Chapter 2: Literature Review.

Urban agriculture as climate change adaptation response strategy in South African cities.

1 Introduction

Climate change is a global crisis that requires innovative and novel solutions that span continents, political boundaries and different economic classes. Defined as a wicked problem by Roggema (2012), climate change is increasingly complex to conceptualise as its cause and effects are often temporally and spatially separated (Roaf et al. 2009). It is also important to implement these climate change mitigation and adaptation strategies immediately with long term goals in mind, as any delays in implementation will only result in added costs due to growing impacts of climate change (Stern 2006). While climate change has a global impact, Stone (2012) reasons it is on a local regional scale where climate change is both being driven and where its impacts are acutely experienced. Yet in order to develop an effective local climate change response strategy, aligned and collective global action is needed to achieve tangible results.

The chapter is structured along the following sections. It starts by considering climate change as a global crisis and what the current intentional response policies are. Subsequently, the impacts of climate change on the Southern African region, and specifically its cities, are discussed. It continues unpacking the various response measures undertaken in South Africa and how they impact the built environment. Next, cities and their roles in addressing climate change along with the associated vulnerabilities are considered. The section concludes by considering calls for smaller scaled networks of in-situ response measures to complement existing strategies. The literature review continues discussing urban agriculture (UA) and building-integrated agriculture (BIA) as land-use strategies that can be implemented in existing cities. It continues to consider the climate change adaptation (CCA) potential of UA and BIA. Finally, the literature review concludes by considering the focus of the South African UA discourse and consequently identifies knowledge gaps for further research.

2 Climate change: an international crisis

2.1 Current status of climate change

In 2014, the Intergovernmental Panel on Climate Change (IPCC) published the fifth assessment report (AR5) which unequivocally confirms that climate change is a direct result of anthropogenically generated greenhouse gas emissions (IPCC 2014a). In total the human race has generated 2 040 Gt CO_2 emissions from the start of the industrial revolution in 1750 until 2011 (IPCC, 2014a:04), even more concerning has been the fact that half of the global Greenhouse Gasses (GHG) emitted since 1750 were generated in the last 40 years (IPCC 2014:03). While 60% of the GHG have been absorbed equally by land processes (plants and soils) and the ocean, 40% of the GHG emitted are still in the atmosphere and will be there for an extended period (IPCC 2014a).

Since its inception the IPCC has been tracking the global GHG concentration, defining it as carbon dioxide equivalent (CO_2eq) particles per million (ppm). By tracking the global GHG concentration the IPCC noted a marked increase from the 1960's rising from 310ppm to crossing the 400ppm mark for the first time in 2015 (IPCC 2014a; Watts 2017). In December 2019 the global CO_2 ppm level measured at the Mauna Loa Observatory in Hawaii was 414.83 ppm CO_2 (CO2 Earth 2020). The global GHG concentration has therefore crossed a critical point and is consistently above the 400ppm level.

The 400 ppm level plays an important role in the work of the IPCC as it is considered one of the key thresholds which, if crossed, can result in extensive long term impacts (Bodle et al. 2016). The IPCC AR5 report has considered four representative concentration pathways (RCPs) (IPCC 2014:08). These scenarios predict the GHG concentrations in the atmosphere resulting from different development pathways to predict possible temperature increases and other related impacts. As the 400 CO_2 ppm threshold was already crossed in 2015, these models put the expected mid twenty first century values at 500 CO_2 ppm, meaning that the lowest representative concentration pathway, RCP 2.6, will be impossible to achieve by 2100 (IPCC 2014a). The most positive scenario assumes that our GHG emissions will peak by 2040 (IPCC 2014a). This still results in a temporary overshoot (between RCP 2.6 and RCP 4.5) requiring extensive land-use changes to stabilise the CO_2 eq concentration in the atmosphere (van Vuuren et al. 2011). As a result, permanent changes with increased impacts can be expected.

In the recent 1.5°C report by the IPCC (2018), concerns regarding the ability of countries, as a global community, to limit the average global temperature increase to below 1,5°C, as proposed by the Paris Agreement, is questioned. The report argues that the current 400-560 Gt CO_2 produced annually will need to be adjusted through mitigation efforts to 0 (zero) Gt CO_2 in 9 years (IPCC 2018b). This will be no small feat and will require highly expensive deep mitigation pathways to achieve such measures.

Climate change has already caused significant changes on a global level. The last three decades have been consistently warmer than the previous documented global temperatures; the global average of ocean acidification increased with 26% since 1750; and ocean temperatures are steadily warming at 0.11°C per decade since the 1970s (IPCC 2014a).

Increasing GHG emissions and the impact of climate change has had a series of adverse effects on all continents worldwide ranging from:

- changes in precipitation patterns,
- loss of ice and snow stocks,
- changes in ecosystems and specie ranges,
- adverse effects on crop yields,
- acidification of oceans affecting local biodiversity,
- sea-level rise causing coastal flooding
- and extensive erosion and groundwater salinization (IPCC 2014a).

These changes affect countries differently and are dependent on the local capacity to respond to these impacts.

The IPCC (2014a) identifies population and economic growth as being mainly accountable for the higher GHG emissions. The same report also notes that economic growth is a concerning factor due to increasing GHG emissions associated with it, while population growth has basically stabilised in most regions on earth. Satgar (2018) agrees that a neo-Malthusian view to control population size will not enable deep-seated change; these changes must confront the current economic structure and system. While the proportionate impact of either one of the two causes can be disputed, our manufacturing processes and our practices of inhabitation in the cities that we have built are contributing factors to the climate crisis. Currently, the international building sector consumes 32% of the globally generated energy and contributes 19% to the total annual Global GHG emissions (IPCC 2018b). The cities that we construct and inhabit accommodate large populations, facilitate certain lifestyles, and concurrently contribute significantly to the global GDP. Cities must therefore form part of climate change mitigation (CCM) and climate change adaptation (CCA) strategies. Yet in order to understand the actions that must be undertaken, these must be framed within the global climate change response strategies.

2.2 International response strategies

The IPCC uses RCP's as one of the methods to model scenarios and the potential impact of climate change. The RCP 4.5 model predicts periods of temporary overshooting during which extensive impacts will be experienced (IPCC 2014a). To minimise the impacts and stabilise carbon levels a concerted global effort must be undertaken that includes extensive carbon capture and storage methods, large scale afforestation and full adoption of bio and renewable energy in all countries (IPCC 2014a; IPCC 2018b). As climate change impacts are not spatially and temporally contained to specific regions with extensive GHG emissions, mitigation efforts by individual countries have limited success in securing their own future. A coordinated global effort to responding to climate change is needed.

2.2.1 Initial identification of climate change as concern

Climate change was initially postulated as a concern in a paper by Svante Arrhenius published in 1896 that discussed the influence of carbonic acid (CH_2O_3) on ground temperatures (Arrhenius 1896). The global scientific community only identified climate change as a concern in the 1980's following the publication of two large scale climate models developed in 1970 and 1971, respectively entitled *The Study of Critical Environmental Problems* and *The Study of Man's Impact on the Climate* (Roaf et al. 2009). These studies followed from continual physical measurements of the CO_{2eq} concentration levels at Mauna Loa volcano in Hawaii by Charles David Keeling since 1958 (Roaf et al. 2009).

Since linking global average temperature increases with global carbon dioxide emissions, a series of global initiatives were undertaken over the years. These include several important meetings: the initial Club of Rome meetings in 1970 during which the global crisis was first discussed; the establishment of the Intergovernmental Panel on Climate Change in 1988; and the establishment of United Nations Framework Convention on Climate Change (UNFCCC) at the 1992 Earth Summit in Rio De Janeiro (United Nations 1992; Roaf et al. 2009). The first Conference of Parties (COP) meeting was held in Berlin in 1995 and has taken place on an annual basis in order to foster a global agreement on climate change (Roaf et al. 2009). From these and subsequent meetings two important global treaties emerged.

2.2.2 Kyoto Protocol as global action

The Kyoto Protocol was the first international agreement working towards limiting global GHG emissions. It was first established in 1997 at COP-3 in Kyoto, Japan, and the aim was to lower the global carbon emissions to 5% below the 1990's levels by 2012 (UN 1998). Its global ratification was delayed by the United States as they insisted on Russia and China committing before they ratified their contribution (Eckersley 2007). As a result it was only adopted by 2011 by 192 nations as a legally binding treaty focusing on lowering the top six most impacting GHG types (UN 1998; UNFCCC 2018). It used the "common but differentiated responsibilities" (UN 1998:09) principle stipulating distinct GHG reductions for specific countries. The focus has been on lowering GHG emissions through improved technology efficiencies, protecting and enhancing GHG sinks, restructuring subsidies and reforming economies to promote GHG reduction, and finally promoting cooperation to facilitate knowledge and technology sharing (UN 1998).

Although ratified at a very late stage the treaty has been seen by many as more meaningful than the current Paris Agreement, as it differentiates responsibility as per historic GHG contribution and also stipulates very specific GHG emissions levels that had to be attained (Satgar 2018a). As criticism though, while the Kyoto Protocol proposed noble ideals in practice, few mitigation successes were achieved (Roaf et al. 2009). It also allowed for technical solutions such as carbon trading for entities that did not achieve the required carbon emissions reductions. While technical solutions are considered innovative, allowing developing countries to contribute through carbon mitigation programs, this approach also allows wealthy entities that fail to improve their practices to continue without undergoing any deep systemic changes.

The Kyoto Protocol primarily focused on carbon mitigation through lowered emissions and carbon sequestration, therefore ignoring the importance of Climate Change Adaptation (CCA) (UN 1998). Finally, as the Kyoto Protocol had a termination date, it left countries with little incentive or security to undertake expensive restructuring programmes as the future climate change response actions beyond 2012 were unclear.

2.2.3 The Paris Agreement as perpetual response measure

In response to the Kyoto Protocol that was only ratified to function until 2012, the Paris Agreement was promulgated on 12 December 2015 (UN 2015). While officially described as a legal framework to promote and facilitate economies to become carbon neutral, it is a voluntary based agreement under which countries choose to report and structure climate change mitigation strategies (Climate Focus 2015). A total of 195 countries, originally including the US and China, signed the Paris Agreement and it covers 55% of the global carbon emissions (Bodle et al. 2016). The recent withdrawal of the US from the agreement has been noted with concern, as it limits the effectiveness of the agreement (Pompeo 2019).

In its preamble the Paris Agreement argues for progressive and effective responses to climate change if an upper limit of 1,5°C (max 2°C) increase in global average temperatures are to be achieved (UN 2015). While the Paris Agreement focuses primarily on climate mitigation through the voluntary reporting of countries' national GHG emissions, it also acknowledges the importance of establishing CCA strategies in vulnerable communities (UN 2015).

The Paris Agreement promotes the use of a National Determined Contributions (NDC) mechanism along which each country structures and determines their own GHG emission mitigation goals, in order to undertake their mitigation measures (Climate Focus 2015; Satgar 2018a). This is shared and updated every five years. The Paris agreement also calls for the establishment of a public fund to assist poorer countries in developing CCM and CCA projects (UN 2015). These contributions are also on a voluntary basis, allowing countries to stipulate their contribution (Climate Focus 2015). The lack of specific direction regarding the funding contributions or differentiating between parties' contribution responsibility in the agreement has been noted (UN 2015).

The Paris Agreement sets out to establish a global vision to enable carbon dioxide production to peak as soon as possible. It requires the signatory countries to commence with carbon mitigation measures by 2020 (Bodle et al. 2016), while the first global stocktake of the agreement's progress will only take place in 2023 (UN 2015). While it is vague on when this peak CO_2 production should occur, it acknowledges that developing countries can peak at a later stage than developed countries (UN 2015). Unfortunately many critics argue that stipulating carbon emission cuts to commence only from 2020 onwards will be too late and by then the below 2°C goals as set out by the agreement will be impossible to attain (Bodle et al. 2016; Satgar 2018).

