Chapter 5: Climate adaptation mapping – Documenting the unused and underutilised spaces in Hatfield, Tshwane[2]

1. Introduction

As the study set out to consider the potential of building-integrated agriculture (BIA) as a climate change adaptation (CCA) strategy to improve indoor thermal temperatures, this chapter mapped and analysed the Hatfield neighbourhood in the City of Tshwane, to consider the existing unused and underutilised spaces in terms of their retrofitting potential. The study set out to reveal any spatial leverage opportunities ingrained in the context by uncovering and defining the spatial and material nature of the unused and underutilised spaces located in the neighbourhood. It specifically considered the food production potential by retrofitting the unused and underutilised spaces in the neighbourhood with BIA. Importantly, this research objective (sub-question A) was undertaken concurrently with sub-question B and as a result the findings discussed in the next chapter also informed this part of the study.

This research objective followed a mixed method, multi-stage mapping process that was conducted in two phases. The mapping protocol used a desktop analysis along with transect walks to document the material and spatial quality of unused and underutilised spaces in Hatfield. The data was collected via an online data repository with geo-location capabilities. This allowed the analysis to be undertaken using an online GIS tool. In addition to the spatial analysis, the findings were also analysed using descriptive statistics. This allowed for a quantitative analysis of a typically vaguely defined spatial condition.

The study was undertaken in Hatfield as it presents a typical multi-nodal neighbourhood in a sprawling city (Chobokoane & Horn 2015). It presents similar characteristics as identified by Trancik (1986), resulting in a neighbourhood with multiple anti-spaces of which a number can be defined as unused and underutilised spaces. Finally, including the isolated Hatfield campus of the University of Pretoria in the analysis of the neighbourhood allowed the study to consider a variety of spatial conditions. These spatial conditions included a typical Southern African urban condition (Hatfield neighbourhood), the boundary condition between the university campus and the city, and finally the “open” undefined character within the campus itself.

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The chapter is structured along four main sections. It starts by briefly discussing CCA and the need to develop deeply embedded CCA strategies. It then commences to discuss the criteria along which the unused and underutilised spaces were analysed. Following the analysis criteria, the findings from the study are discussed by focusing on the overall urban structure and its CCA potential. Subsequent to the overall analysis, the chapter concludes by focusing on the food production potential and the BIA implementation opportunities in the context.

2. Implementing climate change adaptation strategies in cities

2.1. Climate change adaptation strategies to facilitate systemic change

Climate change has been identified as a global concern with a spatial and temporal dislocation between the drivers of climate change and the affected communities. Stone (2012) warns that while climate change has global effects, the impacts are experienced by individuals with specific local sensitivity and exposure to climate change hazards. While we find CCA strategies being implemented in multiple cities, these strategies must be tailored for specific needs and contextual conditions (Carter 2011). This calls for an approach that focuses on place-specific implementation.

While the specific roles or functions of CCA strategies are critical, integrating the various strategies in the urban environment is of similar importance. As a result, in many cases CCA strategies are not new complex interventions, but embody well-known existing sustainable strategies, which include green roofs, cooling corridors, the use of improved insulation, or sustainable urban drainage strategies (Carter 2011). Yet, its implementation requires specific spatial structures that can accommodate these strategies (Carter 2011). Similarly, these must align with other local strategies and the context.

To achieve holistic integration, CCA strategies must be considered on multiple scales and levels. As noted by Kithiia (2011) national CCA policies must be complemented with local strategies that can be implemented quickly and effectively. Furthermore, it is essential to consider and develop these strategies as multifaceted, multifunctional initiatives to leverage their effectiveness (Carter et al. 2015). This requires better integration of the pragmatic requirements with social-cultural and social-political structures (Wamsler et al. 2013). While extensive research has been undertaken to include the social-cultural and social-political factors within specific contexts, methods must be developed that consider the existing urban condition and align these opportunities with existing strategies.

2.2. Climate change adaptation in cities

Cities and their associated increased densities are often considered as sustainable responses to rising population pressures, loss in resource availability, and adverse climate change impacts. Yet this can lead to hyper-densities that significantly increase resource consumption and limited potential to enable adaptive capacity for individuals (Clark & Tsai 2000). This often leaves large portions of the citizens vulnerable and exposed to hazards that are exaggerated by these increased population densities (Romero-Lankao & Dodman 2011). As a result, vulnerability is often ingrained within the structure and composition of the city (Seto & Shepherd 2009; Le Roux et al. 2017). Considering the urban form itself is an important approach to address the exposure and sensitivity of local citizens.

It is therefore important to acknowledge that CCA translates into specific strategic needs based on the local risks and vulnerabilities that are present in particular cities (Carter et al. 2015). These are related to impacts driven by external regional climate change (IPCC 2014a), but also often subject to drivers ingrained within the urban structure itself (Seto & Shepherd 2009). This contextual understanding of these drivers is essential in order to identify and maximise the effectiveness that CCA strategies have to offer.

