methods

3.3.1 Data collection and analysis

Data was collected through desktop studies and information available on the Hatfield precinct plan (Habitat Landscape Architects, 2020). Data was strategically grouped and mapped on a series of maps of Hatfield via ArcGIS to show the relevant layers of information regarding food security. Grounded theory was used to analyse this data and see patterns and gaps within the food system of Hatfield by layering maps and data over one another. This process led the researcher to see specific patterns, gaps and correlations. In understanding the food system of Hatfield as a whole, analysis of different data sets should be considered and analysed to understand the relationship between these data sets. Descriptive statistics aided in the analysis process. By using the tools on ArcGIS (overlaying, clipping and buffering) to analyse the data on the maps, these gaps and patterns emerged from the maps, shedding light on the four aspects of food security status used in this report in Hatfield. To increase the humanity of the analysis, detail spatial analysis was undertaken to understand the human-level spatial qualities of Hatfield. A typical street section was drawn to understand these qualities.

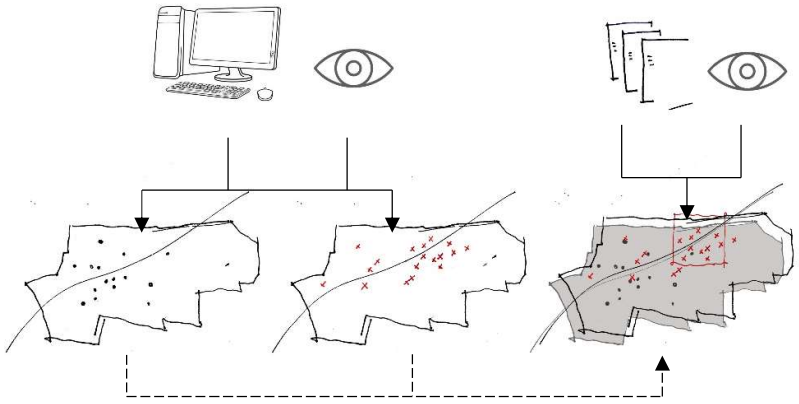


Figure 12. Diagrammatic representation of how maps were made and analysed (Author, 2023).

3.3.2 Metric design

The urban food security of Hatfield is measured based on Bertelli's (2019) definition of food security: 'The availability of local food sources and the ability of the community to produce, access, and distribute nutritious food.' Many aspects of the food system have been investigated to ensure a holistic and systemic understanding of the food system in Hatfield.

These aspects were chosen for analysis for two reasons:
1. It is the main component of the definition of food security and, thereby, the most fundamental information regarding the state of food security in a city.
2. Lives are critical, meaning survival is most important and takes hierarchy above all other aspects of food security. The availability and access to food are considered a primary need over cultural aspects while acknowledging the importance of culture regarding food but first analysing basic human needs.
The goal of the analysis is to see if the population in Hatfield is able to purchase nutritious food within walking distance of their residences, and it speculates that this method will give a clear indication of the state of food security in Hatfield.
The following table sets out how the different aspects of food security have been measured:

FOOD SECURITY	DESCRIPTION	METRICS (UNIT)
Availability		
Formal Food Source Availability	Number of formal food sources (i.e. restaurants, bars, food stores and food trucks, community gardens, among others)	Numeral (count)
Informal Food Source Availability	Number of informal food sources (i.e…..)	Numeral (count)
Financial Accessibility		
Food Accessibility: Financial	Average price on the menu of each food store outlet	Average R/meal/person (rand)
Physical Accessibility		
Food Accessibility: Distance	Distance from the main residential nodes to food sources	Kilometres (km)
Food Accessibility: Fenced-off private zones	Zones that are privatised and inaccessible to the public	Square kilometres (km^2)
Nutrition		
Food nutrition: local food content	Average nutrition of average meal at food producers determined by the presence of various food groups	Low, medium, high. (Value scale)
Food production: local food production zones	Number of urban farms in proximity to (local/neighbourhood/regional?) food producers	Km

Table 7. Table indicating metric used in this report (Author, 2023).

By exploring these metrics, this study aims to provide insights into measuring food security, an important aspect of understanding the social fabric of a city and thereby answering the research questions. Focusing only on mapping and measuring four aspects of food security (availability, financial accessibility, physical accessibility and nutrition) allows the study to focus on an in-depth and holistic analysis of the food security of Hatfield (Pothukuchi, 2004; Bertelli, 2019).

Transferring the general knowledge acquired from literature into the context of Hatfield is instrumental in addressing this particular research inquiry. It is important to analyse food security with its many facets for a holistic and comprehensive understanding and emphasise its nuanced and complex nature. A system can be food secure in terms of availability and food insecure in terms of nutrition. Similarly, a nutritious food outlet can be insecure regarding financial availability. Therefore, to ensure an effective analysis, conclusion and policy recommendation, Hatfield's food security will be classified by a detailed description based on the four main pillars of food security: availability, access, nutrition and stability. The pillars of food security naturally also surface spatially. Therefore these pillars will be explored on a section by analysing the spatial qualities using Lynch's (1960) city elements.

An additional culturally appropriate layer can be seen as the top class of food security. In this study, only the four main pillars (availability, access (financial and physical) and nutrition) were mapped and applied to Hatfield, though the unique taxonomy graph has more layers.

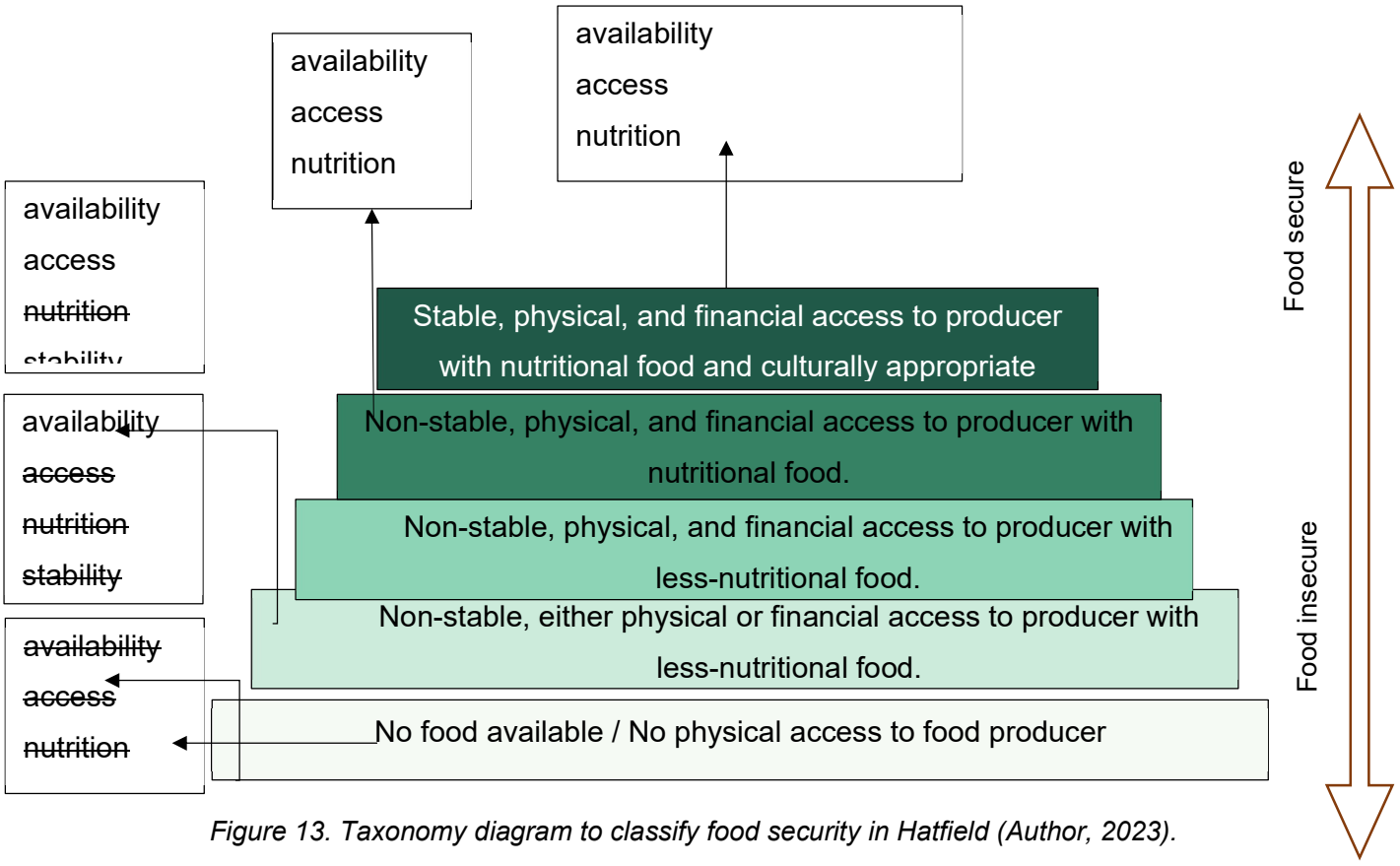


Figure 13. Taxonomy diagram to classify food security in Hatfield (Author, 2023).