Criticism of the Paris Agreement is varied and depends on one's position regarding assigning responsibility to take climate change action. Many welcome the fact that the Paris Agreement established a common goal to which many parties agreed, and that this agreement is perpetual, unlike the Kyoto Protocol (Bodle et al. 2016). In terms of assigning responsibility, the differentiation between developed and developing countries is noted as a positive continuation of the Kyoto Protocol's "common but differentiated responsibilities" (Bodle et al. 2016). On the other hand, Satgar (2018a) argues that the Paris Agreement effectively abandons the "common but differentiated responsibilities" as the agreement is based on voluntary participation with often vague, ambiguous requirements. This effectively frees historically large GHG emitters from any obligation to take responsibility for their historic impacts. Critics hailing from developing countries argue that this does not allow for a just transition towards a global zero-carbon economy and presents countries that have contributed very little with the added globally shared adaptation and mitigation burden (Satgar 2018b). While this argument is fair, it is essential to note that a global shift towards a zero-carbon economy is vital and deep structural changes to the global economy are needed. This is effectively the responsibility of all parties concerned.

In conclusion, while many hope that the Paris agreement will foster significant positive results, extensive global changes resulting in local impacts can be expected due to both slow and inadequate responses from the international community. This calls for the implementation of CCA strategies to respond to the forecasted climate change impacts.

2.3 Climate change adaptation as response to the impacts of climate change.

Due to the global community's inability to take concise and swift action, and as we crossed the 400ppm CO_{2eq} mark in 2015, in the most optimistic scenario forecasts that we are heading towards RCP 4.5 conditions (van Vuuren et al. 2011). Furthermore, there is little hope that countries undertaking CCM actions will sufficiently curb GHG emissions (O'Brien & O'Keefe 2014). O'Brien and O'Keefe (2014) further argue that the current developmental aspirations, globalisation and neo-liberal economic policies, and the substantial quantities of fossil fuels still available for exploitation, reflect the lack of deep critical changes undertaken. Consequently large quantities of additional GHG emissions can still be expected. Responding to the current temperature increase of 0.8°C (IPCC 2018a) may seem prudent, but preparing for much higher temperature increases and its concomitant impacts is non-negotiable.

Climate change adaptation (CCA) is defined by the IPCC (2014c) as "… (the) adjustment (of natural and human systems) to actual and expected climate and its effects… to moderate or avoid harm or exploit beneficial opportunities". While adaptation is primarily focused on limiting the adverse impacts of climate change, there are also numerous co-benefits that can be harnessed for the local community (ASSAF 2011). The implementation of CCA need not only be considered as a negative cost to the community in question, but also provide opportunities to benefit to them.

On the other hand, climate change mitigation (CCM) "is a human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC 2014b). While both CCA and CCM strategies are considered complimentary, Roberts (2010) warns that within resource-constrained developing contexts, these two strategies need to be balanced to limit future risks and address critical developmental needs. While initiatives with specific CCA or CCM foci, such as the reforestation of Buffelsdraai landfill site in the Ethekwini Municipality (CCM focus), or the establishment of a local clinic in Melusi in Tshwane (CCA focus) (Figure 1), are needed these projects need not always have a singular focus. Projects can also address both CCM and CCA needs. That multi-foci projects can be ecosystem-based such as the redevelopment of Patersonpark in Norwood Johannesburg that provides both sustainable public space, manages projected increased stormwater quantities and increase local carbon sequestration capacities (Figure 2) (Brooker 2019). Smaller scaled building-integrated agriculture projects, such as *A Good Year* farm, also potentially lower the local urban heat island impact as well as provide food with reduced carbon footprints (Figure 2). While CCA projects can manifest spatially, some initiatives consider alternative, policy and regulatory based, approaches to stimulate large scale CCA responses.

Figure 1: Images of Buffelsdraai reforestation project (left) and Melusi health post (right). (Source: Aerial photograph - Google earth, Buffelsdraai photograph: Ethikweni Municipality Website, http://www.durban.gov.za/City_Services/development_plan).

Figure 2: Images of Paterson park (left) and A Good Year farm (right) (Pateson park source: Brooker 2019:46).

In the built environment these alternative approaches can be CCA frameworks that guide development in specific contexts. Several more generic CCA frameworks have been developed and can be adjusted for other sectors (Mukheibir & Ziervogel 2007; O'Brien & O'Keefe 2014). These generic frameworks include undertaking initial vulnerability assessments, identifying appropriate response measures, and finally, monitoring the success of these CCA strategies. To enable effective CCA measures, deep-seated change must be undertaken by not merely retaining the status quo but promoting transformation (Pelling et al. 2015; Sharpe et al. 2016). This must involve multiple sectors in the urban and rural environments, which collectively undergo deep structural CCA changes.

A number of studies specifically focus on the built environment and consider the technological adjustments needed to respond to climate change (Roaf et al. 2009; Smith 2010; Gething & Puckett 2013). Gething and Puckett (2013) in particular focus on quantitatively modelling the long term effectiveness of a series of adaptation projects in response to the projected climate change impacts. In South Africa a series of climate change response strategies have been developed for Cape Town (COCT 2006), Durban (ASSAF 2011), Johannesburg (COJ 2015;COJ 2009), and Tshwane (COT 2018). While these deal with CCM and CCA alike, a document developed for the uMgungundlovu District Municipality (uMM 2019) is one of the first guides that focuses explicitly on climate adaptation measures. A recent project undertaken by the CSIR (2019) mapped vulnerability of a number of small towns throughout South Africa, as well as developed a basic lexicon of generic CCA strategies for the South African context.

As noted, adaptation to climate change impacts is imperative for all countries regardless of their contribution to the crisis. To consider what this entails for South African cities, a review of the expected climate change impacts, as well as the CCA measures proposed for South Africa and Tshwane, is discussed in the next section.

3 Climate change in the Southern African context

3.1 Expected impacts of climate change on Southern African cities.

South Africa, similar to the rest of the African continent, is increasingly vulnerable to the impacts of climate change. To understand the climate change impacts on the urban environment, the cascading effects of larger macro disruptions must be considered. In order to contextualise these urban-based impacts, the discussion will briefly consider the macro scale impacts on Africa as a whole, before considering the Southern African region.

According to the AR5 report, Africa as a continent will be severely impacted by climate change, with indications of loss in water security, precipitation and snow cover (IPCC 2014a). Furthermore, the increased temperatures heighten the risk of wildfires both in rural and urban contexts. These increases in temperatures and loss in precipitation have been noted to drive desertification and changes in local weather patterns – resulting in a loss in biodiversity (Ziervogel et al. 2014). Climate change will therefore have multiple impacts, affecting weather patterns, ecosystems and biodiversity, and resource availability.

While multiple climate change-induced impacts are expected, on a social-economic scale the loss of livelihoods – specifically agrarian economies – often result in displaced people and forcing the relocation of whole regions (Roaf et al. 2009; IPCC 2014a). According to Tawodzera (2012), urbanisation in Africa is primarily caused by a loss in livelihoods in rural agrarian regions. These rapid shifts in population groups result in increasing pressures on poor developing cities to provide livelihoods and humane living conditions in already underserviced areas.

On a regional level the following impacts can be expected in Southern Africa. Increased ambient temperatures are the most well-known climate change impact. Currently, a 0.85°C increase in average global temperatures have been documented, this is projected to increase to at least 2°C by 2100 (IPCC 2014a; UN 2015). In South Africa the impact of temperature increases will be felt more severely, where on average South Africa is experiencing a temperature increase of 1.5 to 2 times the global average increase (DEA 2013). Should the IPCC AR5 predictions be correct this will lead to an average temperature increase of at least a 3-4°C by 2100.

Precipitation rates and temperatures are typically linked and changes in these aspects have long term economic, social and ecological impacts within a region. A study conducted in Gaborone in Botswana by Kenabatho et al.(2012), documents the regional temperature and rainfall changes and identifies a drop in rainfall correlating to temperature increases. While Botswana consists mainly of a dry semi-desert climate, these patterns were also identified in South Africa. Research conducted by the CSIR indicates that hot dry conditions will extend toward the interior of South Africa (Conradie 2017). Ragab and Prudhomme (2002) project that in Southern Africa the annual rainfall decrease will be 10-15% (southernmost areas – mostly South Africa) and 5-10% (northernmost areas), in addition, the east coast of Southern Africa will experience an increase in precipitation. This variation in rainfall quantity will increase water stress as some regions have a limited capacity to deal with increased water quantities; while other regions require strategies and systems to deal with extended drought periods.

The above-mentioned findings have been corroborated in many studies predicting a significant rainfall decrease in the central temperate zones of South Africa, with the significant expansion of the hot dry steppe conditions moving south-eastwards towards the Western Cape Area (Engelbrecht & Engelbrecht 2016; Mason et al. 1999; Shongwe et al. 2009). This will lead to interior regions with warmer and dryer winter conditions, and in summer less rainfall days are predicted, yet an increase in precipitation during these rainfall events is expected (Mason et al. 1999; Shongwe et al. 2009). Resulting, therefore, in increased storms and flash flood conditions, while also impacting on water security due to lower rain day frequencies. Generally inadequate infrastructure, due to little climate adaptation measures being undertaken, will result in entire urban regions dealing with both flooding and extended droughts.

The cumulative and cascading impacts of changes in precipitation patterns, as well as increases in ambient temperatures, present a concerning situation. The increase in ambient temperature also leads to the loss in soil moisture content through evaporation (Meadows &

Hoffman 2003; Shongwe et al. 2009). South Africa as a whole will therefore need to prepare itself for a significant drop in water availability (Engelbrecht & Engelbrecht 2016). As a result, Southern Africa can expect extended drought periods, short periods of excessive rain, and the increase in temperatures that will increase water consumption. Southern African inland cities will be especially vulnerable to changes in rain patterns both locally and in the South African mega-dams region (Scenario building Team 2007). These changes to the water supply, coupled with urbanisation, driving high water demand, will perpetuate water insecurity.

3.2 Impacts on an urban scale

These macroscale impacts will translate into a series of adverse impacts at an urban level. Among a range of cascading impacts, these changes can result in higher local temperatures causing heat stress and increased cooling loads, increased risk of debilitating heatwaves, escalating urban heat island impacts (UHI), and water and food insecurity. While several other negative impacts have been documented and forecasted to affect citizens, the literature analysis will only focus on increased temperature impacts, changes in water security, and food insecurity in the urban context.

3.2.1 Higher local temperatures

As already noted, climate change brings about higher local temperatures. South Africa, in particular, has been identified as being highly vulnerable to climate variability. Davis et al. (2017) report a series of climatic changes which in terms of temperature will result in increasing occurrence of very hot days (temperatures above 35°C) and fewer instances of frost days. Furthermore, a number of studies forecast the increasing frequency of heatwaves, as well as a rise in their duration and intensity (Lyon 2009; IPCC 2014a; Russo et al. 2016). These all point towards increased risks of high thermal exposure for inhabitants and the resultant adverse effects thereof.

One of the main climate change impacts related to temperature increases in cities is the phenomenon of urban heat-island effects (UHI). While climate change plays a role in higher temperatures and increased frequency of heatwaves, UHI is often also driven by localised changes and articulation of land-use patterns (Stone 2012). It is therefore important to note that UHI is not only caused by the increase in GHG emissions in the atmosphere, but also influenced by the urban morphology, landforms and local climate, changes in land cover, population density, and related thermal sources in the urban environment (McCarthy et al. 2010; Peng et al. 2011; Yow 2007). Peng et al. (2011), state that the city size and population density have minimal impacts on UHI, but rather the urban structure, i.e. placement of parks, shading of buildings, construction material use. As a result, designing cities to respond to and limit the impact of UHI is critical.