2.3. A method to contribute to climate change adaptation

As noted earlier, the urban structure itself often contributes to local vulnerability, and is frequently exposed to both internal and external pulse and press disturbances (Walker & Salt 2006; Landman 2016). In order to address such vulnerability drivers, deep-seated change is needed (Sharpe et al. 2016). Using local context-specific knowledge can be considered one of the first steps towards bringing about deep-seated change (Pelling et al. 2015). This requires multiple readings of the urban context, along with local knowledge of the city to enable locally centred and integrated strategies (Shaw et al., 2014). In turn, this can enable local property owners and specialists in the built environment to uncover existing spatial opportunities to retrofit the built environment through a series of grass-root initiatives. By developing a holistic overview of these opportunities, top-down strategies and policies can be aligned with the existing ground level-based understanding of the urban structure itself.

The research objective of this component of the study was to map the immediate neighbourhood to uncover the latent spatial opportunities to implement CCA strategies. This process aimed to use an alternative reading of the city (Folke et al. 2010), enabling small-scale transformational strategies to be implemented and linked to larger networks (Ryan 2013). It aimed to uncover a contextual empirical knowledge base of the urban environment that can be used by professionals and communities to enable various strategies (De Souza et al. 2015).

3. Criteria for unused or underutilised spaces

The study analysed the existing unused and underutilised spaces in the urban environment to understand the ingrained contextual vulnerabilities and opportunities for CCA strategies. In this case, the study area was the Hatfield neighbourhood in the City of Tshwane. As the study considered a vaguely defined spatial condition, beyond spaces that are officially considered vacant, the following criteria were used for spatial identification (Table 1).

Table 1: Criteria for the definition of unused and underutilised spaces considered in the study

Scale and spatial condition	**Resultant spatial driver**	**Characteristics**
Complete / whole sites	Neglected spaces	Contaminated and unused
		Greenfield and unused
	Inefficient use of space	Mono-functional site; inactive for extensive periods
		Mono-functional and inactive; extensive proportion of the site is unused and/or underutilised.
		Surfaces, planes or spatial entities of existing spaces are unused.
Marginalised spaces	Design or spatial articulation	Scale of space is too small to be formally activated.
		Spaces are isolated.
		Space functions as barrier or threshold between two active spaces.
Transient/Temporal use	Spatial appropriation	Temporary and transient uses in complete contrast to original design intention.

In Table 1 the various spatial conditions and characteristics considered in the study are defined. The spaces are typically vacant and unused for continual or extensive periods; unused but at times used for alternative functions contrary to their original design intention; or spaces result in being unused due to specific spatial strategies. The study also included spaces that are mono-functional and result in long periods of idle use, for example parking areas.

The study intended to identify these inefficiencies in the existing urban environment and determine the implementation potential of BIA land-use strategies. As these spaces are often present in functioning urban environments, and not only in vacant sites (Trancik 1986), the ill-defined nature of these unused and underutilised spaces requires that one visits these spaces to document them. As a result, a site-level documentation approach was used to map these spaces.

4. Climate change adaptation mapping consideration criteria

In order to develop a method to analyse and map the unused and underutilised spaces in the urban environment and therefore its potential to accommodate CCA strategies, the study identified a series of analysis themes. These themes responded to the critical factors discussed in Chapter 2, identifying water security, temperature increases and food insecurity as principal adverse impacts in the South African urban context. The mapping therefore considered the urban heat island (UHI) impact, renewable energy potential, local food production capability, stormwater and rainwater management potential, and retrofitting potential. The last aspect, retrofitting potential, was added as the research aims to find opportunities to redress and transform current urban environments. A series of spatial and material factors associated with these risks and opportunities were documented during the mapping and subsequently analysed. These factors are discussed in Table 7 (Section 4.6).

4.1. Climate change adaptation - Urban heat island effect

As current climate change forecasts identify Southern Africa as a region expecting above-average temperature increases (IPCC 2014a), UHI is considered as a hazard that can be addressed on an urban scale, as the embodied urban form perpetuates this distinct microclimate. Due to a series of structural and functional attributes in the city the local microclimate is systematically warmer than the surrounding rural contexts (Smith & Levermore 2008). This warmer microclimate is specifically pronounced at night during cooling periods and wind-still conditions (Smith & Levermore 2008). This phenomenon has been documented on a number of scales, ranging from the urban boundary layer (thermal changes on a city scale), the boundary layer up to the top of buildings and trees, and then specific surfaces with urban heat island impacts. These various scales are experienced differently and are also documented following different methods (Yow 2007; Kotharkar et al. 2018; Sherafati et al. 2018).

These temperature increases experienced within the urban environment are concerning as increased incidences of climate change-induced heat waves are forecasted by many (Lyon 2009; IPCC 2014a; Russo et al. 2017). As a result, the inability of the urban environment to effectively cool down and limit indoor thermal increases only serves to exacerbate the impacts of these heat waves. This has been documented in a series of cases in Europe in 2003 (Roaf et al. 2009; Stone 2012). In the Southern African context, average temperature increases due to climate change are forecasted to be 1.5 to 2 times the global average (DEA 2013). As a result, similar vulnerabilities to periods of excessive overheating can be expected.