These taxonomies were designed to put lives at the forefront, meaning that survival is most important and has a hierarchal level above all other aspects of food security. The lowest class applies when there are no food outlets available. The class above applies when food outlets are available but not physically or financially accessible to most of the population and the available food is not deemed nutritious. The categories continue until a stage is reached where there is stable, physical and financial access to producers of nutritional food that is also culturally appropriate. The more food secure, the more pillars are present. Since the food outlets

in Hatfield are mostly non-nutritious fast-food restaurants – another range is identified, divided into two parts within the x-axis, where the left side is non-nutritious, and the right side is nutritious. This allows for an even more nuanced and specific food security status as it allows a food outlet to be classified as 'non-stable, physical, and financial access to producer with nutritional food' that was not possible with the taxonomy mentioned above.

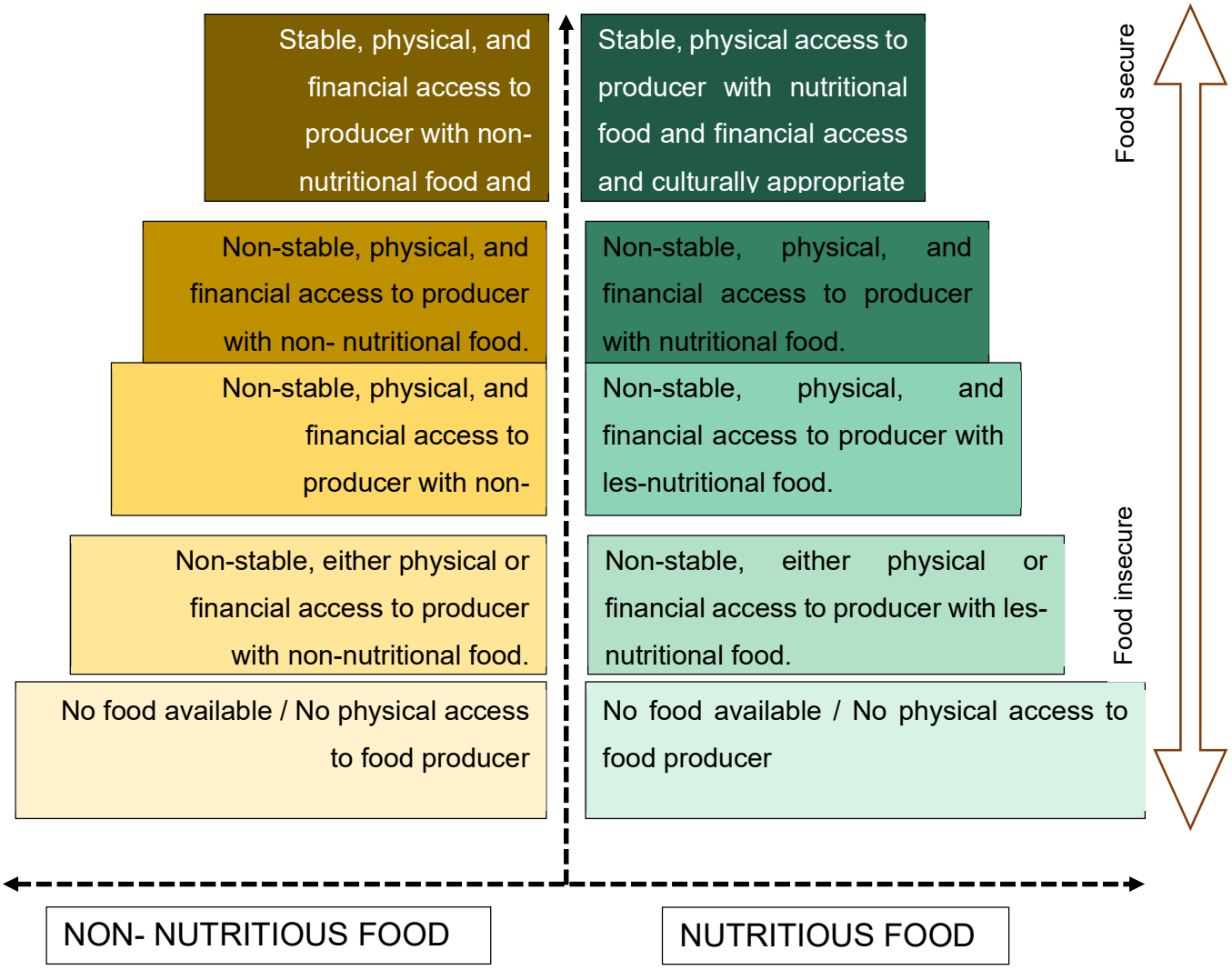


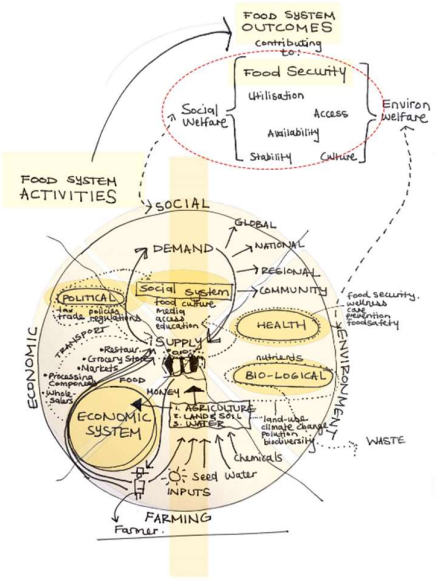
Figure 14. Taxonomy diagram to classify food security in Hatfield, distinguishing between nutritious and non-nutritious food (Author, 2023).

As previously explained, it is important to address food security using a meticulous approach that considers factors such as stability, access and nutrition, etc. The primary objective should be to enhance overall food security by implementing a range of strategies that caters to the entire food system with detailed approaches at different scales. To achieve this goal, it is essential to classify Hatfield using the taxonomy diagram and create a detailed map. This approach will aid in developing a more precise understanding of food security and facilitate the implementation of effective measures and policies to improve it.

4. Results

4.1 Food system map

Figure 1. Diagram of general food system and focus area (Author, 2023).



The food system is a complex network comprising various interconnected elements contributing to food production, distribution and consumption (Zhang, 2017). Several key insights and high-level observations can be obtained by mapping different layers of the food system. At a high level, the food system consists of multiple layers, including production, processing, distribution, retail and consumption. Each layer has a crucial role in ensuring a sustainable and accessible food supply which translates to food security. See systems diagram, 'Figure1'.

Starting with the production layer, it involves activities related to agriculture, farming and food cultivation. This layer includes factors such as crop production, livestock farming, fisheries and other forms of food production. In contrast to most urban areas in South Africa, Hatfield has two urban farms, emphasising the opportunity to increase food security. Moving to the processing layer, it involves activities that transform raw agricultural products into processed and packaged food items. This layer includes food processing facilities, factories and packaging units. There are no formal processing activities within Hatfield, suggesting a gap in the regional system in Hatfield. The distribution layer focuses on the transportation and logistics of moving food from production and processing centres to retail outlets and consumers. It includes distribution networks, transportation infrastructure and supply chain management. This layer was not mapped in this report. The retail layer encompasses the various outlets where consumers access and purchase food and includes grocery stores, supermarkets, farmers' markets, restaurants and other food retail establishments. This level was mainly mapped to note the availability and accessibility of food outlets in Hatfield. Lastly, the consumption layer represents the final stage, where individuals or households acquire and consume food. This layer is mainly showcased in the residential zones, showing where people take their purchased food involving personal choices, dietary preferences and the preparation of meals.

In this process, it becomes evident that various interdependencies and relationships exist between these layers. For example, the availability of diverse and nutritious food options at retail outlets depends on effective distribution networks and a well-functioning processing industry. Additionally, understanding the geographical distribution of food outlets and their accessibility to different populations can highlight disparities in food access and potential areas of food insecurity. By linking the system maps to relevant metrics and data tables, readers can gain a comprehensive understanding of the factors shaping the food system. This approach helps uncover insights such as the concentration of food outlets in specific regions, the range of food prices across different locations and the relationship between food availability and community demographics.

In summary, mapping the food system provides a holistic view of the interconnected elements and layers involved in production, distribution and consumption. It reveals important insights regarding the status quo, disparities and potential areas for improvement, allowing for informed decision-making and developing strategies to enhance the sustainability and accessibility of the food system.

4.2 Food sources

Figure 14 shows all the formal food outlets (restaurants, fast-food stores, supermarkets, etc) in Hatfield. There are 114 formal food outlets present in the precinct. The food stores in Hatfield are clustered in the centre of Hatfield and on the university's property. Food outlets are concentrated mostly in the mixed-use and high-rise/density residential zones and along the railway line. The informal food outlets (19) are in the minority compared to the formal food outlets (114). The informal food outlets are clustered towards the north western part of Hatfield, mainly overlapping with formal food outlets in the centre of Hatfield, just south of the railway line. Generally, the informal food outlets are on the outskirts of the formal food outlets. This could be because of commercial and mixed land use within the centre of Hatfield and a railway station. The Hatfield City Improvement District (CID), which is a specific geographic area within a city established and managed by property owners and stakeholders to enhance the overall environment, safety, cleanliness and economic vitality of the district, exists in central Hatfield (Habitat Landscape Architects, 2020). It may be that the Hatfield CID discourages the informal food trade.

