Chapter 1: Introduction

1 Background to the study

Cities, as collective forms of habitation, can be considered as one of the major successes of human ingenuity. These urban centres developed out of the proliferation of agriculture and its associated surplus resources (Diamond 1997). Since their inception these dense land-use forms have been highly successful, to such an extent that currently 55% of the world's population resides in cities (United Nations 2019). The success of this land-use form seems impossible to quell, and for many it presents both personal and collective opportunities for change and growth (Pieterse 2013). While cities cover only 0.5% of the earth's surface (Schneider et al. 2009), their urban population density and associated resource consumption intensity are often considered as opportunities to leverage sustainable strategies, specifically in addressing climate change (IPCC 2014a; 100cities 2020).

While accelerated urbanisation is a global phenomenon, Africa is noted as one of the fastest urbanising continents (United Nations 2019). However, not all processes of urbanisation are similar, and a myriad of drivers accelerate it (Pieterse 2019). Climate change often leads to displacement due to extreme weather events, conflict to ensure resource control, and a loss in agrarian livelihoods (IPCC 2014a; Welzer 2012). As a result it is considered one of the main drivers of rural-urban migration in Africa (Pieterse 2019;Tawodzera 2012). While climate change leads to rapid urbanisation, it also poses significant risks to it. As noted by Romero-Lankao and Dodman (2011), cities present the potential to implement scalable strategies that address climate change, but the high population densities associated with urban contexts often result in significant increases in vulnerability to climate change-induced disasters. They continue arguing that lower to middle-income cities often have limited capacity to respond to and prepare for the risks associated with climate change. This is particularly relevant in the African context where the lack of climate change readiness is often a result of limited financial resources, skills and capacity (Roberts 2010). Neglecting to generate knowledge and capacity to respond to the expected impacts of climate change on our cities and the citizens' well-being can have devastating consequences.

Climate change poses serious risks to communities globally and its effects are expected to impact human and natural systems indiscriminately (Roggema 2012; Mambo & Faccer 2017; IPCC 2018a). Many of these adverse environmental and social impacts have already been documented in South Africa and other regions in Africa (Welzer 2012; Bloom 2019). In addition, the Fifth assessment report (AR5) by the Intergovernmental Panel on Climate

Change (IPCC 2014) indicates that 3 of the 4 representative concentration pathways (RCP) forecast irreversible impacts caused by increasing greenhouse gas (GHG) emissions. The 1.5 Degree Report (IPCC 2018b) predicts an expected minimum average global temperature increase of 2°C. In South Africa up to twice the global average is expected (DEA 2013), and as a result South Africa must prepare for a minimum average temperature increase of 3-4°C. Consequently, implementing response strategies to the associated adverse impacts of climate change will be critical.

While climate change mitigation (CCM) has long been advocated as the appropriate response to address climate change, climate change adaptation (CCA) strategies, on the other hand, have been lagging in their development and implementation (Stone 2012). The delayed implementation of CCA strategies can be ascribed to a perceived nihilistic response that focuses on the impacts of climate change rather than preventing it, as well as the difficulty in considering the long term impacts and adjustment of current practices in anticipation thereof (Smith 2010). Yet as climate change impacts are already experienced, and with the certainty that it will intensify in future, CCA measures are vital to ensure the health and well-being of citizens worldwide.

In contrast to CCM strategies that can be developed on global scales and often function as international treaties and exchanges (for example the cap-and-trade system) (ASSAF 2011;UN 2015), CCA plans must take cognisance of the local risks and vulnerabilities, as well as the local context and users. As a result, O'Brien and O'Keefe (2014) argue that both top-down and bottom-up processes are required to ensure effective adaptation. Responding to specific contexts is vital when identifying and adjusting potential CCA strategies.

As we note the prolific development of cities globally, the pressing need to adjust our cities in the wake of climate change is accentuated. While affluent cities can afford to implement new, extensive infrastructural projects, many African cities are under severe pressure to both accommodate new inhabitants and adjust to climate change impacts (Lwasa 2010; Kithiia 2011). Identifying measures to retrofit and adjust the existing infrastructure and building stock in poorer cities, can contribute to the overall CCA capacity of these urban centres. The network potential of urban acupuncture as a response strategy has been identified as a potential solution to our current inefficient and vulnerable cities (Tortosa et al. 2010). As measures to improve current resource consumption (Ryan 2013), these ground level strategies can potentially have larger cascading impacts on cities as a whole.