The UHI phenomenon has a series of impacts on the local inhabitants and environment. These range from increased mortality and morbidity in vulnerable sectors of the population (Van Der

Hoeven & Wandl 2015;Yow 2007), increased energy use in order to cool indoor environments (Georgakis et al. 2014; Yow 2007), and amplifying drivers of local climate change (McCarthy et al. 2010). It also perpetuates already concerning conditions by affecting local climate patterns, stormwater quantities and quality, and the local urban ecology (Yow 2007; Kotharkar et al. 2018).

While the phenomenon of increased temperatures has been documented in many cities worldwide, the resultant impact of UHI differentiates significantly due to the urban structure, local climate and location of the city (Lindén 2011; McCarthy et al. 2010). As a result, this requires a contextual understanding of the impacts and drivers of the local UHI. The factors that impact the UHI can be identified as seasonal changes, pollution, activities producing heat and the urban structure itself (Kleerekoper et al. 2012; Peng et al. 2012). From the review the study identified a series of factors ingrained within the urban environment that affect the UHI (see Table 2 in Appendix B for more information and references):

- **Urban structure:**
    - Skyview factor (SVF) - percentage of the clear sky open to the ground surface.
    - Local airflow – ability of urban structure to channel airflow through it.
    - Urban Canyon – orientation and scale of the urban structure that increases or limits solar exposure.
    - Density – density of built-up volumes in the urban environment.
- **Bio-matter:**
    - Vegetation coverage.
    - Tree canopy coverage.
- **Surface and material use:**
    - Waterbodies – proximity and size.
    - Land surface type – material use, thermal capacity and albedo factor.
    - Surface permeability–material use and surface coverage.
- **Anthropogenic activities:**
    - Local pollution rates.
    - Heat generating activities – air-conditioners, vehicles, etc.

Table 2: Factors driving the urban heat island impact ingrained in the urban environment.

Climate Adaptation Response	Impacting Factors (Lit review)	Spatial and Material factors
Urban Heat island Impact	Sky view factor, vegetation coverage, surface material, soil moisture content (Jonsson 2004).	Surface treatment of material (albedo value)
	Material use, reduction in vegetation and human activities producing heat, air pollution (Seto & Shepherd 2009).	Surface treatment of material (texture and colour)
	Vegetation coverage, thermal capacity of building materials, albedo factor of surface materials, city structure (building density and heights) (Peng et al. 2011).	Thermal capacity of material (texture and colour)
	Vegetation coverage, land surface type, open water availability (Lindén 2011).	Vegetation coverage
	Land surface treatment, vegetation coverage, surface water bodies (Monana 2012).	Sky view factor
	Airflow, evapotranspiration (vegetation), thermal capacity of materials, anthropogenic waste heat, sky view factor, air pollution, albedo value of materials (Kleerekoper et al. 2012).	Heights of adjacent buildings and edge definition
	Building densities, urban morphology, sky view factor, urban canyon orientation, surface materiality and thermal capacity, waste emissions from buildings (Taleghani, et al. 2014).	Site Orientation
	Material use of surfaces, anthropogenic heat sources, vegetation coverage (Di Leo et al. 2016).	Open water coverage

4.2. Climate change adaptation – Stormwater and rainwater management

Urbanisation has a series of impacts on the local environment; water is one such aspect critically affected by land-use changes. Urban growth is typically associated with an increase in water consumption, loss in soil permeability, lower water ingress to the water table, and higher stormwater quantities resulting in increased localised flooding (Johannessen & Wamsler 2017). Water insecurity has been noted as one of the principal global concerns resulting from climate change (Dos Santos et al. 2017). While water scarcity is often associated with rural development, the recent rapid and spontaneous urbanisation in sub-Saharan Africa drives water insecurity in urban contexts as well.

Urban water management is a complex problem, as cities subjected to water scarcity have also been noted to frequently experience periods of extensive localised flooding. This is due to increases in extreme weather events, as well as changes in the local drainage basin quality (Kundzewicz et al. 2014). The extensive changes in land-uses and surface characteristics, the lack of infrastructure maintenance, and the fact that people often settle in vulnerable flood-prone areas drive local water insecurity (Douglas et al. 2008). Notably, both internal and external factors drive water insecurity.

Climate change will further impact this already complex problem. In a study by Kenabatho et al. (2012), higher ambient temperatures are projected to result in lower rainfall quantities over the south-western section of Southern Africa. Concurrently, eastern and north-eastern regions of Southern Africa will experience a higher frequency and increased quantity of rainfall (Shongwe et al. 2011). According to a study by Mason et al. (1999), while certain central South African regions might not experience significant drops in annual rainfall quantities, a loss in rainfall days can be expected. This reveals an increased risk of precipitation-driven flooding and lower water security due to the complexity of safe onsite water storage for extended periods.