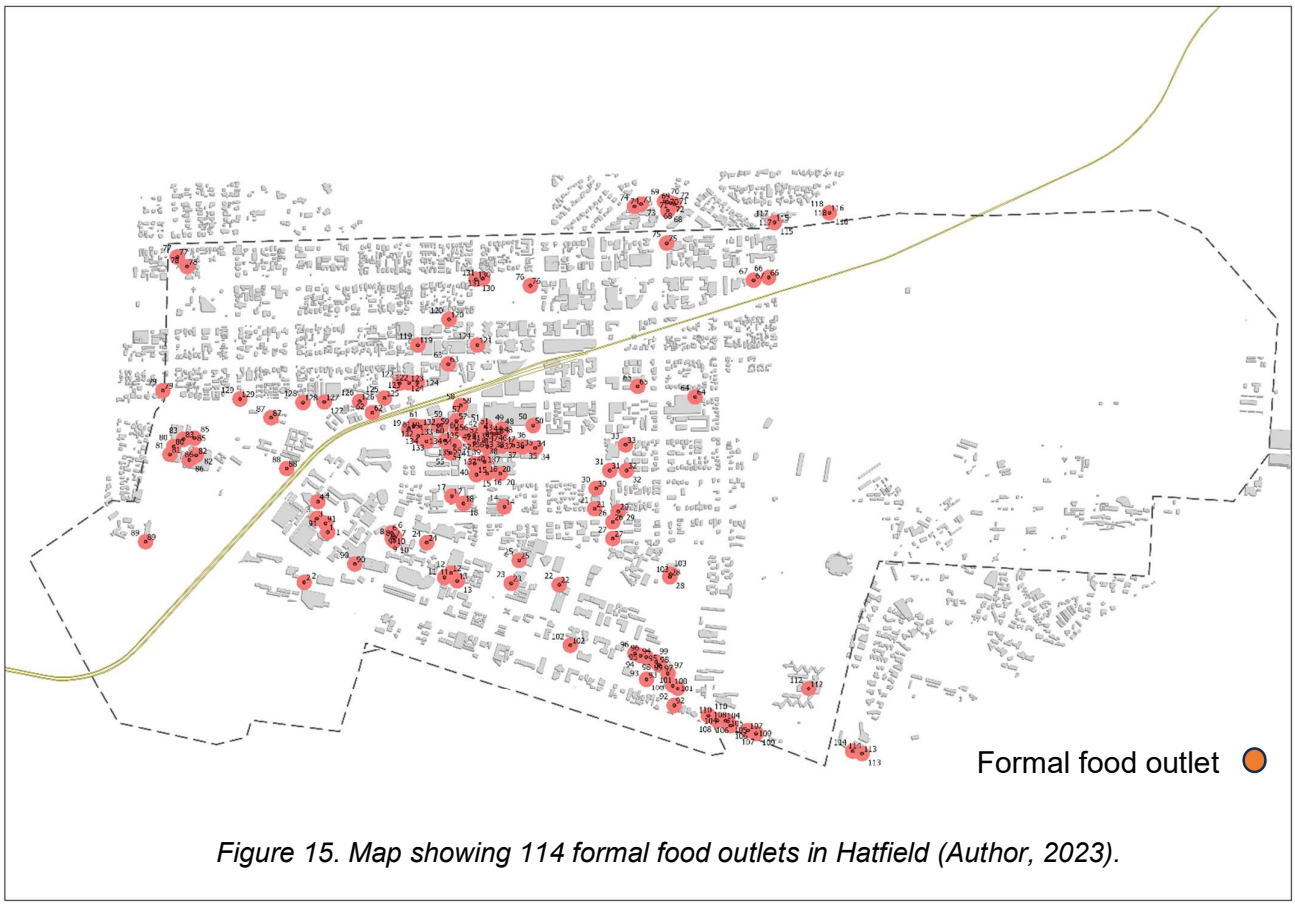


Figure 15. Map showing 114 formal food outlets in Hatfield (Author, 2023).

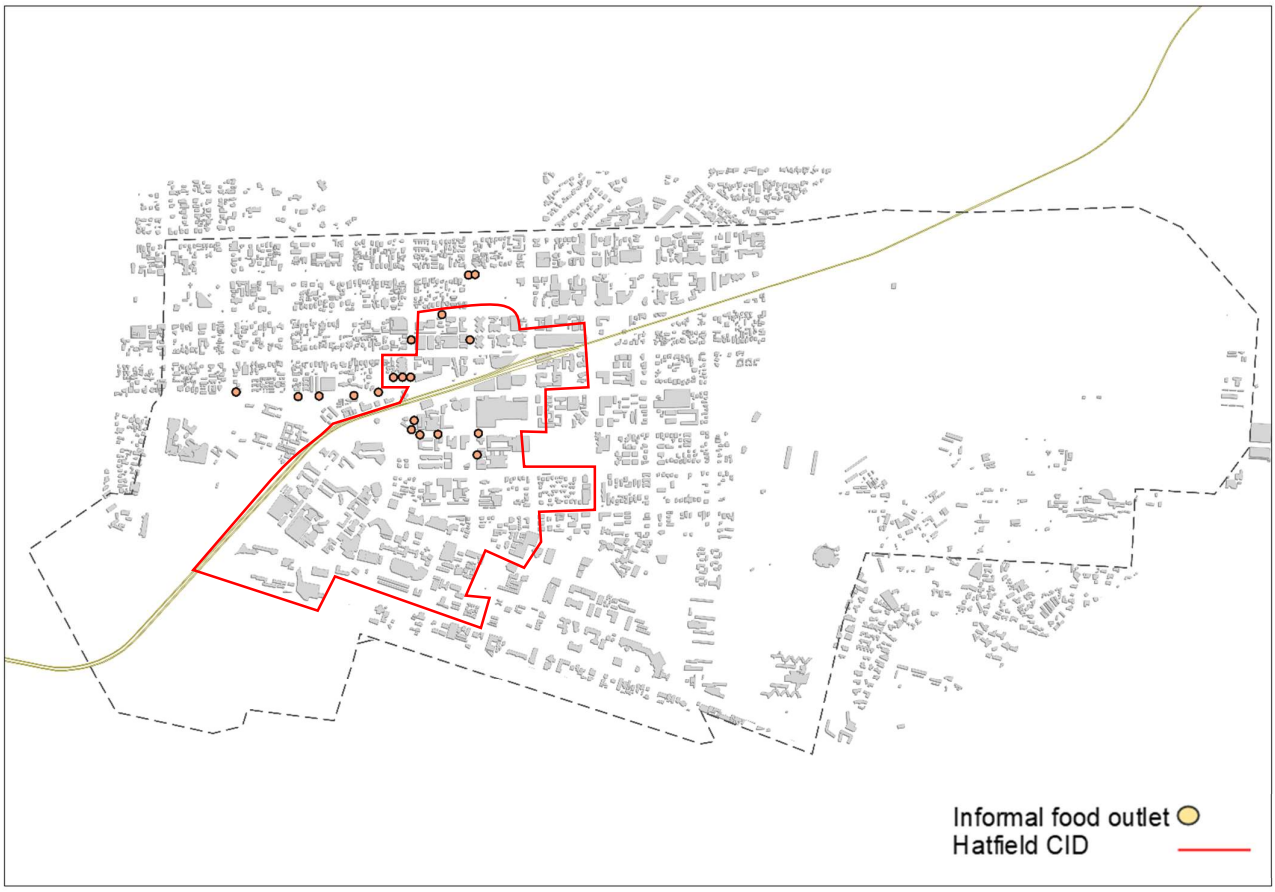


Figure 16. Map showing 19 informal food outlets in Hatfield and the Hatfield CID zone (Author, 2023).

4.3 Food accessibility: finance

Figure 17. Map showing all food outlets in Hatfield and average price per meal (Author, 2023).

In examining the financial accessibility of each food outlet, the average price per meal for each establishment has been meticulously recorded. Each data point is visually represented using distinct colours, effectively illustrating the relative degree of affordability associated with the average meal offered at each food outlet. The analysis reveals a range of average food prices from R35–R120 per meal across the surveyed stores. The food outlets marked yellow are within a price range of R30–R53, and the most expensive food outlets, between R126 and R150, are marked in red.

- The average cost/mean of a meal in Hatfield is: R68,74
- Median: R65
- Therefore, the data is skewed to the left
- Standard deviation: R24,177495

There are, however, meals in all food outlets that are much more expensive and cheaper than the store's average price per meal. Observing food outlet clustering reveals an intriguing pattern, where such clusters exhibit a greater diversity in pricing. Notably, these clusters include food outlets with average prices surpassing the overall average and falling within the higher end of the price spectrum.