Urban Agriculture (UA) has been advocated as a land-use type that can be implemented as a decentralised network that can easily be adjusted to specific conditions. One such visionary approach by Viljoen (2005) advocates for the integration of productive and public spaces within cities. In practice, the results of implementing productive landscapes have been varied, being highly successful in Cuba during its Special Period (Rosset 2002), while unfortunately poorer outcomes were documented in the Eastern Cape in South Africa (Thornton 2008). Notwithstanding the evidence, this discourse and industry have developed significantly both locally and abroad, and this land-use form is often associated with projects that are focused on sustainability or socially conscious initiatives.

Building-integrated Agriculture (BIA) developed as a novel land-use type within the urban agriculture (UA) discourse. While originally defined by Caplow (2009:55) as the integration of "…high-performance hydroponic farming systems in and on buildings using renewable sources of energy and water…", this study considers a more inclusive definition of this land-use form. Aligning with the definition of zero-acreage farming (ZF) that includes "all types of urban agriculture characterized by the non-use of farmland or open space" (Specht et al. 2014:35), this study argues that BIA must be considered along these broader terms. Similar to ZF, BIA represents the integration of the built environment with productive spaces, and within the industry multiple forms of farming systems have been documented. Based on the work of Despommier (2010) that calls for closer integration between productive spaces (agriculture) and the built environment, BIA presents a number of improved resource consumption opportunities. While BIA affects the local urban metabolism through alternative resource management and provisioning, proponents such as Specht et al. (2014), Thomaier et al. (2014) and Goldstein et al. (2016) argue that BIA can effectively improve the performance of the built environment and by extension be considered a CCA measure within cities. Not only is the discourse developing on a theoretical basis, but globally a number of projects have developed exploring the opportunities of integrating farms with the built environment. This trend was also documented in South Africa (Davie 2018).

In closing, while cities manifest as robust land-use forms that will possibly continue and grow for further millennia to come, the threat that climate change presents to South African cities cannot be ignored. Retrofitting the South African built environment in response to climate change impacts is therefore critical. However, while many propose using BIA projects to improve the performance of the built environment, little research has been undertaken to consider the resultant impacts that the BIA land-use form has on buildings within the South African context. This study, therefore, considered the potential of BIA as a CCA tactic to improve the indoor thermal environment in South African cities.

2 Problem statement

While the AR5 (IPCC 2014b;IPCC 2014c) advocates for both CCM and CCA strategies to be implemented in rural and urban contexts alike, it is important to note that CCA strategies are resource intensive and often implemented with a degree of uncertainty of their long term necessity and success (O'Brien & O'Keefe 2014). Furthermore, South African cities face intense pressure to grow and provide essential services (Tawodzera 2012; United Nations 2019). As a result, retrofitting the existing built environment as leverage point, and understanding the potential of certain CCA strategies are important when working within resource-constrained contexts.

While food security is an obvious concomitant benefit to UA, the literature has explored various co-benefits associated with this land-used type over the years. One such argument advocates that UA present significant CCA benefits to local communities (De Zeeuw 2011; Lwasa et al. 2014; Padgham et al. 2015) and this is similarly postulated for BIA applications (Specht et al. 2014; Thomaier et al. 2014). However, the implementation and potential CCA impact of BIA in formalised multi-storey South African urban environments are yet to be assessed.

Several studies have considered the cooling potential of soil-based UA in the urban environment through evapotranspiration and changes in albedo factors (Corburn 2009; Lwasa et al. 2014). These cooling benefits have also been posited for BIA applications, specifically postulating benefits to the indoor thermal environment (Goldstein et al. 2016; Thomaier et al. 2014). While these studies present important findings, there is limited research into how effective BIA applications are in ameliorating climate change affected thermal conditions in South African urban environments.

3 Research question

As BIA is considered a novel land-use type with limited application in the South African context, the project is explorative in nature. As a result, the project was initiated with a research question rather than a specific hypothesis as advocated by Hofstee (2006).