Managing local rain and stormwater present, therefore, opportunities to limit the frequency and exposure to flooding. It also provides opportunities to increase local water security through rain and stormwater harvesting and storage. As land-use changes have such extensive impacts, establishing water sensitive cities are important. This requires developing adaptive multifunctional infrastructure in the urban environment to manage and store stormwater (Carden & Armitage 2013). To contribute to local stormwater and rainwater management strategies the following characteristics of the urban structure must be considered (see Table 3 for more information and references).

- **Urban structure and surfaces:**
    - Proportionate coverage of pervious and impervious surfaces.
    - Local soil quality and infiltration rates.
    - Local function and land-use type.
    - Slope and catchment area.
- **Infrastructure:**
    - Status of existing stormwater infrastructure.
    - Space available for new infrastructure.
    - Adaptive capacity of existing infrastructure to be retrofitted.
    - Potential storage capacity.
- **Context and climate:**
    - Precipitation rates.
    - Evaporation rates.
    - Vegetation coverage.
    - Pollution risks and sources.

Table 3: Spatial and material factors impacting on the local water security, stormwater and rainwater management.

Climate Adaptation Response	Impacting Factors (Lit review)	Spatial and Material factors
Water Security and stormwater management	Pervious and impervious surfaces, groundwater storage capacity, evaporation rate, water consumption, existing infrastructure and infiltration rate, local precipitation level (Mitchell et al. 2001).	Surface treatment - permeable vs impermeable
	Pollutants, seasonal climatic characteristics, precipitation rate and intensity, land-use, surface treatment, available stormwater infrastructure (Barbosa et al. 2012).	Vegetation coverage
	Surface coverage and terrain characteristics, vegetation, pollution contamination, controlling infrastructure (source point, local or regional) (Armitage et al. 2013).	Terrain slope & characteristics
	Catchment area, pollutants, treatment and controlling infrastructure (Akram et al. 2014).	Area size
	Surface treatment, slope, adjustment to guide runoff, vegetation (green infrastructure) (Adegun 2014).	
	Catchment area, surface characteristics, space availability for infrastructure, infrastructure and storage, precipitation and evaporation rates (Fisher-jeffes et al. 2017).	

4.3. Climate change adaptation – Urban agriculture implementation potential

Food security can be considered as both the ability to acquire sufficient quantities of food as well as consuming a nutritious, healthy and balanced food diet (Battersby 2012). The work of Battersby (2012) and Faling (2012) therefore argue that it is not only the ability to grow nutritious food that must be considered, but access, storage, and capacity to prepare the food are also important. These factors in the urban environment play a significant role in creating distributary food networks, providing resources and opportunity for economic development as a means to ensure food security.

The AR5 report (IPCC 2014) projects that Southern Africa will experience significant changes in food security resulting in lower capacity to grow food. This can be attributed to the expected increases in temperature, lower rainfall, and shifts in the rainfall season (Bassey 2018;Faling 2012). These climatic changes, along with social changes such as increasing unemployment and lower economic growth, will result in increased urban food insecurity (Battersby 2012).

Urban Agriculture is promoted by many for its potential to address food insecurity (van Averbeke 2007; MacRae et al. 2010; Jenkins 2018). Apart from the various benefits that it presents to the city (see chapter 2), it is the flexibility and adaptability to adjust and respond to multiple urban conditions that are valued within diverse urban contexts (Matos & Batista 2013). While many urban farmers agree that their contribution cannot wholly replace the current food system, they note its beneficial role in providing fresh, nutritious, healthy food to supplement the local inhabitants’ diets (Vilakazi 2018, also see Chapter 6).

Although these farms can be considered flexible in their application, there are specific spatial and technical needs that must be met. In order to consider the developmental potential of urban agriculture in the urban context the following urban conditions must be considered (see Table 4 for more information and references):

- **Context and microclimate:**
    - Solar exposure.
    - Wind protection.
    - Local climatic patterns.
- **Spatial Structure:**
    - Access to the site and circulation within.
    - Availability of spaces for food production.
    - Building envelope, or envelopes, as space defining elements.
- **Infrastructure:**
    - Existing available infrastructure and resources.
    - Existing structural integrity of the space.
    - Clarity and robustness of existing envelope structure.
- **Social structure and community:**
    - Existing community and stakeholders.
    - Existing services and facilities in the neighbourhood.
- **Legal and developmental context:**
    - Ownership of space.
    - Developmental rights.

Table 4: Spatial and material factors driving the potential to implement urban agriculture and address local food security.

Climate Adaptation Response	Impacting Factors (Lit review)	Spatial and Material factors
Food Security (Local Food production)	Solar exposure, access and circulation, soil quality, resource access (water), space for waste management (Phillips 2013).	Envelop material and structure (Walls and floors)
	Economic potential (scale of farm), structural integrity of carrying structure, farming technology requirements (structural and resource needs), crop requirements, development rights (Sanyé-Mengual et al. 2015).	Sky view factor
	Edge definition and access, integration with local community (Napawan 2015).	Adjacent building heights and defining envelopes
	Resource inputs, fixing structure (Goldstein et al. 2016).	Access control of site
	Solar exposure, microclimate, average rainfall, surface slope, access and neighbourhood context (Napawan 2016).	Access to site
	Building structure, water and electricity connection, physical access for construction and maintenance (Roggema 2017).	Area/space available
	Resources and infrastructure availability, microclimatic conditions such as solar irradiation and wind protection, space availability, existing retrofittable structure, access points and integration with local urban context (see chapter 6)	Existing on-site resources