Increases in UHI often result in a series of negative impacts. The increase in the intensity of UHI leads to higher mortality and morbidity due to temperature increases, higher energy use during hot spells, changes in biodiversity and cycles, changes in microclimate and finally increased extreme weather events (Yow 2007; Seto & Shepherd 2009; Van Der Hoeven & Wandl 2015). When considering a typical building and its location in the urban context, developing strategies to limit additional external heat gains are important to both ensure that a comfortable indoor environment is achieved even during extreme heat spells, but also limiting the required cooling load that in turn drives the local UHI (Gething & Puckett 2013; Conradie 2017).

While increased ambient temperatures can be expected, a study by Conradie (2017) concludes that the required hours to apply solar protection for the built environment will increase significantly. The study establishes that in Tshwane the cooling period during which shading of the northern façade will be critical, need to be increased with six weeks (3 weeks at both the start and end of the summer season) to ensure thermal comfort (Conradie 2017). While improved bioclimatic design and shading are important, a study by Monana (2012) specifically focussed on Tshwane and the UHI effect on the city. Using remote sensing, the study concluded that the areas north of the city centre experience the highest degree of UHI. These areas are historically marginalised neighbourhoods that were developed during the Apartheid era, have high levels of exposed bare ground, and limited vegetation. As a result these areas experience significant overheating. These findings therefore call for the inclusion of vegetation in the urban environment and the appropriate bioclimatic designs that respond to higher temperatures.

These current and future impacts point towards adjusting buildings to retain comfortable indoor environments. On a larger scale, interventions must also respond and limit their contribution to the local UHI, improving the urban microclimate. On a more strategic level, response measures to increased heatwave events must be developed.

3.2.2 Water security

A second critical factor that will be experienced in South Africa is water insecurity. The City of Cape Town has since 2015 experienced severe water shortages (Oliver 2017), resulting in level 6B water restrictions, limiting users to 50 litres of water per day in 2018 (Felix 2018). This situation has been evident in many informal neighbourhoods and will possibly be extended to many established neighbourhoods in South African cities. On a macro scale climate change is affecting the availability of water, which affects functioning food networks, and health and sanitary standards. Similarly, a series of localised impacts on the water network within the urban environment have been noted.

A study conducted by Carden and Armitage (2013) argue that water consumption and water security is a complex nexus of both supply and demand. Two of the main drivers in increasing the demand for water supplies are population growth and urbanisation, resulting in increased consumption to maintain urban sanitation and grow urban economies (Vairavamoorthy et al. 2008). In terms of the supply of water, changes in macro precipitation patterns and increase in intensity in rainfall events result in lower water sources and difficulty in managing water resources (Mason et al. 1999; Shongwe et al. 2009). Urbanisation can therefore be identified as one of the drivers accentuating the impact of climate change through the resource system centralisation, increased water consumption, and limiting groundwater recharge by increasing impermeable surfaces.

In Southern Africa the provision and management of water as resource is of significant concern. While urbanisation has been noted as an important driver in water consumption, Dos Santos et al. (2017) note that considering water in urban contexts requires cognisance of the resource itself and the maintenance and distribution of this as a resource. In this regard many Southern African cities still lag in providing safe, affordable and accessible water to its inhabitants (Dos Santos et al. 2017).

Considering the complexity around water provision, a study by Johannessen and Wamsler (2017) investigated the various disturbances to water consumption in urban environments in South Africa, Sweden, Philippines and India. It concludes from a series of interviews with specialists that the primary causes for water services failure are internal bad management and maintenance (62%), following with the risk of hazards such as flooding (23%), and long term unsustainable extraction (15%) (Johannessen & Wamsler 2017). Therefore, not only is the availability of the source itself concerning, but also how it is managed, the methods of reticulating the resource, and finally how responsive the system is to change.

While water availability is a significant concern in the Southern African region, sub-Saharan cities have also been periodically affected by precipitation driven flooding. While the weather and increased extreme weather events are cited as factors impacting on flooding (Douglas et al. 2008), there is little conclusive evidence that changes in precipitation are driving these disasters (Kundzewicz et al. 2014). The principal causes of damage and casualties during urban flooding events are population increases and urbanisation within flood prone areas (Douglas et al. 2008; Kundzewicz et al. 2014). As a result, the choice in land surface coverage, lack of and inflexibility of stormwater infrastructure, little or no maintenance of infrastructure, and lack of land-use control lead to increasingly vulnerable cities that are exposed to flooding risks (Douglas et al. 2008). Urban flooding is therefore as much an externalised risk as being internally driven due to inadequate planning and regulation of city development.

3.2.3 Food insecurity

Food security is a complex issue as it is influenced by a multitude of factors, including temperature increases, cost of transportation, droughts, land availability, as well as socio-political conflict. Battersby (2012) argues that food insecurity within the urban environment is notably different from its occurrence within the rural environment. As it is not directly linked to a loss in food quantities itself, urban food deserts are often transient, invisible and complex (Battersby 2012). As a result we see food insecurity in the urban contexts unfolding in numerous ways. Battersby (2012) and Frayne et al. (2012) identify the following impacts of climate change on the food network that ultimately negatively affect the end-user:

a) Reduced food supplies – due to the adverse effects of climate change on agriculture.
b) Shorter shelf life – increased temperature and more exposure to vector and waterborne pathogens.
c) Limited food diversity – due to shorter shelf lives, consumers choose to only ingest a select range of non-perishable food types.
d) Less access to food - resulting from socio economic disruptions to the economy, impacts of extreme weather events, and poor urban planning.
e) Lowered fluid intake concern – due to increased temperatures and higher water insecurity.

A rural solution, ensuring that large quantities of food are made available, only addresses part of the problem. In addition, we see that climate change and the urban structure itself have negative effects on food security. As a result, more complex approaches must be undertaken in cities: addressing the food network, access to it and ensuring that high quality, diverse food types are made available. A concern is that the food network itself cannot respond to abrupt changes and disturbances, incorporate existing informal urban networks, or use waste as a resource (Battersby 2012; Paxton 2005).

While the food network is important to consider, the loss in water availability will have a cascading effect on food security. A study by Hanjra and Qureshi (2010), cites UNDP (2007), and states that water availability is a much more pressing concern in the agriculture sector than access and tenure of land. In addition to the quantity of water, they also voice the concern around the quality and safety of the water used for agriculture (Hanjra & Qureshi 2010). Water scarcity and higher exposure to temperature increases caused by climate change require innovative and efficient technological water management solutions, and changing crop types to heat tolerant and water hardy cultivars (Hanjra & Qureshi 2010). These added stresses will affect the poor as the most vulnerable due to limited access to water resources, but also since these adaptation measures are often expensive - doubly affecting the vulnerable populations (Hanjra & Qureshi 2010).

It is clear that the various adverse impacts on water, food and temperature are interconnected in terms of consumption and availability, as well as being sensitive to cascading impacts due to changes in any of these three sectors (IPCC 2014a). It is also important to identify these three factors' synergistic and competitive nature, balancing their impact through specific mechanisms and strategies are critical. The materiality and morphology of the urban environment has been identified as a vital component in how these three risk factors intersect. In order to consider how the urban environment should be adjusted to limit our exposure to these climate change hazards in South Africa, the national, provincial and local policies for CCA strategies will be discussed in the next section.

3.3 Existing South African policies and strategies that respond to climate change

3.3.1 National response measures

In response to the various adverse effects of climate change and the two global climate change agreements, the South African government issued a series of official responses. Part of the initial responses has been the “Climate Action now” conference in 2005 where a national commitment to promoting renewable energy sources was undertaken (ASSAF 2011). This resulted in the approval of the National Climate Change Response Policy published in 2008 where South Africa committed to plateauing its GHG emissions by 2020-2025 and lowering it in absolute terms from 2030-2035 (ASSAF 2011). Subsequently, the National Climate Change Response Policy Green paper was published in 2010 and ultimately led to the South African White Paper response to Climate Change published in 2011 (ASSAF 2011).

The South African White Paper Response to Climate Change, published by the Department of Environmental Affairs (2011), sets out a series of CCA strategies to respond to climate change. The document deals with adaptation on a national level (DEA 2011) and therefore has limited detail. It is also important to note that it was developed in response to the Kyoto Protocol. In June 2018 the draft Bill for Climate change (SA Government 2018) and Draft Carbon Tax proposal (SA Government 2017) have been published for public comment and will become effective on a national level. The carbon tax proposal was signed into law in May 2019, being effective from the 1st of June 2019 (National Treasury 2019). Furthermore, in 2019 the updated National Spatial Development framework was published, that also responds to the projected impacts of climate change. Finally, in 2019 the Draft National Climate Change Adaptation Strategy was published for comment. The National Climate Change Adaptation

Strategy builds on the White Paper Response to Climate Change published in 2011 and was finally approved in August 2020 (DEFF 2020).

The above mentioned White Paper (DEA 2011) is organised along climate change adaptation and climate change mitigation sections. It focuses on five specific sectors to address, being a) water, b) agriculture, c) health, d) biodiversity and e) cities. As a broad-based document it only sets out the principles to respond to climate change. The specific adaptation and mitigation strategies are at times vague or unclear in terms of its implementation. However, it does consider the developmental prerogative of the State and endeavours to balance development, adaptation, and mitigation as advocated by Lwasa (2010) and Roberts (2010). Finally, it aims to promote a polluter pays principle to stimulate sustainable growth and plans to structure the strategies along the three pillars of sustainability – economic, ecological and social.

In terms of water security, the white paper proposes a two-pronged approach: 1) establishing water provision as a short term measure in underserviced areas; and 2) enabling long term adaptation and response strategies. The response strategies are structured to be regionally responsive, considering water catchment areas as a whole, considering new water sources, and establishing new legal frameworks and regulations around water use (DEA 2011:17).

As a pressing concern, food security is addressed under the agriculture sector. The focus is on promoting large scale industrial agriculture practices, suggests using *Climate Smart Agriculture* strategies, and encourages employing adapted water and nutrient cycles (DEA 2011:18). Furthermore, the discussions on the health sector focus on public health to lower the impact on the vulnerable and poor. Awareness campaigns around public safety during extreme heat events are proposed, and methods around rolling out additional vector disease control measures are suggested (DEA 2011:19).

As far as supporting local biodiversity, the white paper suggests increased location-based management and research. It proposes renewed efforts to remove alien and invasive species. In terms of land-use management, it proposes expanded ecosystem infrastructure networks to allow for the movement of species and improve the resilience of ecosystems (DEA 2011).

Finally, in terms of cities, the White Paper (DEA 2011) proposes developing resilient infrastructure and behavioural change systems. It calls for the development of *Smart cities* to enable monitoring of the urban environment. In addition, a short discussion regarding improved urban design to improve water control is included. The impending impacts of climate change and the critical role that cities play in responding to climate change, defining how cities are adapted and included in these response strategies are critical (Hunt & Watkiss 2011). There is little discussion in terms of how cities can be adjusted to lower the exposure to climate change-driven hazards. Furthermore, there is a lack of consideration in how the functional, spatial, material and technological adjustments to the urban environment can improve the local climate change resilience and improve resource consumption.

The document entitled "Defining South Africa's Peak, Plateau and Decline Greenhouse Gas Emission Trajectory" published by the Department of Environmental Affairs in 2011 projects South Africa to start plateauing around 2020 – 2025 with a GHG emissions total of 398-583 Mt CO_2eq, with the upper limit being 614 Mt CO_2eq by 2035 (DEA 2011). It is further noted that South Africa's carbon emissions will peak at around 2035 (DEA 2011), if the correct mitigation strategies are implemented, yet it is unclear how those targets will be met. It is important to note that in 2016 South Africa already produced 498 Mt CO_2eq per annum (World Resource Institute 2018).