The study, therefore, argues that while BIA can be expected to be an effective CCA and CCM measure if implemented in the unused and underutilised spaces of our cities (Despommier 2010; Specht et al. 2014; Thomaier et al. 2014), the potential impact of such a retrofitting strategy to contribute to the local CCA capacity needs further investigation.

The study posed the following research question:

> **What is the potential of retrofitting unused spaces in multi-storey urban environments in Tshwane with building-integrated agriculture as a climate change adaptation strategy to modulate the indoor thermal environment?**

3.1 Sub-questions

The research question was divided into three sub-questions. Firstly, the context within which the potential of the BIA application as CCA tactic was analysed (sub-question A). Secondly, the spatial and material considerations when implementing BIA applications were documented (sub-question B), and finally the resultant impact of such a BIA application on the associated built environment was simulated (sub-question C). While these sub-questions are discussed in this particular order, sub-questions A and B were undertaken concurrently informing each other. Their findings were used to investigate sub-question C. The sub-questions are defined as:

a) What are the spatial and material characteristics of the unused and underutilised spaces located in Hatfield, Tshwane?
b) What are the spatial and technological parameters of BIA when used to retrofit the existing built environment?
c) What are the cooling and heating load impacts on a building when retrofitted with BIA?

3.2 Research objectives

The following research objectives addressed the research sub-questions and are discussed in more detail:

a) Define the spatial and material characteristics of unused and underutilised spaces in Hatfield, Tshwane.

i –Define the identifying criteria for the unused and underutilised spaces.

ii – Establish the important CCA-related spatial and material criteria that require documentation.

iii – Document the unused and underutilised spaces in the Hatfield neighbourhood.

iv – Determine the spatial typologies of the documented spaces and calculate their frequency of incidence (FIO) and potential space impact (PSI).

v – Determine the potential of the unused and underutilised spaces to address food production in the Hatfield context.

b) Define the various technological and spatial parameters of BIA as a retrofitting strategy.

i – Establish and identify a sample of UA and BIA farms to survey, as well as farmers and specialists to interview.

ii – Collect data on the technological and spatial conditions of the UA and BIA farms.

iii – Analyse the textual and visual data to establish the parameters for both UA and BIA farms.

iv – Establish the technological and spatial parameters of BIA farms by differentiating it from general UA farms using the findings established in iii.

c) **Model and assess the thermal impacts of BIA on the heating or cooling loads of the built environment.**

i – Based on objectives A and B, establish predominant BIA farm type to simulate.

ii - Monitor and analyse the microclimatic performance of existing BIA farm types established in i.

iii – Establish and validate model simulation parameters based on field data.

iv – Simulate and assess the thermal impact of BIA on a theoretical building using simulation parameters.

d) **Synthesize the findings from research sub-questions 1, 2 and 3 to consider the capacity of BIA to modulate the indoor thermal environment as a climate change adaptation strategy.**

4 Limitations, delimitations and assumptions of the study

4.1 Delimitations

The study focused on the impact of climate change and our capacity to respond to it in inland Southern African cities. It considered the potential that building-integrated agriculture as a land-use form has to improve the local climate change adaptation capacity in an existing formalised neighbourhood. To achieve these ideals, the following delimitations to the study were established.

a) The research was limited to multi-storey formalised urban conditions, peri-urban and rural conditions were excluded from the study.
b) While climate change will affect Tshwane in several ways, the study only modelled the thermal impacts of BIA on the built environment and how it limits the indoor environment’s exposure to any climate change-driven thermal increases.
c) The study only considered the CCA potential of BIA in terms of its spatial and technological application when retrofitting existing buildings and its resultant thermal impact on the built environment. Aspects such as social, cultural or economic CCA

benefits of UA and BIA were delimited from the study. Several studies have already addressed this both locally and internationally (Kortright & Wakefield 2011; Matos & Batista 2013; Thom & Conradie 2013).

d) Food production quantities were not calculated in the study as the focus has been on the co-benefits associated with BIA as land-use form. A number of studies have considered the food production quantities of BIA and UA with varying results (van Averbeke 2007; MacRae et al. 2010; Orsini et al. 2014; Jenkins 2018).

e) The impacts of BIA on the management of existing buildings and the long-term sustainability of this land-use form were delimited from the study. It is noted that limited work has been conducted on this subject (Specht & Sanyé-Mengual 2017), and more work in this regard is welcome.