4.4 Food nutrition: local food content

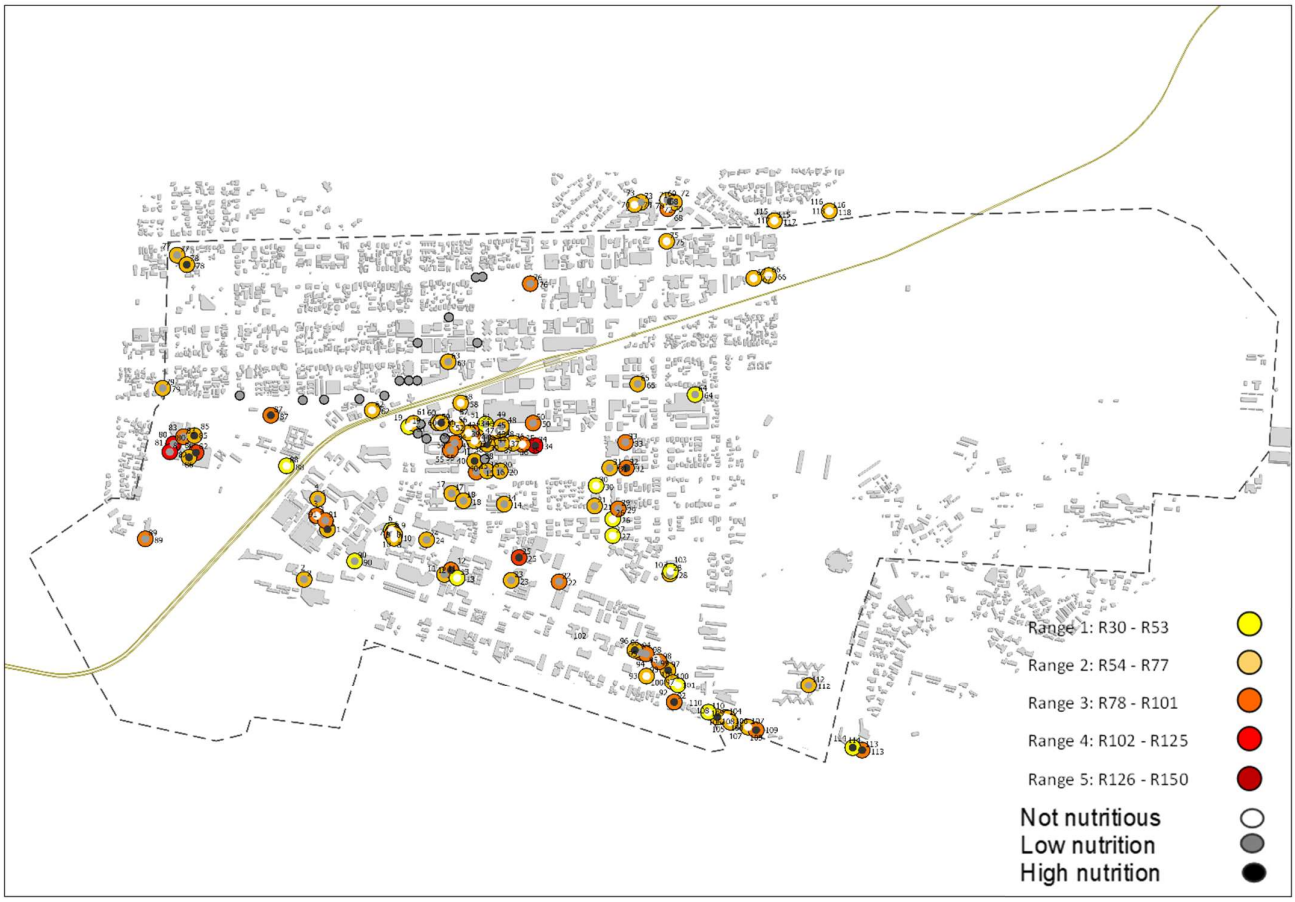


Figure 18. Map showing all food outlets in Hatfield, average price per meal and relative nutrition (Author, 2023).

The South African food guide recommends consuming a variety of food groups regularly (FAO, 2023) to ensure a nutritious diet that includes:

1. starchy foods (carbohydrates),
2. vegetables and fruits,
3. dry beans, peas, lentils, soya, chicken, fish, meat, eggs,
4. milk, maas, yoghurt,
5. fat and oil,
6. and water.

Figure 17 mapped the nutrition of each food store outlet over the average price of each. Since nutrition is one of the four pillars of food security, it is important to understand the availability of nutritious food within Hatfield that is also financially accessible. Nutrition was divided into three relative levels.

1. Not nutritious (White dot)
2. Low nutrition (Grey dot)
3. High nutrition (Black dot)

The level of nutrition was determined by the presence of a variety of food groups available within an average meal within the food outlet, based on the food groups mentioned above. Therefore, if most of the meals on a food outlet's menu only consists of one food group (e.g., carbohydrates), it was labelled as not nutritious (White dot). If a food outlet's average meal consist of two food groups, it was labelled low nutritious (Grey dot). If a food outlet has three or more of all food groups present in most meals, it qualifies as highly nutritious (Black dot). There are many alternative and quantitative ways of mapping nutrition. This report included the method explained above to get a basic understanding of nutrition.

Figure 17 shows some correlation between the price of each meal and the nutrition. The cheaper stores are often not - too low nutritious, but there are some exceptions. The eight red circles indicate nutritious, less expensive food stores. The south eastern and north western parts of Hatfield offer reasonable, less expensive, highly nutritious food. These stores are widely separated and atypical. Supermarkets usually have the most nutritious/less expensive food since raw, unprocessed food is available.

4.5 Food accessibility: distance

Figure 19. Map showing all food outlets in Hatfield and main residential nodes (Author, 2023).

Figure 18 overlays four buffered points at the main residential nodes. The blue circles represent 500m around the node, a six-minute walk from the residential node to a food outlet (formal and informal). This means that students can quickly walk from where they live to purchase food. The centre of Hatfield is well integrated in terms of food outlets and residences. The northern residential areas are more segregated from most food areas as large parts of the buffer residential nodes do not have a walkable food outlet within the buffered zone. However, most food outlets are within a ten-minute walk from most residential nodes in Hatfield. The centre of Hatfield is more integrated regarding residential nodes and food outlets, and the northern and eastern parts are less integrated or developed.

4.6 Food accessibility: exclusivity/inclusivity

As shown in Figure 19, the University of Pretoria is fenced off and only physically accessible to students registered at the university. This means many of the food sources may be inaccessible to Hatfield's public or residents who are not students, lowering food security for non-students in terms of physical accessibility. Approximately 16 per cent of the total food outlets, specifically 18 out of 114, are inaccessible to individuals not affiliated with the university.

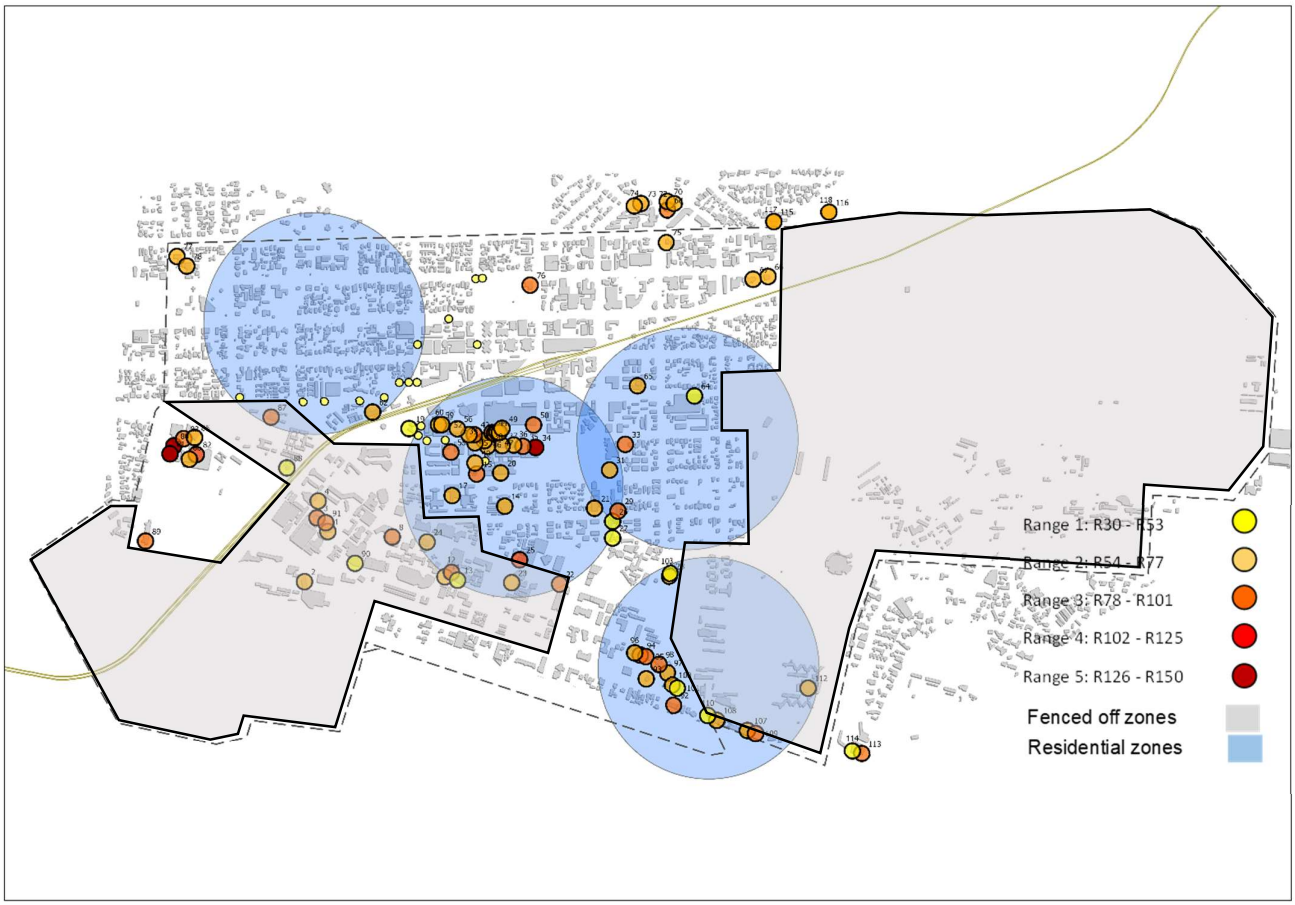


Figure 20. Figure 19 with boundaries of privatised, fenced-off institutions shown (Author, 2023).