As a mitigation mechanism, the White Paper (DEA 2011) calls for the implementation of improved building, transportation and technologies to enhance energy efficiencies. Effectively proposing the use of improved technologies to achieve mitigation levels – importantly calling for a redevelopment of the current electricity system (DEA 2011). It also mentions changes in consumption and production patterns and incorporating land-use based carbon mitigation sinks. While little detail is given in this regard, it proposes a broad-based approach to climate mitigation other than only using technological solutions (DEA 2011). Yet the findings from the Long term mitigations scenario study (Scenario building Team 2007), identifies limited carbon sequestration options through land-use practices, such as REDD+ programmes, and mainly proposes improved efficient technologies, and market incentives and taxes to achieve the proposed mitigation goals.

In 2018 and 2019 the Government of South Africa published four documents for public comment:

a) The Draft Carbon Tax Bill (dated 2017)
b) The Climate Change Bill (dated 2018)
c) The National Spatial Development Framework (draft version dated 2019)
d) South African Climate Adaptation Strategy (draft version dated 2019)

The Climate Change Bill (2017) builds on the White Paper on National Climate Change Response published in 2011 and also shows commitment to achieve the National Determined Contributions (NDC) as published under the Paris Agreement (SA Government 2018). It mandates the integration and coordination of various Government spheres to develop a National Environmentally Sustainable Development Framework (SA Government 2018). The Bill calls for provincial and municipal governments to also undertake the necessary changes and develop context-specific multi-sectoral climate change response strategies. Finally, it articulates the need to develop both mitigation and adaptation strategies and monitor the national GHG emissions per sector.

Along with the publication of the Climate Change Bill, a Draft Carbon Tax Bill was published for public comment. The Draft Carbon Tax Bill (SA Government 2017) aims to penalise industries that fail to adapt to the climate change imperative by using the “polluter pays”-principle. Furthermore, it aims to stimulate sustainable development through tax incentives and generate funds to address climate change concerns.

The Draft Carbon Tax bill sets out to tax all CO_2 eq emissions associated with an industry or product, which include the raw material used and fuel consumed during its transportation and manufacturing (SA Government 2017). The tax bill also makes certain allowances for GHG emissions and sequestration strategies to be implemented. Criticism of the Carbon Tax Bill includes the fact that the GHG emission allowances are only presented as a percentage and not a sliding scale – therefore neither rewarding market innovators nor adequately penalising polluters that are slow to undertake changes.

The two additional documents aim to address the long-term adaptation and mitigation strategies on a national scale. These include the draft National Spatial Development Framework (SA Government 2019a), and the draft South African Climate Adaptation Policy (SA Government 2019b). Both these documents aim to guide development and the adaptation of existing regions, settlements, and assets in line with national policies and the expected climate change impacts.

The National Spatial Development Framework (NSDF) is based on the Spatial Planning and Land-use Act (SPLUMA) that was passed in 2013, and aims to guide public and private development to achieve an equitable and resilient spatial structure that addresses historic and current inequalities. It aims to accommodate population growth and rapid urbanisation, support a service-based economy, protect critical ecosystem resources, redress historic negative development, and balance urban and rural development (SA Government 2019a). As a national vision it aims to promote dense urban centres and, aligned with intense service corridors, promote human capital, limit carbon based industries, decentralise the food network, redevelop low carbon transportation networks, and develop improved public space in urban centres (SA Government 2019a). The document, therefore, addresses specifically equitable development, but also touches on the need to promote CCM through conservation of ecosystems and developing low carbon economies. Furthermore, it promotes CCA by identifying and protecting critical ecosystem service areas, as well as the adaptation of infrastructure and settlements to expected climate change-induced impacts.

The NSDF (SA Government 2019a) identifies multiple frameworks along which national development can be planned. One such principle framework focus on densifying urban development. In this framework the Eastern half of South Africa is identified as a potential region for development, as the western half of South Africa will experience significant water insecurity due to climate change. This requires balancing urban and agrarian regions for food production. Unfortunately, the document only mentions agrarian reform to climate change and not any changes in cities themselves. In the third framework specific regions that are both of ecological and resource importance are identified. The NSDF (SA Government 2019a) proposes the protection of these regions limiting any developmental activities in these regions in order to preserve the national water sources. The fourth framework addresses national service provision; identifying transportation networks and infrastructure, energy sources, and agriculture regions as critical foci areas. It proposes the re-establishment of the national rail infrastructure to promote sustainable transportation. Furthermore, it suggests transitioning from fossil fuel electricity plants to renewable energy sources, and finally promoting small-scale farmers as critical economic players in the national economy.

Even though the NSDF does not explicitly address climate change, its intention to balance climate change mitigation and adaptation along with critical developmental needs is commendable. Furthermore, as the document gives spatial guidance on a regional scale, to achieve the vision set out by the NSDF, a series of regional and local frameworks must be developed from this guiding document. This can potentially promote the required changes to the urban environment.

In 2019 the Draft South African Climate Adaptation policy was published for public comment and finally accepted in 2020 (DEFF 2020; SA Government 2019b). This document aims to function as a common reference point for multiple sectors and guide departmental and interdepartmental strategic planning. Based on the feedback from COP 16 (Cancun in 2011) and COP 21 (Paris 2015) the document specifically addresses the climate change adaptation requirements on a national level (SA Government 2019b).

This policy document hopes to achieve the following outcomes:

a) Increase local adaptive capacities.
b) Develop early warning systems.
c) Adapt specific sectors timeously.

d) Increase local knowledge and research.
e) Promote improved governance to achieve results.
f) Monitor and evaluate the progress of strategies undertaken.

(SA Government 2019b)

In contrast to the White Paper (DEA 2011), the Climate change Adaptation policy identifies a series of processes and strategies that must be undertaken to establish adaptation strategies. These include undertaking risk and vulnerability assessments, defining appropriate strategies and funding needs, and monitoring the results (SA Government 2019b). The policy should be successful its implementation as it is process orientated, ensuring its long-term implementation.

The assessment of the document reveals a holistic well-structured approach to climate change adaptation. Further analysis of the preliminary strategies or key focus areas for adaptation reveals little information regarding the transformation of South African cities. While the strategies focus on improved agriculture and additional food sources, monitoring biodiversity, resilient infrastructure, disaster management, and health management of individuals and communities; the impact and adaptation of built fabric, public space and urban structures are not addressed (SA Government 2019b). As the strategy makes provision for vulnerability assessment and continued monitoring thereof, this approach will hopefully allow additional focus areas to be identified as needed.

Although the national response has been slow, a series of important policies and bills have been developed and passed in recent years. These policies should assist local municipalities by providing the institutional and legal mandate to promote low carbon development. Unfortunately, none of the climate change centred policy documents explicitly address the urban and built environment.

3.3.2 Provincial and municipal response measures relevant to Tshwane

On a provincial level the Gauteng Department of Agriculture and Rural Development (GDARD 2011) developed a climate response strategy to guide projects undertaken in both urban and rural contexts. The document considers both mitigation and adaptation strategies. It proposes a multisectoral approach to mitigation – identifying the need for renewable energy sources, but also improved energy efficiency of the building stock (GDARD 2011). In addition, it promotes reducing and recycling waste, therefore lowering off-gassing in landfill sites. In terms of adaptation it has identified five areas of concern: water management and security, restructuring and developing of cities and infrastructure, protection of biodiversity, ensuring public health, and improving food security. The document also clearly articulates additional details regarding the objectives and who the various responsible stakeholders are.

The Gauteng Climate Change Response Strategy (GDARD 2011) translates high-level national strategies and identifies specific actions that should improve the local CCA capacity of the province. In terms of the urban contexts, it identifies densification strategies, improved regulation to collect rainwater and promote groundwater infiltration, stricter zoning and land-use management strategies to protect local biodiversity, and finally, promoting local food production in rural and urban settings on both commercial and subsistence levels.

The City of Tshwane (COT) itself has developed three documents. The first is an undated document entitled "Development of the Tshwane sustainable energy and climate change strategy" (City of Tshwane no date). The report focuses on major energy needs within the city and considers strategies to address it via alternative energy sources and monitoring methods. It identifies the Transport, Industry and Construction sectors as main areas of concern and proposes improved building stock, developing innovative products and implementing smart measuring methods to respond to the climate change crisis (City of Tshwane no date).

The second document is a draft report developed by the South African Cities Network (2014) the *City of Tshwane Vulnerability Assessment to Climate Change.* The document thoroughly identifies a series of risks and vulnerabilities in Tshwane and proposes the following eight adaptation focal areas:

a) Preventing the further loss of ecosystem services and goods.
b) Proactively dealing with the expected cooling demand in buildings.
c) Responding to increased risks and diseases to human and animal health.
d) Limiting damage to infrastructure due to flooding.
e) Addressing water insecurity.
f) Lowering the exposure to flood damage and extreme weather events.
g) Monitoring and addressing increases in sinkholes in certain areas.
h) Responding to the loss of food security in vulnerable communities.

Building on the vulnerability assessment undertaken in 2014, the COT developed the *Climate Response Strategy* (COT 2018), this document takes a much more structured and rigorous approach to address both CCM and CCA measures. Identifying expected high temperature increases, lowered water availability and localised precipitation driven flooding, and high levels of informal urbanisation as risks to the city. Ten climate change response strategies are proposed:

1) Protect natural ecosystems as climate change buffer.

   This specifically includes promoting the health of local wetlands to enhance flood control and improve water sources.

2) Develop integrated water management.

   Improving the water network and identifying diverse water sources such as groundwater, greywater and rainwater.

3) Building climate resilient cities.

   This includes formalising informal settlements, developing local infrastructure, and addressing the local food network with small scale projects as foodbanks.

4) Promoting densification and transit orientated development (TOD).

   This requires improved spatial development frameworks and adjusted precinct plans.

5) Low carbon and clean energy mobility.

6) Retrofitting existing buildings.

   The document advises that the COT goes beyond the existing National Building Regulations and implements its own Green Building Policy and By-Laws.

7) Improved energy efficiency.

   The document calls for improved access to energy-efficient technologies and energy monitoring on a household level.

8) Promoting the use of cleaner renewable energies.

   It proposes the use of small-scale energy generation but notes COT's dependence on revenue collected through the sale and distribution of energy.

9) Diverting waste from landfill sites and developing novel improved uses of waste sources.

   On a smaller scale it aims to improve local recycling, while on a larger scale the document proposes the development of waste to gas projects at the various municipal land-fill sites.

10) Promote and develop sustainable strategies and projects.

In conclusion, in South Africa a series of national and local response documents, policies and acts addressing climate change are available. Furthermore, it is positive to note that many of the initiatives and policies are recent developments and there seems to be momentum to create national change. Unfortunately, the number of years that the development of these documents has taken is concerning. The limited implementation of these policies, to bring about substantial national changes that contribute to the NDC's and local CCA capacity, is notable.

On a provincial and municipal level we see much more actionable response measures being proposed. These range from improved regulation and monitoring, to potential initiatives that can improve the local CCA capacity. While the intentions as set out by these documents are noble and encouraging, the limited implementation thereof is worrying. As noted by Lwasa (2010), Roberts (2010) and Kithiia (2011), Tshwane, similarly to other cities in developing contexts, is under severe developmental pressure and lacks the funding and capacity to effectively implement and develop CCA initiatives. As a result, there has been limited implementation of the proposed changes.

Implementing these strategies in the urban environment is critical due to both the increased vulnerability of cities (Romero-Lankao & Dodman 2011) and the urban structure's contribution to increase its citizens' exposure to adverse climate-induced impacts (Carter et al. 2015). While the local and provincial documents reviewed in this section identify a series of initiatives that can be undertaken in the build environment, this will require improved monitoring and regulation capacity. As a result, considering and testing in situ, ground level, strategies that can be implemented by individuals, building owners or communities themselves can potentially contribute to local climate change resilience. To develop such responses the urban structure itself, the nature of Southern African urbanisation, and its ingrained local adaptive capacity, needs consideration.