f) The study chose to limit the interviews of urban farmers and surveys of urban farms to the Netherlands, Belgium, Singapore and South Africa. In addition to South Africa, these three countries were included due to their significant development and success in urban agriculture and food production (CBS 2019; WUR 2019; MFA 2018).

g) The mapping of unused and underutilised spaces focused on a ground level survey of the city and documented only observable factors on site. Zoning rights and cadastral regulations were excluded from the analysis.

h) The modelling objective only considered passively controlled non-integrated RTGs that use nutrient film technique (NFT) hydroponic systems as a BIA typology, as this was the most widespread form of BIA implemented on a commercial basis in the Johannesburg and Tshwane urban contexts during the time of the study.

i) During the simulation phase, the study delimited the modelling to an Office building type. This building type was chosen as this function presents homogeneity in its building construction and layout. Residential and commercial building functions were excluded due to their diversity in occupation patterns and scheduled use.

j) This study only reviewed the retrofitting of existing buildings. While the high global demand for new buildings is noted (GABC 2016), Eames et al. (2013) argue that the turnover of buildings in existing formalised urban contexts are much lower and will require retrofitting to improve their energy efficiency. As a result, this study focused on a segment of the built environment that will require retrofitting to address climate change.

4.2 Limitations

The following limitations to the research outcomes must be noted:

a) Statistical findings from the unused and underutilised space mapping were only undertaken in the Hatfield neighbourhood in Tshwane. Generalising these findings to other neighbourhoods will require further mapping to be conducted.

b) The climate change risk analysis used to develop the mapping criteria was only applied to the Southern African interior and the CCA framework can only be considered relevant to cities in this region.

c) Due to financial constraints the survey of UA and BIA farms and interviews with farmers were restricted to four countries. This also limited the available time to visit each farm. As a result each farm was only visited once during the research period.

d) Due to limited monitoring equipment availability, the fieldwork and data collection periods of the rooftop greenhouses in Tshwane and Johannesburg were limited to between five to ten consecutive days for each season.

e) Unfortunately, the De Hoofd building farm burned down in October 2019, and as a result there are only winter data available for this site.

f) The performance modelling only simulated buildings in the City of Tshwane; to apply the findings to buildings in other regions, further location-specific modelling will be needed.

g) The modelling only considered one form of BIA, in this case passively controlled non-integrated rooftop greenhouses (RTGs). The statistical findings only apply to the specific construction and climate control methods used in the greenhouses documented in this study area. Interpretations of other BIA farm types will require additional modelling and experimentation.

h) The office building simulation in Tshwane used a weather file generated from data provided by the Proefplaas weather station located in Hatfield. The weather station is situated within the urban parameter and should provide the most accurate information regarding the local climate conditions. While the Proefplaas weather station would be affected by atmospheric changes due to local urban heat island (UHI) effects, its position does not consider the microclimatic impact of surface-driven UHI effects. Accordingly, the local UHI impacts were excluded from the study.

4.3 Assumptions

a) While little quantitative empirical data are available on the success of small-scaled catalytic CCA projects with cascading effects, the study builds on the urban acupuncture theory arguing for the implementation of a network of small scale in-situ projects to bring about change.

b) The spatial and material characteristics documented by the research assistants during the mapping phase were assumed to be accurate readings of the urban ground level conditions.

c) The feedback and responses by the farmers and specialists given during the interviews were assumed to be correct and accurate. The researcher assumed that their responses were based on their experience and knowledge gained in practice.

d) It is assumed that the farmers did not adjusted their practices and strategies while the microclimate field data were collected at the various rooftop farms.

e) The weather files used the final simulation phase were assumed to be accurate and correct.

f) During the long-term climate change affected simulations, the performance of rooftop greenhouses were assumed not be unaffected by prolonged weathering and continual maintenance of the structures is assumed.