4.7 Food accessibility: city spatiality

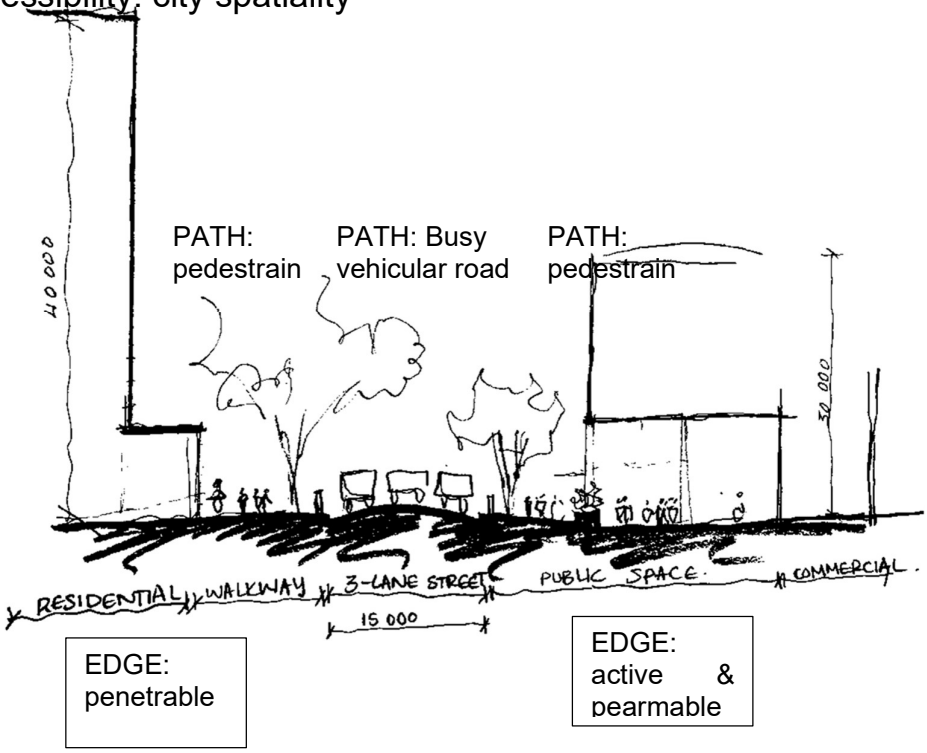


Figure 21. Section of Burnette Street, Hatfield to showcase city elements (Author, 2023; Lynch, 1960).

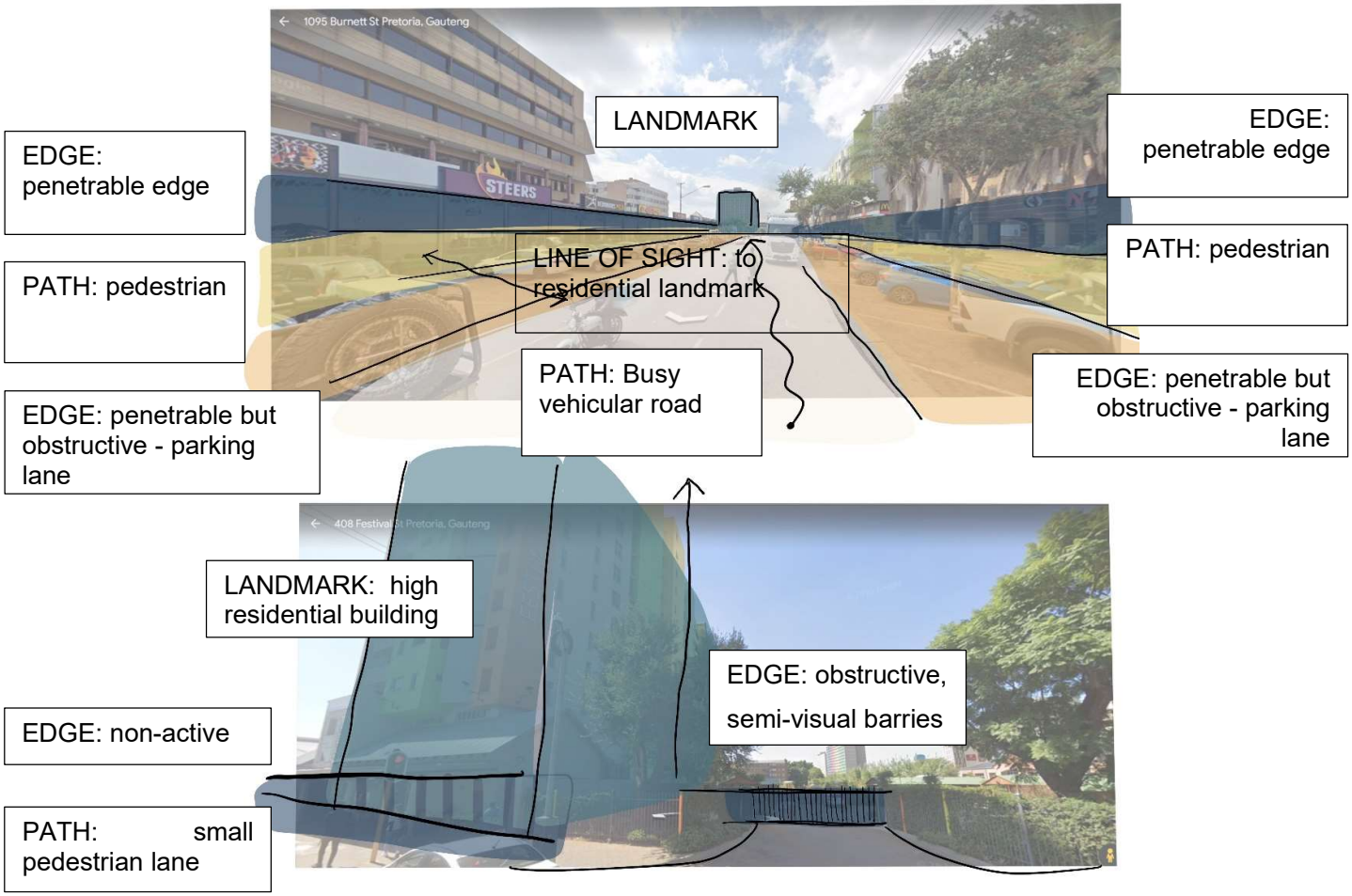


Figure 22Google Earth images analysed to showcase city elements (Author, 2023; Google Earth, 2023; Lynch, 1960).

Figure 20 and the top diagram in Figure 21 showcases a section through one of Hatfield's busiest streets. Within Burnette Street there are more than 20 of the formal food outlets in Hatfield. Both the images showcase the presence of both vehicular and pedestrian paths that is defined by an active and penetrable edge on both sides of the street. The formal food outlets in Hatfield are relatively easily, physically accessible for pedestrians. The bottom diagram of figure 21 shows the street edge of the only, public urban farm in Hatfield, Modge Gabeni. The farm is fenced off and has an obstructive, semi-visual barrier as a gate at the street entrance. This decreases the physical accessibility greatly to fresh produce (Lynch, 1960).

In all both images in Figure 21 one can see that a residential landmark is evident within the line of site. Food outlets (in any form) has less prominence than residential programmes in Hatfield.

4.8 Food production: local food production zones

In Figure 20, urban farming zones are presented in dark green and open spaces/parks in light green. The food outlets and their prices are also highlighted. This map clearly shows the segregation of agriculture and food stores since there is little or no overlap. Food is not served or consumed where it is produced. Another indicator is the isolated shape/form/position/location of each farm from food outlets. The farms act as islands instead of a continuous network woven into the city, as promoted by the Continuous Productive Urban Landscape (CPUL) theory. There are 133 food outlets in Hatfield but only two farms, where only the small, inner-city farm (Modja Gabedi) provides food to Hatfield users. This means most of Hatfield's food is transported from external sources indicating high food miles – low sustainability, a non-dense food system and low self-reliance regarding food.

Figure 23. Map showing all food outlets, productive zones and open spaces(Author, 2023).