4.4. Climate change adaptation – Decentralising energy sources

The energy sector, especially the current large centralised networks using fossil fuels as primary energy source, is one of the single main driving greenhouse gas producers in South Africa (IEA 2020; World Resource Institute 2020). In 2016, 90.5% of the total energy generated in South Africa was derived from fossil fuels (Maluleke 2016). Furthermore, this centralised power generation system is highly inefficient with 66% of the energy being lost before it reaches the end-user (Syed 2012). As identified in resilience theory, these centralised energy systems are massive in scale and their inability to adjust to rapidly changing conditions result in systems that are vulnerable to sudden dramatic changes (Walker & Salt 2006). Implementing small-scale renewable energy networks can address these risks and climate change mitigation (CCM) needs.

The long-term adverse impacts of fossil fuels are well known. Adopting renewable energy sources provides the opportunity to incorporate environmentally benign technologies with limited local impacts (Ramachandra & Shruthi 2007). It also provides the opportunity to adopt smaller-scaled, diverse, decentralised energy networks, which, if implemented correctly, provides more diversity and stability in the energy network (Schneider et al. 2007; Ahern 2011). Promoting renewable energies, therefore, not only provides alternative low-carbon embodied energy sources that mitigate climate change (Tillie et al. 2009), it also contributes to adaptation strategies by improving the adaptive capacity of users.

It is often assumed that renewable energy sources are simple technological solutions that can be implemented without much consideration. On the contrary, renewable energy systems are often highly dependent on meteorological conditions (Schneider et al. 2007). In addition they have spatial and location-specific implications due to the exergy of these energy sources (Broersma et al. 2013). Furthermore, if effectively implemented, renewable energy strategies can also use local waste energy sources (Tillie et al. 2009). The following spatial and systemic characteristics must be considered if these systems are to be implemented (see Table 5 for more information and references):

- **Climatic Conditions:**
    - Global solar irradiation.
    - Wind speeds and duration.
    - Local ambient temperature fluctuations.
- **Geological morphology:**
    - Geomorphological height differences.
- **Physical Characteristics:**
    - Water sources, rivers or dams.
    - Aquifers and level of the ground water table.
    - Vegetation and bio-energy sources.
    - Livestock population.
    - Urban morphology and building densities.
    - Population density.
- **Anthropogenic factors:**
    - Waste energies.
    - Heat sources.
    - Land-use types.
    - Local energy consumption
- **Infrastructure:**
    - Existing infrastructure.
    - Location of large waste resource stocks (sewerage, solid waste etc.).

Table 5: Spatial and material factors driving the potential to implement renewable energy sources.

Climate Adaptation Response	Impacting Factors (Lit review)	Spatial and Material factors
Renewable energy potential	Solar energy - annual solar irradiation per square meter. Wind energy - annual average wind speed for an area. Hydroelectricity - height difference and flow rate of water. Geothermal heating or cooling - volume and temperature of aquifer. Bio-energy - land-uses, livestock population, and coverage of biomass. Anthropogenic sources - land-uses and energy use and wastage (Broersma et al. 2013).	Global irradiation level
	Area coverage (biomatter coverage), climatic information (wind speed, global irradiation), specific locations with potential (water sources, height difference and flow rate of water sources, land-uses (location of biomatter), efficiency rates of technology (Ramachandra & Shruthi 2007).	Annual local wind speeds
	Photovoltaic energy potential irradiation levels, wind energy average wind speeds, biofuel document land-uses (farms and forests) and municipal waste or sewerage, hydro-energy document river locations, geothermal energy aligned low exergy uses with heat sources (Schneider et al. 2007).	Sky view factor impacted by the urban morphology
	Four steps approach - analyse use, reuse waste energy, develop renewable energy sources, provide high exergy needs using clean technologies (Tillie et al. 2009).	Adjacent building heights
	Energy potential mapping - energy generation potential consider spatial requirements, define and map energy and exergy demand, align waste energy location with energy needs (Dobbelsteen & Tillie 2014).	Site orientation
		The edge definition of the enclosing space
		Regional conditions – vegetation and available biomatter
		Adjacent building programmes - energy use and waste
		Existing available infrastructure
		Groundwater capacity and depth

4.5. Retrofitting urban spaces

As extensive resources have already been invested in our cities, and considering the developmental pressures that Southern African cities are experiencing to accommodate a large number of new urbanites (United Nations 2019), finding solutions that allow for the extensive adjustment of cities whilst retaining their functionality is important. Bullen (2007) addresses the concept of value and environmental impact of changes; he argues that reusing the city's existing fabric allows one to reassess its value and enhance its use for citizens. Furthermore, he also argues that it is environmentally more sustainable to change or improve the urban environment than reconstructing newly built interventions.