5 Definitions of specific terms and concepts

In this thesis, terms are used that have specific definitions in the context of the study. The following list clarifies their use in the study:

a) Aquaponic system: "A closed loop system consisting of hydroponics and aquaculture elements" (Dos Santos 2016).

b) Building-integrated agriculture (BIA): Any form of agricultural food production system implemented within, on top, or attached to the built environment that enables synergistic exchanges between the buildings and agricultural functions (Thomaier et al. 2014).

c) Bioclimatic design: Bioclimatic design can be defined as the optimal use of local climatic and environmental conditions to achieve a controlled indoor environment with minimal energy use (Almusaed 2011; Conradie 2012). In this study a bioclimatic design approach also includes optimising a design to improve the growing conditions for plants with limited energy use.

d) Celsius: "a scale of temperature on which water freezes at 0° and boils at 100° under standard conditions" (Oxford dictionary 2020).

e) Climate change adaptation: "(The) adjustment (of natural and human systems) to actual and expected climate and its effects… to moderate or avoid harm or exploit beneficial opportunities" (IPCC 2014c).

f) Climate change mitigation: "… is a human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC 2014b).

g) CO_{2eq} ppm: The density of carbon dioxide equivalent gasses per million atmospheric particles.

h) Frequency of incidence (FOI): The number of instances where specific spatial conditions are documented (Hugo & du Plessis 2019).

i) Ground level observations: Fine-grained in-situ observations undertaken to ensure that current realities within a given context are documented (Hugo & du Plessis 2019).

j) Hydroponic system: “A crop production system where plants are grown in an artificial medium other than natural soil. All the nutrients are dissolved in the irrigation water and supplied on a regular basis to plants” (Nierderwiese & Du Plooy 2014).

k) Kelvin: “SI base unit of thermodynamic temperature (equivalent in size to the degree Celsius)” (Oxford dictionary 2020). This unit is often used to discuss variations in thermodynamic conditions.

l) Nutrient film technique: NFT systems consist of a thin layer of nutrient solution (called a film layer) flowing through plastic channels by gravitation and which contain the plant roots (Nierderwiese & Du Plooy 2014).

m) Parameter: A set of conditions for the successful operation of a specific land-use form.

n) Potential space impact (PSI): The aggregate spatial (area) potential of a specific space type (Hugo & du Plessis 2019).

o) Representative concentration pathways (RCP): “Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols… as well as land-use cover…” (IPCC 2014a).

p) Urban Agriculture (UA): “(A) ‘local food’ system that provides urban populations with a wide range of horticulture crops… grown within the city or in its surrounding areas.” (FAO 2012).

q) Zero-acreage farming: “All types of urban agriculture characterized by the non-use of farmland or open space…” (Specht et al. 2014).

6 Significance of the study

This study was based in a pragmatism paradigm, and can be considered a critique on a specific land-use type and its resultant impact on the built environment. Denscombe (2008) argues that this form of research is often developed in communities of practice and its findings generally aim to inform practice itself. While Hofstee (2006) proposes the differentiation between theoretical and practical significance of a study, due to its intention this research project rather mediates between the two forms of significance.

The research was undertaken in the built environment context. As a result, the research findings contribute to the South African climate change adaptation discourse by considering its application and impact on a smaller architectural scale. Furthermore, it is also significant in terms of its inquiry into a specific UA land-use type as a climate change response measure undertaken in South African cities. Finally, it also investigated the impact of a novel BIA farm type, passively controlled non-integrated rooftop greenhouses, on the thermal performance of office building typologies in South African inland cities.

Considering climate change crisis that the world is facing, this study considered an alternative avenue to implementing CCA measures. It responded to the concern noted by Smith (2010) that the development and implementation of CCA strategies have been protracted and ineffective. While Ziervogel et al. (2014) identify a lack of research and development towards implementing CCA measures in South African cities, there have been recent developments in this regard such as the work undertaken by the CSIR (2019). On the other hand, there has been little research considering the in situ, site level, implementation of CCA strategies and how the built environment contributes to climate change resilience and, importantly, is affected by these strategies. This study addressed this knowledge gap, and tested the potential of one land-use form, applied to office building typologies, as a retrofitting strategy to leverage the current urban context as a climate change response measure in South Africa.

Concurrently, the study also considered BIA as a novel land-use form as defined by Thomaier et al. (2014) and Goldstein et al.(2016). In accordance to the concern noted by Goldstein et al. (2016) that unsubstantiated assumptions in the urban agriculture discourse can unfortunately lead to misaligned policy decisions and the misappropriation of funding, this research project responded to many studies that identify BIA as an effective CCA strategy (Despommier 2010; Specht et al. 2014; Thomaier et al. 2014) and tested the efficacy of one such BIA farm type as CCA strategy.