In conclusion, this data collection analysis aimed to assess the availability of nutritious food within walking distance of residences in Hatfield, providing insight into the state of food security in the area. The findings indicate that Hatfield is generally more food secure than initially anticipated, with numerous restaurants, open spaces and a notable interest in food. However, the level of food security varies across different regions, individuals and groups within Hatfield, highlighting existing disparities and revealing gaps within the local food system. This requires a comprehensive analysis of the entire food system to identify food-secure and food-insecure regions. Considering the complex nature of food security, an integrated approach to classifying food security holds promise, as outlined in the literature (Vicente-Vicente et al., 2021). The subsequent analysis section will further explore the relationships between various aspects of food security by integrating the collected maps and data.

5. Analysis

Figure 24. Map showing nuanced food security status in Hatfield (Author, 2023).

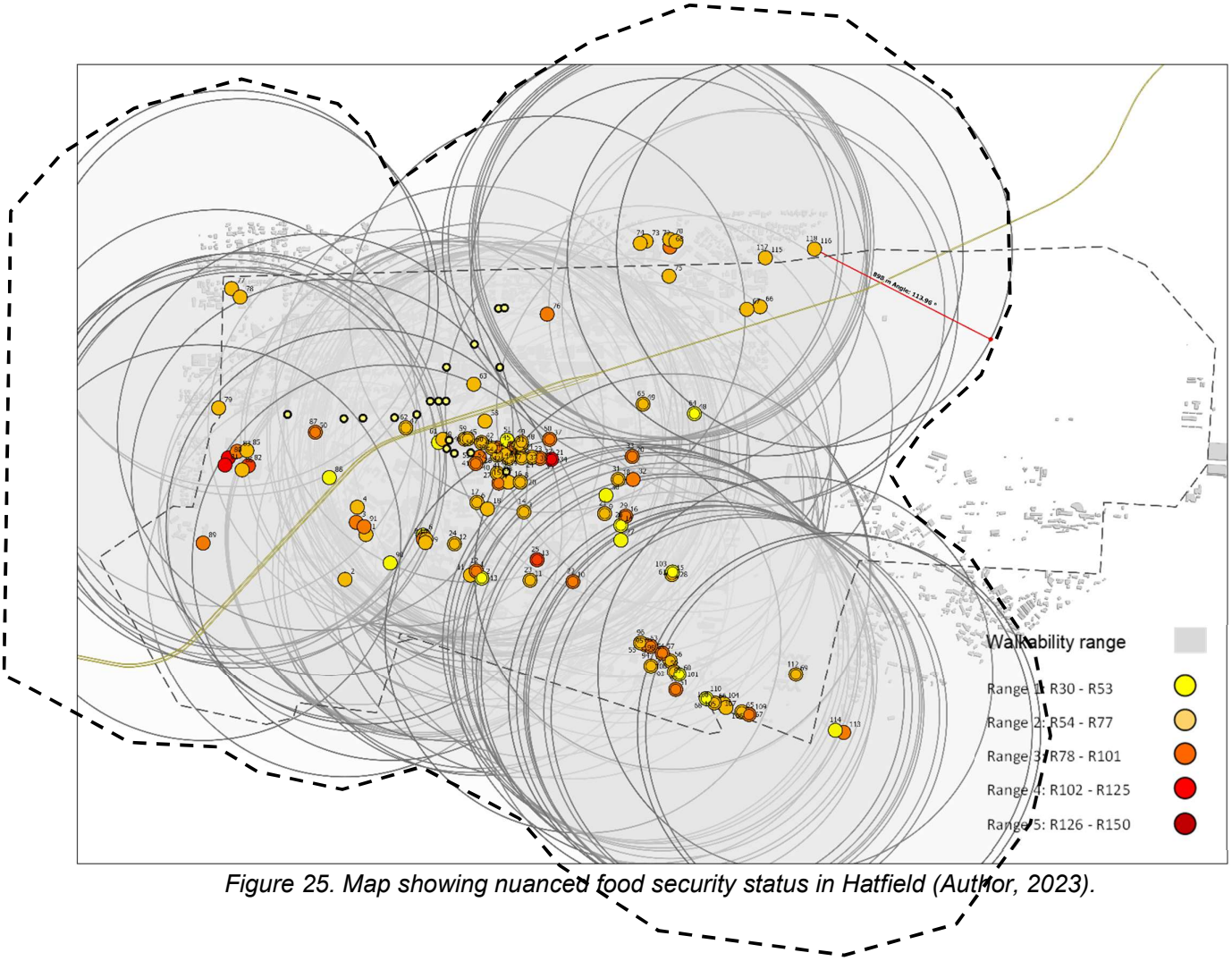


Figure 25. Map showing nuanced food security status in Hatfield (Author, 2023).

In this analysis section, we examine various aspects of the food system layered in Hatfield, highlighting key findings and implications for food security.5.1 Connectedness (Physical and financial accessibility)

Farr's (2018) 'Sustainable Urbanism' theory emphasises the importance of a walkable and integrated city. Applying this theory, we map the food outlets within a six-minute walk of the main residential nodes in Hatfield. The central residential node shows the highest overlap of food outlets, indicating better integration. However, the north western and north eastern nodes exhibit variations in the number of formal food outlets. Out of 114 formal and 19 informal food outlets, the map reveals only 49 food outlets within the overlapping nodes. This suggests a lack of connectedness between the residential and food systems, potentially contributing to food insecurity.

In terms of physical and financial accessibility, Hatfield's centre demonstrates successful integration between different land uses, enabling increased access to food outlets from residential buildings. Most food outlets are clustered in this central area, providing a variety of nutrition and price ranges. In these food clusters, higher prices may lead to financial inaccessibility. Although, cheaper options are also available, food clusters lead to a variety of options. However, the outskirts of Hatfield have fewer food outlets and limited financially accessible, nutritious options. Densification and integration of land use within Hatfield are recommended to ensure walkability and diverse food options throughout the precinct. This approach aligns with sustainability principles and can contribute to enhancing food security (Farr,2018).

5.2 Lack of nutrition

One of the major concerns within Hatfield's food system is the lack of nutritious food options. Supermarkets, in the minority compared to other food outlets, offer relatively affordable and nutritious choices. However, the presence of expensive and unhealthy fast-food restaurants is a significant issue. It is necessary to increase the availability of nutritious meals that include a variety of recommended food groups to improve overall nutrition and food security in Hatfield. Exploring options such as urban agriculture and informal trade spreading to more parts of the city that also produce fresh produce could contribute to addressing this concern.

5.3 Abundance vs quality

As Bertelli (2019) and Clapp (2016) proved, the production amount or availability of enough food is not the main problem. As seen in Figure 22, Hatfield seems food secure if only the amount of food outlets is considered. The food outlets are buffered in Figure 22 to see the walkable range around the food outlets. From this, one can see that the food outlets are abundant and even cater to other precincts. However, food security stands on more than availability; therefore, Figure 23 gives a more accurate representation (Bertelli, 2019; Clapp, 2016).

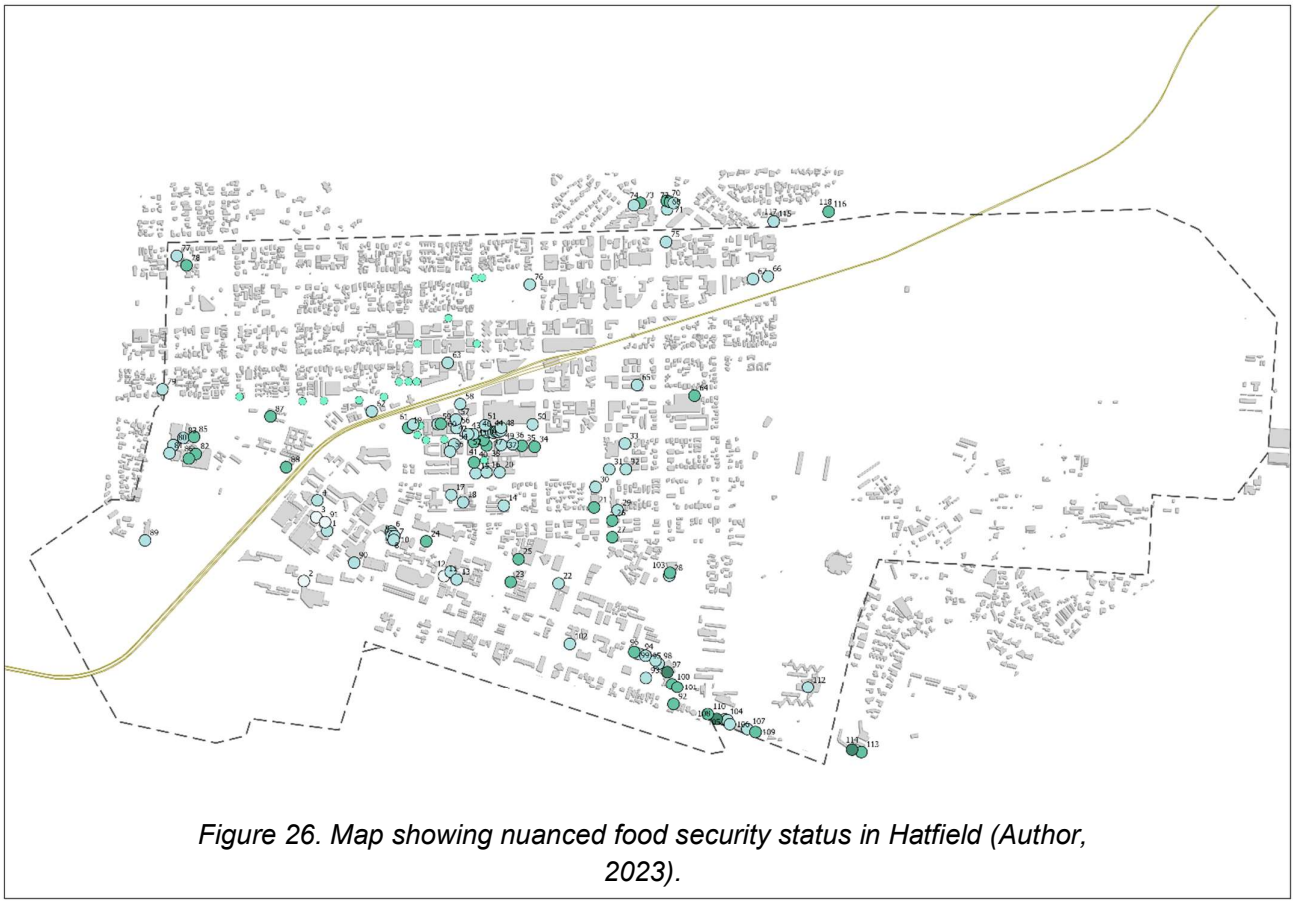
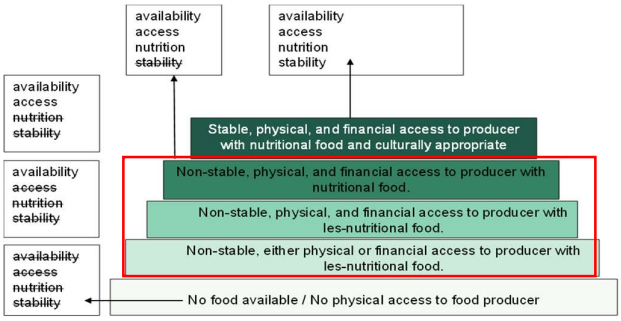