Retrofitting, as one such approach, is differentiated from renovation or refurbishment as being comprehensive, large-scale, and resulting in integrative changes (Dixon 2014). Eames et al. (2013) define retrofitting as “directed alterations of the fabric, form, or systems which comprises the built environment in order to improve energy, water and waste efficiencies”. This direct alteration of the built fabric requires a holistic approach that is compatible with the existing users or context (Eames et al. 2014). While Dixon (2014) and Eames et al. (2013) both call for integrative holistic approaches to retrofitting, their suggested scale of implementation can be contested. They argue for large-scale changes, but it is more apt to consider *broad-ranging or extensive systemic* applications. These can be small-scaled but integrated into a network to enable broad-ranging changes to the context (Casagrande 2014). This requires that one considers the retrofitting potential of the existing urban fabric to improve its resource efficiency and functionality. To do so, the following aspects are important to consider (see Table 6 for more information and references):

- **Existing built fabric:**
    - Surface quality and condition.
    - Structural clarity.
    - Structural condition.
    - Availability of robust fixing points.
- **Existing technology and infrastructure:**
    - Current infrastructure systems.
    - Availability of connecting points to resources.
    - Existing flexibility to adjust.
- **Function and Users:**
    - Existing programmes and building functions.
    - Existing users and community.
    - Current energy sources and sinks.
- **Spatial Structure:**
    - Volume of retrofitting space.
    - Spatial continuity potential of the series of retrofitting entities.
    - Edge definition of the spatial structure.
- **Microclimate:**
    - Solar exposure and sunlight.
    - Wind exposure.

Table 6: The spatial and material factors driving the potential to retrofit the urban environment.

Contextual Urban Response	Impacting Factors (Lit review)	Spatial and Material factors
Retrofitting Potential	Surface quality, structural clarity, robust fixing points, resource and services provision, accessible, un-programmed spaces (see chapter 4)	Adjacent Building heights
	Social-technical systems, multi-scalar analysis and implementation, existing urban fabric, current technological and social regimes (Eames et al. 2013).	Boundary envelope characteristics and materiality
	Existing infrastructure, the catchment area or resource coverage, resources storage and implementation area needs, technological requirements (Shafique & Kim 2017).	Material quality of the structure
	Stakeholders' perceptions, data on existing spatial and material conditions, simulations, and testing of retrofitting solution (Ahmed et al. 2017).	Structural configuration
	Type of existing structure, morphology of the structure and material use of the structure (Mallinis et al. 2014).	Available spatial volume
	Multidisciplinary approach, document energy sources and sinks, consider policies and their implementation, socio-technical systems, urban morphology and planning, existing social networks and potential transformation opportunities (Thornbush et al. 2013).	Boundary envelop definition
	The current fabric, form and system; long term and visionary-orientated change to energy, waste and water efficiency; compatible with existing context, people and processes (Eames et al. 2014).	Existing hard infrastructure
	Comprehensive retrofitting strategy, large scale and integrative approach; retrofitting approach include what was omitted and ensure that it fits (Dixon 2014)	Existing soft infrastructure
	Context and building specific retrofitting solution - consider materiality, systems and geometry (Agostino et al. 2017).	Ownership and users
	Building specific retrofitting strategy consider management structure, existing fabric and system (Mancini et al. 2016).	Existing programmes
	Structural quality, presence of hazards or hazardous materials, microclimate of existing spaces, space morphology optimisation potential and spatial continuity (Bullen & Love 2011).	Adjacent building programmes
	Cultural and historical significance, economic sustainability, technological ability to adapt (Bullen 2007).	Solar irradiation exposure
	Define various actors or users, consider the existing fabric in terms of physical quality, additional intangible values present, and needs of the site (Misirlisoy & Gunce 2016).	Vegetation cover
	Spatial capacity to change and retain flexibility, open space potential (alternative to current function), existing microclimate and lighting quality (Petković et al. 2016).	
	Material quality of the existing context, existing economic activities, structural and functional flexibility, and accessibility to the site (Ferretti et al. 2014).	

4.6. Collating the spatial and material considerations to promote climate change adaptation

From the analysis, various spatial and built technological factors that drive UHI, water insecurity, food production, renewable energy generation, and retrofitting potential were identified. Several critical factors to consider during the CCA mapping procedure have been defined. The research aim was to understand the interconnected nature of the various spatial, material and technological characteristics of the city and how these contribute or limit the CCA potential of the urban environment.

The criteria specifically considered the existing spatial and material urban conditions, along with important climatic and programmatic factors to understand the urban environment's ingrained and structural contribution to the local climate change vulnerability. By retrofitting the existing urban context, potential additional resource sources, resource circularity opportunities, and elements that drive climate vulnerability can be addressed. The mapping process aimed to identify and define these spaces with leverage potential.

In Table 7, the factors identified in the analysis are discussed. These factors can be categorised according to scale, being precinct, block and site-specific. Furthermore, technological and material conditions, spatial conditions, social aspects, and natural conditions have been identified. Broadly, these aspects include contextual and climatic conditions, urban morphological aspects, ownership and programmatic considerations, and local biomatter.