4 Rapid urbanisation and increasing vulnerabilities

4.1 The role of cities in responding to climate change

Cities have the potential to play a major role in responding to climate change. While cities cover less than 0.5% of the earth's surface (Schneider et al. 2009) the high population densities and growth trajectory emphasise the potential of cities to mitigate climate change and adapt to the various climate related impacts (IPCC 2014a). The AR5 notes that buildings contribute 19% to the GHG emissions, transportation consumes 27% of the global energy, and industry contributes 30% to the GHG emissions (IPCC 2014b). While this does not represent the full carbon footprint of cities, as these three sectors are closely related to cities, it gives us a fair indication of the resource consumption concentrated in 0.5% of the earth's surface.

While cities have significant environmental impacts, they are also notably vulnerable to adverse impacts of climate change. This is especially concerning in cities that are experiencing service-delivery deficiencies, increased population densities and higher than average climate change impacts (Lwasa 2010). Romero-Lankao and Dodman (2011) identify cities as being vulnerable due to their dependency on outside resources and services, therefore cities are impacted by distant disasters as well as localised effects. As a result we see cities being exposed to increased extreme weather events, heatwaves, flooding and salination of groundwater, increases in morbidity and mortality due to water and vector-borne diseases, water scarcity and flooding, loss in biodiversity and increased air pollution due to increased cooling loads (Hunt & Watkiss 2011). These impacts are both internally driven by the urban structure itself and through external drivers such as extreme weather events (Seto & Shepherd 2009).

Currently, it is estimated that 55% of the global population resides within cities – this figure is projected to grow to 68% by 2050 (United Nations 2019). While Asia and Africa are at the moment the most rural continents, they are urbanising at the fastest rate, with 46 of the fastest growing cities (growing at least 6% annually) located in these regions (United Nations 2016; 2019). A study by the United Nations Department of Economic and Social Affairs (2016) argues that while the growth of megacities is important to consider, the development of smaller cities (< 500 000; & 500 000 - 1 000 000 inhabitants) and the proportion of inhabitants that will occupy these are of similar importance. Globally these smaller cities will accommodate 32% of the total global population, four times more than what is projected for megacities (United Nations 2016). In Africa close to half of the urban population, approximately 25% of the total population, lives in cities smaller than one million inhabitants (United Nations 2016; 2019). Finally, these cities are projected to grow most rapidly in the next 30 years (United Nations 2016).

In South Africa the urbanisation patterns project that five of the larger cities will potentially grow to between one million and five million, while the bulk of the smaller cities in South Africa will fall under the less than one million population mark (United Nations 2016). As a result, the argument by Romero-Lankao and Dodman (2011), that poor-to-middle-class cities (often smaller to medium sized cities) with a limited capacity of to respond to the impacts of climate change, bodes true of most, if not all, of the South African cities.

The study acknowledges that a significant proportion of the newly developed urban areas in Africa, South Africa included, is informal in nature. These areas are often established beyond the urban edge and lead to polycentric cities, with significant levels of underutilised and low-density areas between these economic centres on the urban periphery (Chobokoane & Horn 2015). While in South Africa apartheid city planning is the primary cause of this urban typology (Dewar 2000; Schoonraad 2000), this phenomenon is also noted in many other postcolonial cities (Mabin et al. 2013). As a result, many of these new urban areas are poorly serviced, isolated and disconnected from the city centre.

While new informal cities are important to consider, Southern African cities also constitute older formalised neighbourhoods that are also changing to accommodate new denser urban populations (Mabin et al. 2013). These neighbourhoods typically receive less attention, yet they still require retrofitting as these neighbourhoods are affected by climate change internally, but also drive external impacts beyond their periphery. It is therefore important to not neglect the existing formalised urban conditions within the cities that are becoming more informal in nature.

4.2 The existing formalised Southern African city as research context

While several studies emphasise the high level of informal urbanisation taking place in Africa, specifically Southern Africa (United Nations 2019), it is important to acknowledge that urbanisation in Africa is diverse in nature (Dodman et al. 2017). As a result, the importance of understanding both the informal and formal urban contexts is critical, yet currently the overwhelming proportion of the studies still focus on the informal, under-serviced, small-scaled urban conditions (Schoonraad 2000; Turok & Watson 2001; Chobokoane & Horn 2015; Dodman et al. 2017).

In addition to the focus on the informal nature of African urbanism, a number of studies compare both informal and formal cities and neighbourhoods to improve our understanding of the differences and benefits that informal neighbourhoods provide. These studies focus on the nature of ecosystem services in the various contexts, service delivery, well-being and living conditions (Mcconnachie & Shackleton 2010; Cilliers et al. 2013; Sartorius & Sartorius 2016). While these studies are important, the focus remains on the potential interventions needed in the informal urban context, using the formalised only as comparative entities. Consequently, strategic thinking regarding interventions in formal neighbourhoods is still lacking.

Studies that have considered the formal urban conditions in Southern Africa, have focussed primarily on gated communities and security (Landman 2006; Lemanski & Landman 2008), gentrification (Visser & Kotze 2008), and the nature of public space (Landman 2016). The limited studies documenting formalised suburbs and neighbourhoods in Southern Africa and South Africa, note the changing nature of these older formalised neighbourhoods to accommodate increased densities, functions and new demographics (Mabin et al. 2013; Mabin 2014).

While Mabin (2014) notes these changes in the existing formalised neighbourhoods, these neighbourhoods have generally been neglected as a study field as they provide basic services and enable basic acceptable living standards (Sartorius & Sartorius 2016). However, these studies are important to understanding the formal context as a spatial entity and integral entity to climate change adaptation strategies.

4.3 The structure of formalised South African neighbourhoods increasing vulnerability and opportunities for adaptation

The water crisis in Cape Town, recent recurrent urban flooding, and the extensive sprawling urban nature of Johannesburg and Tshwane, demonstrate the inability of our cities to respond to climatic changes, extreme weather events and socio-economic shifts. Furthermore, the urban structure often perpetuates inefficient resource and space use. This is a result of both the urban spatial structure and the architectural form as response measure. These inefficiencies and limited adaptive capacities are therefore ingrained within the city structure.

One of the principal reasons for the manifestation of these inefficient cities is the legacy of the Modern, Western urban ideal upon which most South African cities are based (Dewar, 2000). South African cities are typically characterised as low in population density, and structurally separated and fragmented (Dewar, 2000). This often results in urban contexts with poor-quality public spaces, which neglect social and cultural activities within these spaces, and promote the isolation of functions and classes (Trancik, 1986; Schoonraad, 2000). Trancik (1986) argues that these spaces are caused by constraining zoning practices, modern urban planning, and car-centred spatial solutions, often resulting in mono-functional, inflexible urban spaces that are primarily designed to accommodate vehicular movement. Furthermore, Trancik (1986) argues that the focus on private property ownership, disregarding the value of public spaces and shared spatial entities, as well as typical anti-urban sentiments result in the abandonment of the urban centre, further degrading the city and leading to the phenomenon of open unused and underutilised spaces within the city. Trancik (1986) defines these spatial phenomena as “anti-spaces” – spaces that are undefined and that contribute little to the urban context, yet hold significant potential for redevelopment.

“Anti-spaces” (Trancik 1986) manifest on various scales, impacting the city and its inhabitants to various degrees. These open unused spaces often reflect an unplanned spatial phenomenon, yet in South Africa such spaces have also been purposefully designed to enforce separation and dislocation of certain neighbourhoods and races from each other and the city itself. The Natives Act of 1923 (Chipkin, 1998) and various revisions of Group Areas Act of the 1950s (Chipkin, 1998) and 1966 (Dewar, 2000) were instrumental in separating class and race in South Africa. While resulting in neighbourhoods with limited functional and response diversity, this planning approach was specifically aimed at marginalising specific racial groups. Unfortunately, the *Restructuring and Development Program (RDP)* implemented post 1994, continued this planning approach, developing isolated neighbourhoods with freestanding housing (Schoonraad 2000).

While the public investment and development focused on the periphery of the city continue the anti-urban sentiments as identified by (Trancik 1986), similar anti-urban strategies, as noted before, are implemented in existing formalised urban conditions as well (Trancik 1986). Furthermore, in response to the level of insecurity and crime, buffer zones, security measures and anti-spaces are often used in the Post-Apartheid cities as restriction and control measures (Landman 2016; Lemanski 2006). As a result, we find significant levels of unused and underutilised spaces on a macro scale in South African cities – yet on a meso-scale these cities are also characterised by similar levels of sprawling unused and underutilised spaces.

Upon considering the climate resilience of South African cities, Faling (2012) points out that in order to deal with the inefficiencies and inadequacies of these cities, processes of compact infill development, densification and urban renewal must be promoted. These forms of densification must be well-considered and located along structured networks, typically public transport networks, functioning as development corridors (Todes et al. 2000), thereby ensuring that services and goods are in optimum proximity to housing (Faling 2012).

While the proximity of goods and services is important to consider, using these anti-spaces to implement CCA strategies can significantly improve the climate resilience of these South African cities. These existing “anti-spaces” can present novel spatial opportunities as these spaces can be implemented as “novel, innovative, ‘disruptive’ design interventions” that can enable alternative modes of consumption (Ryan 2013:196). It is therefore the open-ended, indeterminate nature of the spaces that presents the opportunity to retrofit the cities on both a large macro and smaller detailed scales (Crowe & Foley, 2017). The existing formalised neighbourhoods present therefore opportunities to change and respond to climate change impacts – if the potential spaces to retrofit are identified and used.

5 Small scale retrofitting strategies to enable climate change action

While the IPCC has long promoted mitigation strategies, adaptation strategies have been lagging in their application, especially in urban contexts (Stone 2012:135). This has meant that the focus has been primarily on restricting GHG emissions, while strategies to limit the negative impact of climate change have been ignored (O’Brien & O’Keefe 2014). Fortunately, the AR5 acknowledges the value of adaptation. It argues for adaptation strategies that are context-specific, respond to multiple needs and include cross-sectoral stakeholders (IPCC 2014c).

As mitigation and adaptation strategies often have contrasting outcomes, implementing these in a balanced systematic manner is critical (Bulkeley & Castán Broto 2013; Leichenko 2011). To achieve coherence the AR5 argues that adaptation and mitigation strategies must be based on common principles and regionally and internationally coordinated (IPCC 2014c). Yet, balancing mitigation and adaptation strategies become increasingly complex when implemented in developing countries or cities. Within these contexts developmental and urbanisation pressures to provide basic services add complexity to implementing climate change adaptation and mitigation strategies (Bulkeley & Tuts 2013; Hamin & Gurran 2009; Lwasa 2010; Roberts 2010). This means that the developmental agenda of many governments must be limited. As a result, impacting on the ability of these very governments to achieve certain sustainable development goals. The integration of climate change mitigation and adaptation along with effective developmental strategies is therefore vital.

The extent and depth of CCA must be carefully considered. Satgar (2018a; 2018b) argues that merely using techno-fixes, solutions that retain the current status quo and economic model, do not allow for effective paradigm changes. In order to achieve effective change, deep-seated restructuring that addresses technological and structural, political and personal aspects is needed (O'Brien 2018). Systemic changes that restructure the current growth economy model need to be revised to enable *just transitions* at grass root levels (Satgar 2018b). These changes must therefore not only be technical solutions, but also socially and culturally responsive solutions (Wise et al. 2014). Strategies that address multifaceted aspects following ecosystemic approaches are needed.