Figure 26. Map showing nuanced food security status in Hatfield (Author, 2023).

Since the literature is clear that approaching food security is nuanced and hyper-contextual, it is crucial to adopt a holistic approach when classifying food security data. Such an approach holds more validity for UDTs as it reflects the complex reality of food security more accurately (Vicente-Vicente et al., 2021).



5.4 Classification of food security in Hatfield

Based on the map analysis, it is evident that most of Hatfield can be classified as having 'non-stable, physical, and financial access to producers with less-nutritional food'. This classification provides a comprehensive understanding of Hatfield's food security, considering various dimensions of access and availability (Figure 23). This map is significant as it shows specific problems and gaps within the food system regarding specific geographical locations, which holds the potential to implement nuanced strategies and policies for specific problem areas. Not all parts of Hatfield are equally food secure/food insecure. The mixed-use zone within the inner core of Hatfield is the most food secure regarding the four aspects.

Nutritional, physical access, financial access and availability were considered for this map (Figure 23). These food outlets are marked with the darkest green. Food outlets that are successful in all three of these aspects were regarded as food outlets that are:

- physically assessable to any member of the public
- that has an average price of less than R50 per meal
- nutritious (see analysis section for defining nutrition in this case)

By classifying Hatfield within a nuanced taxonomy, 'non-stable, physical, and financial access to producers with less-nutritional food', specific challenges regarding food security within Hatfield surfaced.

The original assertion regarding the food security of Hatfield was that: *A user in Hatfield is able to purchase nutritious food within walking distance of their residences. The statement holds partial validity, since the following taxonomy is more accurate:*

A user in Hatfield is mostly able to purchase less-nutritious food within walking distance of their residences.

The report also speculated that the analysis method would indicate the state of food security in Hatfield. Figures 22 and 23 clearly show the gaps, coherences and nuanced nature of Hatfield's food system.

5.4.1 Food sources: Availability

The availability of food stores in Hatfield is not a major concern, as there are an ample number of outlets within the precinct (133 in total). Most residential nodes have easy access to a food store within a walkable distance, indicating sufficient availability of food (Figure 22).

5.4.2 Food access

- **Physical access, in general**

A small part of the residential zone to the North Western part of Hatfield has no food outlets

- **Physical access to farm**

The experimental farm in Hatfield is fenced off and primarily used for testing chemicals and pesticides on crops. Consequently, the farm is inaccessible to many students, and its produce is unsafe for consumption because of these chemicals. Therefore, even though it is classified as an experimental farm, it is unsafe for consumption and cannot be classified as a food outlet. As the experimental farm takes up a large part of the

precinct, a more integrated systemic approach to urban farming should be considered, where certain parts of the area deliver fresh, safe produce to increase the area's nuanced food security.

However, the urban farm at Modga Gabedi, located in the inner part of Hatfield, provides accessible and safe edible produce, although its output is not sufficient considering its potential and land size. The location of Modga Gabedi holds great promise, as it can potentially integrate production and consumption within a residential node. This could increase the success of all four aspects of food security.

- **Physical access to university grounds**

Food stores and restaurants within the University of Pretoria are not physically accessible to non-students in Hatfield, limiting their options for food access. The land use zone of Hatfield appears to be an open and integrated precinct, but in contrast, most of Hatfield is fenced off, leading to inaccessibility to food on campuses by non-students.

- **Financial access**

Hatfield's residents, predominantly students, have low incomes and limited financial independence. Nutritious restaurants or food stores are often financially inaccessible, leading to decreased food security as nutritious meals are beyond the financial reach of many students. The average cost per meal is approximately R68.74, and the average cost per nutritious meal is higher. Buying raw, fresh produce from a greengrocer or supermarket is the best option financially and nutritionally. This, however, requires the student to cook and prepare the meals, which is not always possible in highly dense residential environments.

- **Safe access**

Safety is a multifaceted aspect of food access. The experimental farm's produce may not always be safe for consumption due to the use of chemicals. Additionally, food sources outside the Hatfield CID may not be situated in safe environments for purchasing food. A short walk instead of a long walk from residential areas to food outlets is safer and more convenient. If the food outlets are clustered, it can be deduced that there is more passive surveillance and activity throughout the day, increasing safety within these areas. From the map, one can clearly see where busy areas are regarding food outlets and more desolate areas. While safety was considered at a high level, extensive research in this area was not conducted.

- **Nutrition**

Hatfield exhibits an abundance of fast-food restaurants, indicating a market preference for quick and inexpensive meals. However, this raises concerns about malnutrition, as fast-food options are typically high in salt content and low in the presence of various food groups. Affordable and nutritious food outlets are scarce in Hatfield, with only a few options available among the many food outlets. These nutritious food outlets are primarily located on the outskirts of Hatfield and tend to cluster with other food outlets. Few food outlets in Hatfield offer meals with three or more food groups, highlighting the limited availability of nutritionally balanced options; most were supermarkets in the south eastern part of Hatfield.

- **Stability**

The seasonal nature of Hatfield, with a predominantly student population, impacts the stability of the food system. During holidays, Hatfield experiences a decrease in population, resulting in a less stable retail environment due to reduced economic activity. Since the population is primarily students, it leads to gaps within the larger system. Designing the urban framework to allow for different types and sizes of households to live within the precinct could decrease the risk of an unstable food system. By increasing diversity within a population, Hatfield could avoid becoming deserted during the holiday season.

The methodology employed for mapping and analysing the subset of the social fabric, particularly food security, in Hatfield proved successful in revealing the complex categories of food security in detail. These maps serve as valuable information and potential use cases for the development of a Hatfield UDT, enriching the available datasets and enhancing the quality of social fabric analysis.

This analysis significantly contributes to our understanding of the food system in Hatfield and its implications for food security. By mapping and classifying the city's social fabric, we have gained valuable insights into the methodology of mapping urban environments and assessing the state of food security. This knowledge

brings us closer to realising an inclusive and dynamic UDT that can inform policies and interventions to uplift communities economically, socially and environmentally. The generated maps provide a holistic view of the food system while highlighting specific layers, uncovering gaps within the larger system, and enabling targeted policy recommendations for Hatfield's unique precincts.

Furthermore, this analysis emphasises the potential of UDTs in addressing urban food security. The mapping and classification of food security data contribute to the development of UDTs that can simulate and test changes related to food security within urban environments. By incorporating social characteristics and environmental factors, UDTs offer valuable insights for improving food access and availability, thus promoting food security and guiding the development of sustainable and resilient food systems.

While it provides valuable insights, it is important to acknowledge its limitations. Future research should consider factors such as average income and financial ability to understand the affordability of restaurants in the area. Additionally, a more quantitative methodology and further exploration of cultural preferences and spending habits could enhance the understanding of food security in Hatfield. It is also recommended to conduct regular assessments of food security to provide continuous and accurate data for UDTs.