These factors were used to inform the mapping (data collection) and analysis processes. An aggregate table of the data findings is presented in Table 68 in the Appendix C. In table 68 the various spatial typologies identified in the study are discussed in terms of the spatial and material factors noted in Table 7. The interpretation of the data findings is discussed in section 5 of this chapter.

Table 7: Important spatial, technological, social and natural factors to consider during an urban adaptation analysis process

	Technological & material	**Spatial**	**Social**	**Natural**
Precinct scale				
		Global irradiation levels		Existing groundwater depth and capacity
		Wind speed conditions		
Block scale				
	Adjacent building resource use	Adjacent building heights	Adjacent building programmes	Existing natural resources available
	Existing infrastructure	Definition and position of edges	Ownership and users	
		Porosity of the city block		
‘Site scale				
	Surface material	Edge definition	Existing Programmes and functions	Open water coverage
	Surface albedo factor	Site orientation	Existing unprogrammed uses	Vegetation coverage
	Space envelope material	Sky view factor		Existing biomatter
	Space envelope structure	Access to the site		
	Existing available resources	Area size		
		Terrain Slope		

5. Mapping findings

5.1. Location and overall quantity of spaces available

The mapping identified and documented a series of underutilised and unused spaces in Hatfield. These spaces were analysed along two parameters: frequency of incidence (FOI) and potential space impact (PSI) (Hugo & du Plessis, 2019). These parameters allow one to identify instances or opportunities to retrofit the existing urban condition (defined as FOI), as well as the potential spatial impact that transforming these spaces have on the larger neighbourhood (defined as PSI). These spaces were analysed in order to understand the inherent vulnerability and opportunities ingrained within the local urban environment of the study area. Finally, in line with the research question, this analysis focussed on the potential to implement BIA in the Hatfield neighbourhood.

A total of 202 spaces were documented; these include a series of rooftop spaces, left-over spaces resulting from security and management response measures, large mono-functional spaces such as parking areas, and vacant spaces. These 202 spaces collectively cover a total area of 230,202 m^2 and represent 11% of the study area (total: 2,150,000 m^2).

While a number of studies were undertaken considering vacant spaces within the urban environment, these studies often considered sites officially defined as vacant by the local municipality (Kim et al. 2018; Németh & Langhorst 2014). While this approach is effective, the study concurs with the argument posited by Bhaskaran (2018) that often, especially in developing contexts, underperforming spaces exist beyond the formal official spatial definitions. A comparison with other cities is difficult at this stage, as a limited number of these ground level studies have been undertaken thus far. Yet in comparison with the findings of Németh and Langhorst (2014) and Kim et al. (2018) the total proportion of space deemed unused or underutilised is lower than their findings of more than 15%. It is important to note the extensive differences between these cities (or study areas) and the analysis methods that were used.

The unused and underutilised spaces were analysed according to the criteria set out in section 4. To define the spaces, five spatial typologies were established: *Open roof level, Open ground level, Attached ground level, In-between ground level,* and *Enclosed ground level.* Due to the undefined nature of these spaces, these definitions were developed to be applied beyond functional descriptors, but rather convey the spatial and retrofitting condition of the various spaces. In Table 8 the overall spatial incidence (FOI) and the total area coverage (PSI) are defined.

Table 8: Overall comparison of the spaces identified and defined in the study

Space Type	**Number of incidence**	**Frequency of incidence (FOI)**	**Total area covered**	**Potential space impact (PSI)**	**Proportion of study area**
Open roof level	52	26%	71,055 m^2	31%	3%
Open ground level	35	17%	86,532 m^2	38%	4%
Attached ground level	48	24%	31,555 m^2	14%	2%
In-between ground level	39	19%	17,684 m^2	8%	1%
Enclosed ground level	28	14%	23,376 m^2	10%	1%
Total	202		230,202 m^2		11%

In terms of the FOI the study revealed that *open roof level* spaces (26%), *attached ground level* spaces (24%), and *in-between ground level* (19%) spaces present the highest number of spaces found within the study area. The area coverage analysis revealed an alternative picture in terms of the PSI; *open ground level* (38%) and *open roof level* (31%) spaces present the highest leverage potential to retrofit. *Attached ground level* presents a much lower spatial opportunity, covering only 14% (31,555 m^2) of the total unused and underutilised spaces. The *open ground level* and *open roof level* spaces collectively constitute 7% of the total study area and 69% of the total underutilised and unused spaces in the neighbourhood (Table 8).