Wise et al. (2014) argue that while an incremental approach to adaptation is typically advocated, it is often still reactionary to disaster events. A more proactive approach to implementing adaptation strategies is needed, especially when dealing with higher than 2°C temperature conditions (Wise et al. 2014). Long lead transformative initiatives and practices must be developed to promote effective adaptation strategies (Wise et al. 2014). In response to the top-down formal, often reactional, process through which national governments prepare and adjust to projected climate change impacts, an alternative approach to enable in situ smaller scaled networked adaptation strategies is needed. It is on an urban level where Ziervogel et al. (2014) highlight long term adaptation planning is lacking, therefore reiterating the concern noted by Wise et al. (2014). Developing strategies that can enable individual building owners and professionals in the built environment is critical.

Southern African cities often accommodate vulnerable poor populations and originally developed following Modern planning principles. As a result, these cities are often sprawling in nature and contain several isolated, unused and underutilised spaces. Additionally, these cities often have limited funding and expertise to apply extensive climate change adaptation initiatives (Kithiia 2011). Strategies that use the existing formalised city with its various inefficiencies and vulnerable elements, and retrofitting these to advance climate change responsive entities are needed.

To enable this Faling (2012) promotes a form of asset adaptation strategy and survey, similar to the regional survey techniques (conservation surgery) conducted by Patrick Geddes (Meller 1990), figure ground studies and linkage theory as developed by Roger Trancik (1986). Faling (2012) argues that by improving the existing assets and linking these to unused or underutilised land, compact infill development can be promoted. This requires identifying the unused and underutilised spaces in our cities and using these to upgrade and improve the current assets to be climate change resilient by promoting local CCA initiatives. These unused spaces can be retrofitted, as advocated by Eames et al. (2013), by altering the existing material or systemic context to improve the local resource consumption and use.

The use of large-scale unused or underutilised spaces has been considered extensively in the green infrastructure and ecosystem services discourses (Jim & Chen 2003; Lovell & Taylor 2013; Schaffler & Swilling 2013). Upon considering these spaces on a smaller scale within a neighbourhood setting, Tonnelat (2008) argues that these spaces can satisfy the unmet needs of citizens. These spaces, which are often considered worthless by authorities and planners, have a certain value to the inhabitants of the city. This contrasting reading of the city and its spaces is the very basis that brings about the opportunity for the recycling, retrofitting, regeneration and re-appropriation of these unused spaces (Trancik 1986; Jorgensen & Tylecote 2007). These spaces present opportunities to promote diversity, flexibility, modularity and multi-functionality (Trancik 1985; Tonnelat 2008; van Eegham 2011). All these above-mentioned aspects are important considerations in promoting resilience (Ahern 2011) and present opportunities for transforming South African cities to be more climate change resilient. Urban agriculture (UA) and building-integrated agriculture (BIA) projects are exemplary of retrofitting processes, such as this urban agriculture project in an unused space adjacent to stormwater infrastructure in Tshwane or the rooftop greenhouse installed on an existing factory building in Den Haag (Figure 3).

Figure 3: Existing UA farm in Tshwane and BIA farm in Den Haag, that are retrofitted to existing spaces or buildings.

6 Urban Agriculture as response to climate change.

6.1 The spatial nature of Urban Agriculture

As latent potential, a series of unused and underutilised spaces are often hidden within existing formal and informal cities. These unused and underutilised spaces in cities present diverse opportunities for novel and innovative retrofitting strategies. Defined as open roofs, dead facades, servitudes, worthless and neglected spaces, in-between spaces, and abandoned sidewalks (Trancik 1986), these unused and underutilised spaces provide a range of spatial retrofitting opportunities. Both the scale of the spaces and the articulation of the various spaces reveal the potential to develop complex and diverse spatial solutions. The study therefore postulates the implementation of UA in these spaces as a means to promote asset adaptation.

6.1.1 Urban Agriculture as a network of spaces

UA presents one of the retrofitting solutions that can be implemented in these unused and underutilised spaces. These can be implemented as networks of interventions, as Lovell (2010) argues that cities must accommodate various scales of UA solutions, ranging from city-wide networks and green corridors, to larger public spaces and private parcels for individual landowners. As suggested by Napawan (2016), this requires extensive spatial networks acting as productive spaces, as well as UA support networks.

Using these unused spaces to implement UA as CCA strategies in the urban environment can facilitate the transformation of the city. While UA cannot necessarily replace the conventional industrialised agriculture network, it is important to emphasise its potential supportive role in the food network (Bohn & Viljoen 2005a; Lovell 2010). This was specifically evident in the Cuban Special Period after the dismantling of the Soviet Bloc, during which UA played a vital role in supporting the existing local Cuban food networks, and ensuring food security (Rosset 2002; Howe et al. 2005).

Bohn and Viljoen (2005a) were among the first proponents of full-scale integration of the city with productive landscapes. They propose the concept of Continuous Productive Urban Landscapes (CPUL). CPULs aim to link, grow and build existing landscapes in cities to provide spaces that are environmentally, socially and economically productive; in addition these also promote multi-functional leisure spaces in an integrated linked network (Bohn & Viljoen 2005b). The concept of CPULs therefore promotes a new paradigm of open space development, advancing alternative landscape management and attaching new values to these open space networks.

Grant (2012) suggests that UA can be defined as an element in existing green infrastructure networks, which contributes to the four roles of green infrastructure, being cultural, supporting, regulatory and provisional (Grant 2012). Due to the heterogeneous nature of these spaces, a variety of green infrastructure systems and solutions can be implemented (Lovell & Taylor 2013), providing ecological, economic and social-ecological benefits (Schäffler & Swilling 2013). Senes et al. (2016), and Matos and Batista (2013) argue that UA can play a critical role in green infrastructure networks, and as a modular element it allows for easy implementation within greater systems of nodes, corridors and networks (Jim & Chen 2003).

Upon considering the open, unused and underutilised spaces in the city, the multifunctional and multi-scalar nature of green infrastructure (including UA as subset entity) makes it highly appropriate to implement in these left-over spaces (Lovell & Taylor 2013). Retrofitting these spaces provides the opportunity to address the underserviced urban conditions in Southern African cities and implement these as networks of provisional projects.

While many of these benefits are present in isolated UA projects, they can potentially provide an added advantage in cases where UA starts playing a role in a linked network of projects and systems. It is therefore vital to consider UA not only as stand-alone entities, but also as part of a greater network.

6.1.2 The adaptable and flexible nature of Urban Agriculture

One of the principal transformative qualities of UA is its ability to overlay a series of functions and activities on existing programmes. It therefore promotes flexibility and adaptability in various spatial conditions that makes it such an effective land-use strategy. Two examples of this approach have been the studies by Sanyé-Mengual et al. (2015) and Nadal et al. (2017), both authors developed methods to retrofit industrial warehouses with rooftop-greenhouses in Barcelona, Spain. Prompted by the scale of the industrial warehouse roofs, the notion of successfully adding contrasting functions to existing mono-functional spaces, emphasises the opportunity for cross-programming, promoting spatial diversity in cities. Both these studies also revealed the ease and relative low cost of transforming these mono-functional neighbourhoods.

The notion of increasing the programme intensity, and not only the population density, of cities is a critical measure in preparing and responding to the impacts of climate change in Southern African cities (Faling 2012). Krikser et al. (2016) argue that UA presents an opportunity to increase not only intensive productivity of land-use, but also an increased diversity of land-uses. Effectively enabling quality upgrades of the urban areas themselves. As a land-use strategy this provides alternative opportunities for new programmatic and land-use patterns in the city (Krikser et al. 2016). Krikser et al. (2016) continue arguing that as part of developing existing urban landscapes to accommodate productive spaces, we will also start seeing the development of Agro-Industrial spaces, which are intensive indoor farming spaces using highly developed technological applications. This requires a different innovative approach to consider both the exterior and interior space as productive (Despommier 2010), and ultimately using production within the city as a means to drive programmatic diversity.

While productive space is but one element in the city, dense urban centres often have limited open space. This leaves their residents with little access to spaces that are less regulated, controlled and programmatically defined. UA is often associated with the establishment and development of these new forms of undetermined public spaces. Napawan (2015) considered community gardens in San Francisco, USA, and noted that UA contributes to the public spaces in cities on multiple levels – as green infrastructure, educational and leisure spaces. Using UA as public space also holds certain limitations. Napawan (2015) notes concerns around access to the spaces for non-participants and the use of pesticides and herbicides during the cultivation of the produce. It is therefore important to also consider the conflicting needs of productive spaces and public spaces and designing for these spatial requirements.

Finally, UA has also been associated with a series of multifunctional projects developed on marginal, under-utilised and wasted spaces in the city. Matos and Batista (2013) noted the potential of UA to provide multiple multifunctional programs within unused, lost spaces in the urban environment. As a result, using the varied, heterogeneous spaces within the urban environment can enable more ecological intensive spaces (Bohn and Viljoen 2011). The use of these spatial conditions has been especially prevalent in a recent study by the United Nations Food and Agriculture Organisation (FAO 2012), which documented UA in many African cities. While the use of vacant sites, often brownfields, provides the opportunity for the poor to grow produce, these spaces also present a series of health and food safety concerns

(FAO 2012; Pennisi et al. 2016). Ultimately a balance between the safety standards and agriculturally productive potential will be needed.

In conclusion, UA can play a complementary and integral role in the spatial definition of the urban environment. It presents the opportunity to develop alternative functions, adds leisure spaces, and increases the productivity of the urban environment. Furthermore, it presents the spatial flexibility which allows it to be implemented in multiple spaces, especially existing unused spaces. These spaces can be integrated in a networked whole.

6.2 Urban Agriculture as climate change adaptation solution

UA has the potential to address both CCM and CCA needs in the urban environment (De Zeeuw 2011). While several studies have identified the CCM potential of UA, the review will specifically focus on the latent CCA capacity of this land-use form. Roberts (2010) argues for holistic integrated adaptation strategies to ensure successful contribution to the overall climate resilience of an urban environment.

Roberts et al. (2012) further build on the notion of integrated adaptation, promoting Ecosystem-Based Adaptation (EBA) strategies that focus on initiatives that enable “bouncing forward” strategies to promote development and improved solutions. Roberts et al. (2012) propose using the impending climate change-driven disasters and need for responses as a means to develop better alternative strategies enabling “systemic and proactive” approaches. This requires a deep understanding and implementation of sustainable strategies, and using green infrastructure and ecosystems services as premise for alternative systemic development (Roberts et al. 2012). This study argues that UA has a role to play in these adaptation strategies.

As noted in the AR5 report, Southern Africa can expect impacts on its food networks and water security and will have to deal with increased average temperatures (IPCC 2014a). While there are various other linked negative changes to be expected from the increase in GHG emissions, the focus will only be on the above-mentioned climate change impacts.

6.2.1 Adaptation to improve food security

In terms of food security, Viljoen et al.(2005) argue that UA has a limited capacity to completely replace existing agro-industrial systems, yet developing alternative growing methods allow additional food sources to complement the current food system (Samangooei et al. 2016; Dos Santos 2016). Dubbeling and De Zeeuw (2011) further elaborate on food security by considering diverse food sources, varying scales of implementation, and continuous innovation in the UA field. They argue that this improves the resilience of urban inhabitants by increasing the diversity of stakeholders in the food network (Dubbeling & De Zeeuw 2011).

Thomaier et al. (2014) consider zero-acreage farming (farms that are integrated with the built environment and do not use open land or agricultural land) in the urban environment to promote food transparency, and improve the quality of the food produce and food equity. In response to the concerns noted by Battersby (2012), UA can therefore contribute to food security by providing localised employment, increasing access to diverse food types and extending the shelf life of the food due to limited travel needs. When considering food security, it is often not the quantity of food but rather the quality and diversity of food types that are considered important (Faber et al. 2013). Even though food quantities are limited, access to critical mineral and nutrient rich food can make a difference in local diets (Faber et al. 2013). A study by Nierderwiese and Du Plooy (2014) indicates the range of food types that can be grown through hydroponic systems or on feasible scales in the urban environment. This can enable improved access to critical minerals and vitamins but not staple food types. UA therefore does not always need to focus on providing quantities of food, but instead promotes access to healthier food options.