In conclusion, the holistic approach to classifying food security in Hatfield reveals the nuanced challenges faced in the area. The overlapping of factors by holistically analysing food security provides the most accurate finding. A comprehensive understanding of Hatfield's food security is obtained by considering various dimensions, including physical and financial access to producers and the availability of nutritious food. These insights contribute to the knowledge base required for the development of UDTs, enhancing the quality of social fabric use cases and promoting sustainable and resilient food systems in Hatfield and beyond.

. Discussion: Mapping Food security for Urban Digital Twins

Datafication is the conversion of data into useful information. Without this knowledge, effective research cannot take place (Bibri, 2019). This study investigated how we could map social fabric data for UDT readiness, as seen through the food system landscape.

6.1 The implications of every finding

***Research Question**: How can we effectively measure and classify food security within Hatfield to enhance its readiness for urban digital twin implementation?*

By dissecting and deconstructing any subset of the social fabric, it becomes possible to systematically examine and analyse the individual components that constitute a given concept. This rigorous approach allows for a comprehensive exploration of the various characteristics inherent within the subset, leading to a more profound understanding of its intricate nature. By meticulously unravelling and scrutinising the constituent elements, one can gain valuable insights into the multifaceted aspects that shape and define the concept under study. Such analytical dissection enables researchers to delve deeply into the core components, facilitating a holistic comprehension of the underlying dynamics and enhancing scholarly knowledge in the field.

Food security was conceptually defined in alignment with relevant literature, allowing for identifying fundamental elements. Subsequently, metrics were established to facilitate effectively mapping and measuring these elements. Utilising ArcGIS, these elements were spatially mapped and classified within respective ranges. Grounded theory methodology was employed to layer these maps, unveiling patterns,

gaps and consistencies within the social fabric. Given the intricate nature of the social fabric, employing taxonomies is a valuable approach to a nuanced and comprehensive analysis of food security. By individually identifying and characterising each food outlet based on its specific food security status, a comprehensive depiction of the entire city's food system can be attained through geospatial mapping. Such an approach allows for a holistic understanding of the patterns and dynamics shaping the food landscape within the city.

***Sub-Question**: What is the existing state of food security in Hatfield, considering factors such as access to nutritious food, affordability, and availability?*

Hatfield's food security was also classified using the above method, with the goal of mapping for digital twin readiness. Hatfield can be categorised as 'non-stable, physical, and financial access to producers with less-nutritional food'; specific challenges regarding food security within Hatfield surfaced. A user in Hatfield can mostly purchase less-nutritious food within walking distance of their residences.

***Sub-Question**: What are the implications and consequences of accurately measuring and classifying food security as a subset of Hatfield's social fabric? How does it impact the community's overall well-being and resilience?*

Accurately measuring and classifying food security as a subset of Hatfield's social fabric has profound implications and consequences for the community's overall well-being and resilience. By gaining a comprehensive understanding of the existing food security landscape, policymakers, urban planners and community stakeholders can make informed decisions and devise effective strategies to enhance food security within Hatfield.

The mapping and classification of food security provide valuable insights into the specific areas or regions that face challenges or exhibit strengths regarding safe, nutritious food. This information enables targeted interventions and resource allocation to address the identified gaps and enhance the availability, affordability and accessibility of food within the community. Improving food security in Hatfield has significant implications for the overall well-being of its residents. Access to safe and nutritious food is essential for maintaining good health, promoting proper growth and development, and reducing malnutrition-related health issues. Addressing food security challenges can improve the community's health outcomes, leading to a better quality of life and enhancing overall well-being.

Ultimately, accurately measuring and classifying food security within Hatfield's social fabric empowers stakeholders to proactively address food security issues, improve community well-being and strengthen the community's resilience in the face of challenges. It lays the foundation for evidence-based policy-making, planning and interventions that promote a more sustainable, equitable and resilient food system for the benefit of the entire Hatfield community.

6.2 Reflection on the process, methods and learnings of the study

Reflecting on the study, process and findings, the analysis in this report provided a foundational understanding of Hatfield's food security. The process primarily involved desktop research and grounded theory facilitating a relatively smooth and insightful exploration. It revealed that Hatfield exhibits a higher level of food security than initially perceived, which is an interesting finding, since most of Hatfield's residents are economically inactive (Habitat Landscape Architects, 2020). However, a more intricate methodology could be employed to enhance the rigour of the analysis, such as a quantitative data analysis approach, to further refine the study and increase precision.

In terms of urban theory, it is evident that connected zones are beneficial in many ways (Farr, 2018). Within the mixed-use zone in Hatfield, there are a greater variety of food outlet stores, more nutritional options and within walking distance of a residence. Within this zone, there is also an urban farm, which holds the possibility of further integration and densification of the local food system.

Furthermore, given the seasonal nature of food security, conducting recurring studies could enhance the validity of the findings. By examining food security trends over time, a more comprehensive understanding of the dynamics and fluctuations within Hatfield's food system could be achieved. This would contribute to a more robust and reliable assessment of the community's food security status.

The nutrition of the meals within the food outlets was mapped for a basic understanding and analysis. Nutrition is a much more complex study; therefore, a more in-depth study, zooming in on nutrition, would increase the accuracy. An economic study could be conducted to understand the term ‘affordability’ in the context of Hatfield to increase the accuracy of the financial pillar of food security.

The emergence of food delivery in a city could significantly impact food security, and students are prone to ordering food (Gamba et al., 2021). A future study could research food delivery patterns, costs and human preferences. No human preference studies were conducted for this report, and to further strengthen the social layer of food security, interviews and perception studies could be conducted.

The overall process was enlightening and indicated the importance of a further and refined study.

6.3 Usefulness of mapping food security for Urban Digital Twins

A useful Urban Digital Twin would be seasonal, accurate and encompasses physical data and multiple subsets of the social fabric, one of which is food security. This could allow designs, urban policies and framework strategies to be tested and implemented to increase urban wellness and success.
From this report a Food Urban Digital Twin could possibly be built and be one step closer to understanding and designing for real-time food information within the city. The more comprehensive the data within the twin the more accurate the information will be. In future, a detailed food UDT could possibly give data regarding the hunger level of residents in certain parts of Hatfield at certain times of the day and year. Policies and development could respond to these scenarios with spatial interventions. Developers and city-makers could use this information to understand the real-time needs of the city’s residents and make decisions accordingly. For instance, within Hatfield it would be interesting to see the correlation between the presence of fast-food outlets and hunger level of residents vs if the urban farm is designed to be more physically accessible to the public. A Food UDT would make it possible to test and understand spatial interventions such as Continuous Productive Urabn Landscapes (CPUL), inter-use building etc and the social impact thereof from a social and need perspective.

7. Conclusion

In conclusion, a comprehensive understanding of food security in a city necessitates considering its various facets. By employing GIS mapping to accurately classify the taxonomy of food security, it becomes evident that this is a complex and multifaceted phenomenon requiring analysis at multiple scales and typologies. Strategic implementation of policies and interventions is required at different scales to enhance food security, addressing specific issues related to food safety, access and nutrition within the local context. This integrated approach not only improves the overall food system but also ensures access to sufficient and nutritious food for all community members.

This study makes two significant contributions. Firstly, it underscores the urgent need for sustainable and ethical food systems, particularly in rapidly expanding cities facing challenges such as food deserts and neglected urban planning. This report aims to raise awareness regarding the importance of developing effective and resilient food systems by acknowledging the adverse effects of urban sprawl on food security. Secondly, it explores the potential of UDT technology to address the social fabric of cities, including food security. By examining the current state of food production and distribution through a food systems lens, the study investigates how the social fabric of a city can be mapped and classified to be UDT-ready, providing valuable insights into the methodology of mapping urban environments' social fabric.

Furthermore, this study establishes the significance of UDTs as tools for urban planning and development in addressing urban food security. It defines food security within the context of Hatfield, providing an analysis of food security in different areas. By adopting a comprehensive definition of food security that encompasses availability, access and value, the study lays the foundation for future research. The recurring study of different aspects of food security can provide accurate UDT information, advancing our understanding of mapping and measuring various subsets of the social fabric. Moreover, the study highlights the potential of UDTs to simulate changes related to food security within urban environments. By incorporating social characteristics and environmental factors into virtual models, digital twins offer insights into improving food access and availability, promoting food security and guiding the development of sustainable and resilient food systems. This study paves the way for mapping other subsets of the social fabric, such as social capital, spirituality and poverty in Hatfield and other cities, contributing to a holistic understanding of urban dynamics.

While this study provides valuable insights, it is important to acknowledge its limitations. Future research should consider mapping residents' average income and financial ability to understand the affordability of restaurants in the area. Additionally, investigating each pillar of food security in more detail, including the cultural layer, would further enhance our understanding. Incorporating more quantitative methodologies, interviews and perception studies can enrich the analysis and provide deeper insights into the food security of Hatfield. Furthermore, future research should consider the seasonality of food security and conduct regular assessments to feed accurate data into the UDT.

In summary, UDTs driven from a needs-driven perspective vs a mere technological perspective could potenitially transform African cities and bring about positive change. This study's mapping and classification of food security in Hatfield provide profound insights into the methodology of mapping the social fabric and the state of food security. Armed with this knowledge, we move closer towards an inclusive and vibrant UDT that can shape policies for the economic, social, and environmental upliftment of communities.

8. References

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9. List of figures

10. List of Tables