The final contribution responds to the expected climate change-induced thermal increases forecasted for the Southern African region (DEA 2013). While several studies have considered the performance of rooftop greenhouses (BIA farm type) in cooler European climatic conditions (Delor, 2011; Benis et al. 2015; Nadal et al. 2017; Sanye-Mengual et al. 2018), this study considered the performance of passively controlled non-integrated rooftop greenhouses in warmer temperate South African climatic conditions. While studies have been done on the performance of greenhouses that are not integrated with buildings (Thipe et al. 2017), this study contributes by providing insight into the performance of *rooftop* greenhouses currently implemented in South Africa. The findings from this study can provide the basis for future research into improved rooftop greenhouse designs.

Finally, the analysis also investigated the long-term performance of these rooftop greenhouses and their impacts on their associated buildings under future climate change conditions. Insight into the long-term performance of specific CCA strategies is critical to developing appropriate strategies for the context in question.

7 Overview of chapters

This thesis consists of three main sections. The first section is both an introduction and premise to the study. The second section unpacks the research undertaken to consider the three research objectives. Finally, the third section is both a synthesis and reflection on the work undertaken and addresses the overall research question.

Section 1 consists of the first four chapters. This includes the introduction, literature review, research design, and a description of the research context. The introduction unpacks the background of the study and the research question as principal driver of the study.

Chapter 2 is the literature review of the study. It considers the current literature on the status of climate change as a global phenomenon, both the local and global climate change responses undertaken thus far, and alternative approaches to undertaking CCA initiatives in the urban context. Following on this, the current status of UA and BIA as CCA response strategies is considered. In conclusion specific research gaps from the literature review are identified.

Chapter 3 discusses the research design of this study. It starts by relaying the research paradigm followed in the study. As the study followed a mixed method approach the research design section is divided into three sections. In order to ensure clarity each section discusses the research design related to the specific research objective as a contained entity.

Chapter 4 elaborates on the context of the study. It commences by discussing the Gauteng city-region as the greater urban context and the similarities between Tshwane and Johannesburg. It then discusses Tshwane and its origin as Pretoria. Finally, the chapter elaborates on Hatfield, its development and current urban condition.

Section 2 unpacks the research undertaken in the project. Chapter 5 explores the urban structure of Hatfield, in Tshwane, in terms of its potential to accommodate BIA farms as CCA response strategies. The chapter starts by considering the mapping criteria and how it conveys an in-depth understanding of the urban structure's impact on the CCA potential of the neighbourhood. After establishing the criteria, the chapter discusses the research findings, and concludes by identifying space typologies that can act as leverage points in addressing the CCA capacity of the neighbourhood.

Chapter 6 relays the findings from the interviews and observational study of the various UA and BIA farms that were documented. The chapter starts by considering principle findings of both UA and BIA farms and how these spatially and technologically correlate or differentiate.

In the second section, the chapter unpacks specific findings relating to the BIA farms and reflects on trends and concerns identified during the analysis of BIA farms.

Chapters 7 and 8 discuss the findings from the final research objective. In Chapter 7 the microclimatic data collected from a series of RTGs are analysed. The chapter starts by giving an overview of the differences and similarities between the RTGs that were documented. It then continues to discuss the research findings using descriptive statistics. It concludes by discussing the differences in performance and how it relates to the greenhouse construction, material choices and the site conditions.

In Chapter 8, the latter portion of the final research objective is discussed. It starts by unpacking the parameters and characteristics of the various digital models that were used. It continues to discuss the findings in terms of their thermal and energy use performances derived from the simulations. Finally, concluding on how the RTGs affect the current and long-term performance of the built environment.

The **final section** reflects on the findings from the three research objectives and synthesizes them to address the research question. Chapter 9, as the synthesis, starts by defining CCA within the context of the project. It then continues discussing the findings from the three research objectives based on the definition.

Chapter 10 is the conclusion of the study. It briefly conveys the pertinent findings from each of the research objectives. It then continues to define the research contribution of the study. Finally, the chapter concludes with suggestions for further research and recommendations for implementation in the BIA industry.