Furthermore, Delor (2011) documented various building-integrated agriculture (BIA) examples, illustrating both improved energy consumption rates and the potential to grow food on an intensive scale using innovative food production technologies. A study by Jenkins (2018) considers the efficiency of using building-integrated, naturally lit technical food systems to retrofit and use existing buildings in Manchester to become productive spaces. The findings concluded that if all cities in the UK retrofit their existing open facades and concrete roofs with BIA, 1.5% of the total calorific needs of the UK will be met (Jenkins, 2018). This calculation highlights the fact that UA will not be able to substitute the existing food network. Yet, if these projects focus on retrofitting buildings in neighbourhoods dealing with malnourishment, these additional food resources can be channelled to vulnerable and food-insecure community members.

In addition to providing climate-resilient food systems, UA also provides climate-resilient jobs. Frayne et al. (2012b) conclude that the current urbanisation experienced in sub-Saharan countries rarely accompanies any economic improvement. As a result, rural poverty is often merely exchanged for urban poverty. It is therefore essential to start developing climate-resilient job opportunities in response to climate change. Dubbeling and De Zeeuw (2011) argue that UA can promote alternative employment opportunities. They argue that, as a climate change adaptation measure, UA can absorb the increased employment losses in rural areas and other industries due to adverse climate change impacts. The added employment options can in turn address urban poverty and its resultant limited access to food as one of the factors affecting food security (Battersby 2012).

6.2.2 Adaptation by providing habitat to increase biodiversity

While UA can provide various benefits to the inhabitants of a city through diverse applications and development opportunities, it also addresses the concerns surrounding biodiversity in the urban environment. In a study conducted by Bernholt et al. (2009), the biodiversity of a series of case studies in Niamey, Niger, were assessed and found a marked increase in those sites that have implemented UA. The study argues that contrary to typical ornamental gardens, the diversity of plant species grown by urban farmers result in higher biodiversity being found on these sites. This argument does not hold true if conventional industrial farming practices are used, but if the farmers adopt permaculture or agro-ecological farming strategies, the biodiversity can potentially be increased.

Lwasa et al. (2014) builds on this notion in a study considering the climate resilience of UA, specifically considering urban arboriculture. Lwasa et al. (2014) and Orsini et al. (2014), argue that through use of urban forests, rooftop gardens and various soil-based agriculture that require pollination, we not only see the retention of the produce itself, but that these farms provide habitat for additional organisms, allowing for mutualism and commensalism. Knuth (2005) also considered urban forestry within city limits and conveys similar findings.

6.2.3 Adaptation by responding to increasing temperatures

In response to the expected increasing temperatures, there has been a growing interest in research into the cooling impact and effect of vegetation through evapotranspiration, improved insulation of buildings, increasing the albedo factor of façades, and providing additional cooling, humidity and wind control (Lovell 2010). A clear correlation between vegetation and the lowering of UHI has been documented (Jonsson 2004; Di Leo et al. 2016). A study considering the UHI in Tshwane found that bare ground with no vegetation experiences the highest land surface temperatures (Monana 2012), while studies by Jonsson (2004) and Lindén (2011) found that added vegetation resulted in more moderate temperature ranges, therefore stabilising the outdoor temperatures in cities and as a result lowering the cooling loads of buildings. UA implemented in various smaller marginalised, unused spaces, holds the potential to assist with lowering UHI impact and, if implemented correctly, cool the built environment itself.

As noted, the cooling effect brought about by added vegetation and managed landscapes in the urban environment enables improved outdoor environments and ameliorates excessive ambient temperatures in the public spaces within the urban environment. Corburn (2009) modelled the thermal impacts of urban agroforestry, planted green roofs and Cool Roofs in New York, USA. The findings noted that urban agroforestry holds significant cooling potential, but must be implemented in combination with strategies which increases the albedo factor of building surfaces and roofs. Corburn (2009) noted though that acquiring enough space to implement agroforestry is difficult and should be carefully considered.

Lovell (2010) and Matos & Batista (2013) considered soil-based UA, using it both as urban design devices and, in the case of Matos & Batista (2013), as means to activate open spaces and leftover interstices within the urban environment. Both these studies cite the cooling effect and means to create comfortable micro-climates by implementing UA on multiple scales. These urban farms cool the immediate environment through added shading and evapotranspiration (De Zeeuw 2011; Lwasa et al. 2014). Similar arguments are made for application of BIA used as both cooling and heating devices to stabilise the indoor environment of buildings (Specht et al. 2014; Thomaier et al. 2014).

A study by Samangooei et al. (2016), comparing soil-based and soil-less agriculture systems, finds that soil-based agriculture provides more potential for UHI amelioration, yet in both cases these systems must be exposed to the outdoors. Indoor UA, therefore, have a limited cooling potential.

While the additional vegetation in the urban environment has been found to effectively cool large urban spaces, the impact of added vegetation to building facades and roofs are also of indispensable value. Castleton et al. (2010) consider the effectiveness of planted green roofs to improve the energy consumption of buildings through added insulation. Castleton et al. (2010) specifically documented and modelled the use of planted roofs and considered its impact on retrofitted buildings; the findings show that the added insulation lowers the heating and cooling energy requirements of buildings. Furthermore, this retrofitting strategy has been the most successful when retrofitting older buildings with low insulation values (Castleton et al. 2010). Delor (2011) extended the research including climate-controlled rooftop greenhouses (the growing technology was not defined) that are integrated with the building below. The findings show an improvement of integrating rooftop greenhouses by between 13-41% for well-insulated and poorly insulated buildings respectively (Delor 2011).

6.2.4 Adaptation through improved air quality

Dubbeling and De Zeeuw (2011) argue that UA reduces both UHI and air pollution by providing local and hyper-local food and as a result limiting the food miles and transportation energy to transport produce – which further disrupts the positive UHI and pollution feedback loop. Studies have argued for the absorption of pollution and capturing of dust particles, which often include heavy metals, as a positive attribute of green infrastructure and UA (De Zeeuw et al. 2011; Samangooei et al. 2016). In a study sampling the dust capturing capacity of creepers in both urban and rural contexts by Ottelé et al. (2010) it is found that in both cases the leaves of the plants capture significant levels of pollution and dust. This has been confirmed for both sides of the leaves and does not differ seasonally.

The ability of crops to absorb dust and toxins carries certain risks. Research by Säumel et al. (2012) confirms that produce grown in polluted conditions absorbs toxins, highlighting food safety concerns. Säumel et al. (2012) found that using planted barriers (strips of non-edible plants) significantly reduce the toxic levels in the produce; as alternative planting leafy greens in safe, controlled environments such as greenhouses also ensure the food safety (Thomaier et al. 2014). Although UA need not always be associated with edible produce and can also include alternative energy resources, bio-fuel stock, and non-edible goods. Importantly, arguments for UA that contributes to cleaner air quality must consider the final use of the product.

6.2.5 Adaptation through alternative water management

UA presents a series of benefits to water security in the urban environment, ranging from lowered water consumption, increased permeability and stormwater management, and ultimately the effective use of rainwater harvesting strategies.

The agriculture sector in South Africa uses two thirds of the water in South Africa (Bronkhorst et al. 2017), highlighting the important link between food and water security. UA covers a wide base of produce growing systems, that include soil-based organic methods, conventional soil-based agriculture, and soil-less agriculture using aeroponics, hydroponics and aquaculture (Thomaier et al. 2014; Samangooei et al. 2016). High-tech agriculture, described by Thomaier et al. (2014) as soil-less agriculture, is known to be significantly more efficient in terms of water consumption, as well as limiting water source contamination through its highly controlled growing environments (Astee & Kishnani 2010). While innovative technologies can be employed in both rural and urban settings, UA also presents other benefits in terms of stormwater management, using alternative water sources, and efficient water consumption strategies.

A number of studies analysing UA farms, found that alternative water sources are often used. These include rainwater collection, use of greywater, and the circulation or reuse of water (Moglia 2014; Thomaier et al. 2014; Samangooei et al. 2016). In a feasibility model considering UA in Singapore, Astee and Kishnani (2010) calculated that sufficient rainwater would be available to grow for up to 35% of Singapore’s vegetable needs. Similar findings were noted by Lwasa et al. (2014) identifying several UA projects where rainwater and stormwater runoff are used to supply water to farms. Lupia and Pulighe (2015) considered the resource potential to use harvested rainwater in Rome, Italy. Their findings indicate that harvesting rainwater and, very importantly, using highly efficient irrigation systems, can ensure that 41% of Rome’s residential gardens can be supplied with rainwater. It is important to note that many of these studies have been undertaken in high rainfall regions with frequent rainfall events. Similar rainwater-use strategies will need to manage lower rainfall quantities and lower frequency of rainfall days in the Tshwane context.

Using soil-based agriculture increases the soil permeability, thereby limiting stormwater runoff and recharging groundwater (Dubbeling & De Zeeuw 2011; Lwasa et al. 2014). A study conducted by Moglia (2014) on a theoretical UA project undertaken in Melbourne considered the financial feasibility of using harvested stormwater for UA produce. Moglia (2014) found that it is feasible to implement large-scale infrastructure if implemented with industrial-scale agriculture, as the produce only requires lower quality, fit-for-purpose water. Also noted in African case studies, UA plays a role in the urban waste cycles using organic and sewage waste in crop production (FAO 2012; Lwasa et al. 2014). While this can be considered as a step towards circular waste cycles in the urban environment, concerns around food safety and heavy metals content have been raised (FOA, 2012).

In conclusion, UA therefore presents diverse alternative strategies to promote CCA agendas in South African cities. As noted in the work of Padgham et al. (2015), the flexible, robust, modular and responsive nature of UA highlights its potential to be a transformative catalyst in the urban environment. UA can potentially play a critical role in implementing robust climate change response strategies in the urban environment and address critical vulnerabilities related to increasing temperatures, water and food insecurity.

6.3 Building-integrated agriculture as novel application to harness co-benefits

In recent years, building-integrated agriculture (BIA) developed as a novel land-use type in the UA industry. BIA was first defined by Caplow (2009) as highly efficient hydroponic systems integrated with the built environment that facilitate in the capture and reticulation of resources within the associated buildings. A subsequent study by Specht et al. (2014:35) uses the definition Zero-acreage farming (ZF) to identify "… all types of urban agriculture characterized by the non-use of farmland or open space…". Specht et al. (2014) argue for broadening the narrow, and exclusionary, definition by Caplow (2009) to include other forms of agriculture that are integrated with the built environment. This study adopted the argument by Orsini (2020) that ZF and BIA can be considered as similar land-use forms. As a result, it chose to use the "building-integrated agriculture" term as it reflects the innovative use of the built environment and conveys new alternative spatial and technological solutions to implement agriculture on or within buildings.

While BIA shares many of the co-benefits that UA presents and provides three additional, and optimised, opportunities namely: improved decentralised food networks, optimised urban land-use efficiency, and increased resource circularity. Integrating farms with the built environment allows these productive spaces to be located close to consumers (Despommier 2010; Specht et al. 2014). This presents the opportunity to disrupt the current food network and provide local and hyperlocal produce. While the integration of consumers and producers holds a number of co-benefits, one pertinent advantage is the role that BIA plays in urban regeneration initiatives. As advocated by many, BIA projects often address socio-economic issues and improve the urban environment by upgrading local building stock (Galt et al. 2014; Jenkins 2018). The BIGH farm in Brussels is a typical example of such an approach (Figure 4)

Figure 4: BIGH farm in Brussels that forms part of the urban regeneration initiative.

As part of these urban regeneration strategies, using BIA can provide opportunities to optimise urban land-use practices. Many authors have noted the potential of BIA to activate unused and empty buildings or spaces in cities by promoting diverse programmes in these spaces (Despommier 2010; Specht et al. 2014; Thomaier et al. 2014). Due to the multifunctional nature of UA and its ability to facilitate alternative programmes along with its application, integrating agriculture with the built environment allows one to develop a range of alternative response strategies that will be appropriate for the specific space and context (Figure 5).

Figure 5: DakAkker, Netherlands, as a typical BIA project that improves the multifunctional quality of the existing building and context by adding additional public spaces to an existing building.

Finally, while many authors have noted that UA improves the resource consumption in cities, a closer relationship between the farms and the built environment increases its efficacy (Goldstein et al. 2016). As stated earlier, many authors have noted diverse and improved circular resource strategies facilitated through BIA (Despommier 2010; Specht et al. 2014). Additionally, Thomaier et al. (2014) argue that BIA can improve the energy efficiency of the architecture that hosts these farms. Integrating these two land-uses allows one to improve the effectiveness of their symbiotic relationship. It is important to note that the various farm types and technologies present varied opportunities to recycle resources and improve the local energy efficiencies. One such example is a highly sophisticated solution such as the ICTA-ICP building located on the Autonomous University of Barcelona campus. The integrated rooftop greenhouse on the ICTA-ICP building is a highly successful precedent that improves both the energy efficiency of the greenhouse and its associated building by retaining and reusing heat generated in the building and the greenhouse as well as using rainwater collected on the building's roof within the rooftop farm (Figure 6) (Nadal et al. 2017).

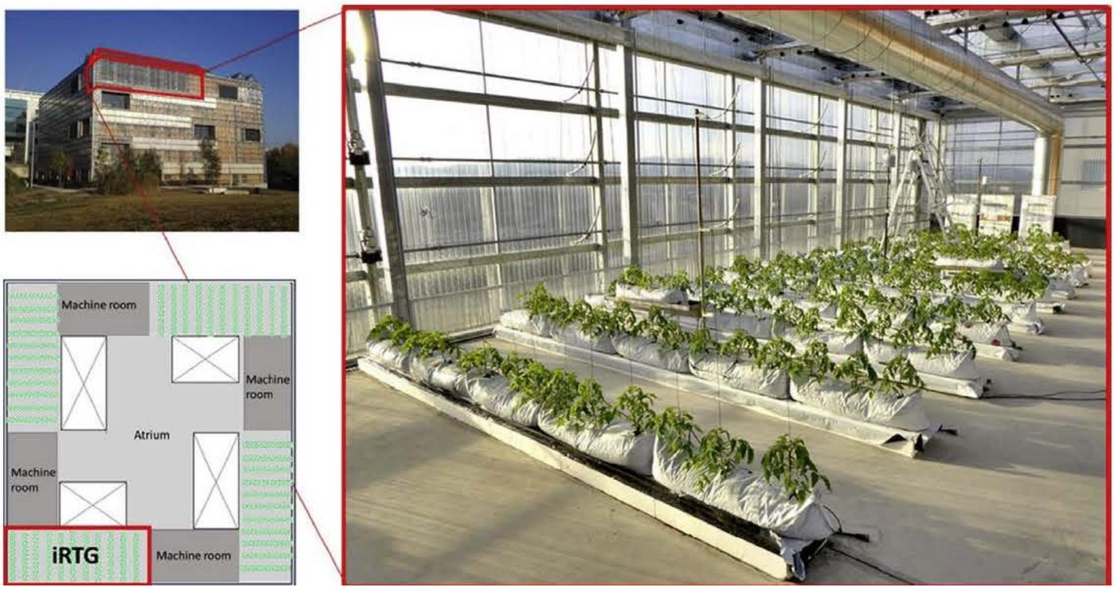

Figure 6: ICTA-ICP building with the integrated rooftop greenhouse (Source: Nadal 2017:341).

In the literature review it is noted that BIA enables a series of co-benefits which would otherwise be difficult to harness in our built environment. This does not mean that entirely new solutions are needed, but rather alternative methods of implementing these projects spatially and technically.

7 Current knowledge gaps and research focus

7.1 The status of South African urban agriculture research

While UA developed as a discourse over many decades, there has been a continuous shift in its role and focus in the urban environment. Urban agriculture is not a modern phenomenon with subsistence farming being part of historic city making. In South Africa the earliest towns were planned to allow food production within the urban boundary (Holm 1998). Importantly a number of important shifts in UA's development are worth noting. Early models of integrating farms with lower density urban forms such as the Garden Cities proposed by Ebenezer Howard in 1898 (Howe et al. 2005) and the Broadacre City design by Frank Lloyd Wright (1935) questioned the limited formal integration of productive landscapes with the urban context. During the second world war it developed as a patriotic act in the form of Victory gardens or War gardens in Britain and the USA, and during the oil crisis UA re-emerged as a sustainable food production strategy (Howe et al. 2005). In the 1980s we also see a return to considering UA as a developmental strategy to uplift the poor. In recent years, with the emphasis placed on climate change, questions around the CCM and CCA benefits and potential of UA have been voiced by many studies. We therefore see UA addressing a social interest with its added economic concern, while its ecological intention was later added, and finally, with the work of Viljoen (2005), its spatial role in the densely occupied city was bought into the discussion.

In South Africa the focus has consistently been on UA as a developmental tool, starting with the work of Rogerson (1993) discussing UA as means to address the inequalities of apartheid urban planning; May & Rogerson (1995) documenting the various poor South African households using UA as income supplement; to Martin et al. (2000) documenting households in Zimbabwe and South Africa (Cape Town and Mamelodi) highlighting the need for UA Policies to enable greater uptake of this as a developmental strategy. Finally, Thornton (2008) considered the low uptake of UA in the Eastern Cape. As a recent initiative by Naude Malan and Angus Campbell (Malan 2015), *Izindaba Zokudla* aims to promote the function of UA through a participatory action process in poorer neighbourhoods in Johannesburg. While UA has not truly moved beyond the developmental consideration in South Africa, one South African author (Webb 1998; 2011) has highlighted the inconsistencies in the reported outcomes and findings on UA's successes as a developmental strategy.

While Webb’s (2011) concerns are important to acknowledge, a system-wide consideration of the food network emphasises that the dilemma does not necessarily lie within UA per se, but within the South African food network. As noted in the work of Bennie & Satgoor (2018) the food network and farm infrastructure in South Africa, echoing global concerns, only function on large industrial scales. This impedes the ability of smaller-scaled UA to establish itself as a complementary entity within the food network, as proposed by Bohn and Viljoen (2005a).

Others have also questioned this notion of considering produce and economic feasibility in the UA discourse. A narrow, purely economic view of UA, misses the multifunctional beneficial quality of UA projects as social, economic, ecological and spatial initiatives. Slater (2001) argues that the narrow economic criterion to assess UA ignores a multitude of additional psychological and social benefits when implemented as a developmental strategy. This has been confirmed in a later study that used in-depth case study analysis of individuals involved in UA projects in Cape Town (Battersby & Marshak 2013). As a result, while rigorous empirical data is needed in the field, the multifunctional nature of UA and its ability to play multiple roles in communities must not be ignored.

7.2 Discussion of current research and identified knowledge gaps

The climate change crisis has resulted in many recent studies that consider the CCA potential of UA. Many of these studies, such as the research conducted by Lwasa et al. (2014), De Zeeuw (2011), and Dubbeling & De Zeeuw (2011), address the problem on a theoretical basis, using logical, argumentative methods or literature reviews based on secondary data from other fields.

As stated, Dubbeling and De Zeeuw (2011); Specht et al. (2014); Thomaier et al. (2014) and Samangooei et al. (2016), as well as in the work of Lwasa et al. (2014) and Padgham et al. (2015), discuss the various CCA benefits that UA and BIA provide. While limited studies have measured and considered UA and its actual CCA impacts, many of the studies expand on the CCA potential of UA citing work conducted on ecosystem services and green infrastructure (See table 67, in Appendix A). As a result, certain aspects of the research require more quantitative empirical research to validate and develop the UA discourse.

Furthermore, the UA discourse has advanced by developing alternative approaches to integrate agriculture with the urban environment as spatial strategies. While UA originated on the basis of agriculture practised in cities, its integration with high-density urban environments from a design perspective was first considered in earnest in the seminal work of Viljoen (2005) as continuous productive urban landscapes. Recently, the work of Specht et al. (2014) and Thomaier et al. (2014), building on the research of Despommier (2010), considered UA's integration with the built environment itself. Thomaier et al. (2014) and Samangooei et al. (2016) conducted analyses of existing building-integrated projects, and, finally, Goldstein et al. (2016) developed one of the first taxonomies of BIA farm types and its associated technological and resource inputs, and environmental benefits.

The following themes have received some attention but can be expanded with additional research:

- Its effectiveness to ameliorate heat island effects. While many studies considered the impact of vegetation on the microclimate and potential energy savings, more research in terms of the thermal impact of BIA is needed.
- Its efficiency in cooling the indoor environment. More research in terms of the energy saving potential when integrating BIA projects with the built environment is needed. While studies have considered this in the colder northern hemisphere (Delor, 2011; Nadal et al., 2017), limited research was conducted in warmer temperate conditions. Notably, research has been undertaken on the performance of greenhouses in South Africa (Thipe et al. 2017), but not in terms of the performance of rooftop greenhouses.
- The efficiency of UA and BIA in filtering, retaining and containing water and storm water. This field needs to be extended to what the impact of smaller agriculture units are and how to deal with longer drought periods as experienced in South Africa. This

will also contribute to the discourse considering opportunities for circular consumption of water in the urban environment.

- The potential food yield that UA, and BIA, can produce and its resultant impact on local food security. Furthermore, the relation between food production and resource use still requires significant research; this will address, inter alia, the embodied energy of the food and how it compares to the produce yield.
- The potential and impact of UA, and BIA, on circular waste cycles. More research into the simulation and modelling of waste cycles are needed – this also needs to include using thermal waste energy as a resource to improve the energy efficiency of architecture in the South African context.
- The sustainability of UA and its potential as climate change response strategy in the South African context. This will both shift the discussion beyond the developmental agenda and further the multifunctional nature or UA. Development in this area can potentially allow for new and innovative facets to be considered when developing UA projects.

This study identified the need to understand the spatial and technical requirements for implementing UA, specifically BIA, in dense urban settings. It also highlighted the fact that while many studies have identified the potential CCA characteristics of UA and BIA, more research in terms of its actual effectiveness to ameliorate the impacts of climate change is needed. In this study, the thermal impact of climate change was addressed by considering the potential of BIA to limit overheating and lower cooling loads in indoor environments. While a study by Delor (2011) considered the thermal impact of rooftop greenhouses in the UK, and Nadal et al. (2017) further developed this in Spain using an existing integrated rooftop greenhouse prototype, this study considered specific local BIA typologies in warmer temperate conditions. It therefore considered existing local BIA typologies within a context where limited research was undertaken.

8 Conclusion

This literature review considered climate change and its current impact on South Africa and its cities. It identified CCA as a critical response measure due to slow international and local responses to the crisis. After discussing a series of current local policies that are proposed and implemented in South Africa, small scale CCA strategies were identified as potential complementary strategies to the current response initiatives. The study postulated that a network of small-scaled in situ strategies can improve the climate change resilience of South African cities.

UA and BIA were identified as feasible response initiatives and their CCA potential was discussed. As many argue that the close integration of farms with buildings increases the beneficial reciprocal relationship between the two land-use forms, the review specifically identified the potential of BIA as a retrofitting strategy to improve the local climate change resilience. It concluded by identifying a series of knowledge gaps needed to promote the implementation and development of BIA as a land-use strategy.

The next chapter discusses the research design that was used to consider the potential of BIA as CCA retrofitting strategy to limit the exposure of the indoor environment to climate change-driven temperature increases.