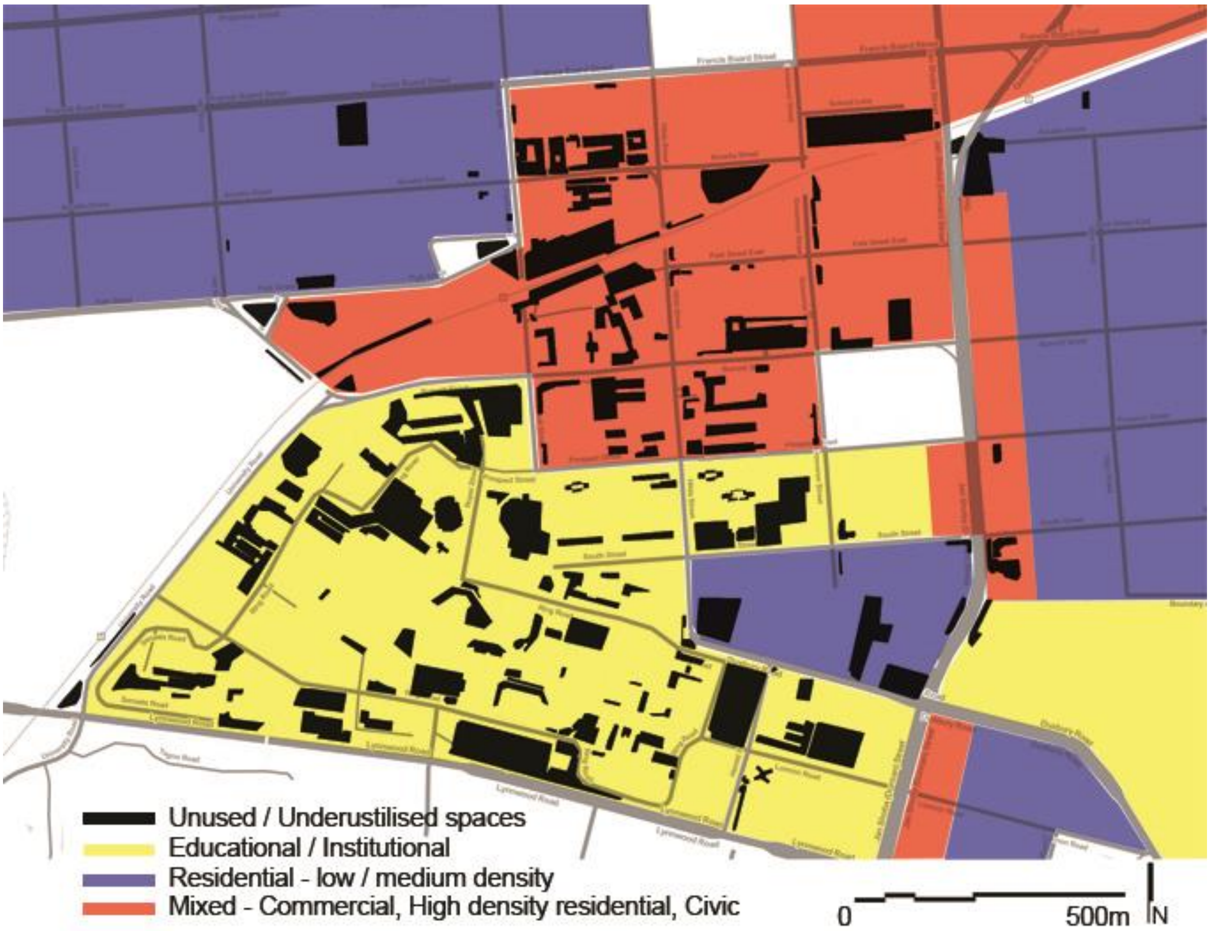

Figure 24: Location and spatial relation of the unused and underutilised spaces in the study area. Note the unused and underutilised spaces are drawn as footprints in the figure.

In terms of the location of these spaces, the study consistently documented unused and underutilised spaces in contexts with large-scale public, civic and commercial buildings. The residential spaces on the eastern and north-western boundaries of the studied area did not reveal any significant opportunities for retrofitting (Figure 24). While the scale of the existing built environment can be a contributing factor, the research assistants (students) revealed a series of small-scaled spaces located within the university campus. This points to two possible conclusions. First of all, access to the back of sites or residential spaces cannot be ruled out as impacting factor, yet the respondents did identify spaces located behind fenced areas in the commercial and office sections of the neighbourhood. Secondly, a scalar bias can develop, which is sensitive to the context of development. The nature of feasible and useful unused and underutilised spaces is therefore influenced by the local context, scale and the respondents' perception thereof. The argument being that should this study be conducted in a different neighbourhood with a fine-grain, small-scaled built environment, alternative spatial opportunities might be identified.

5.2. Material and spatial quality of unused and underutilised spaces

The collective analysis of the spaces considered the various spatial and material attributes as set out in the criteria discussed earlier. An overall analysis of the sites revealed that a high percentage of the sites are highly exposed to insolation. In terms of the sky view factor (SVF), a frequency of incidence (FOI) of 68% (n-138) of the spaces that have an SVF of 0.75-1.0 was derived, this amounts to a potential spatial impact (PSI) of 78% (total area: 179,558 m^2). When taking the surrounding urban morphology and the site aspects into account, it was found that close to 93% (FOI_{total} n=188) of the sites will experience little to no overshadowing throughout the year. This is partly because 50% (FOI_{total} n=101) (PSI_{total} – 52%; 119,705 m^2) of the sites have large northern aspects and are surrounded by built fabric that is relatively low in density.

The tree and vegetation coverage analysis of the sites revealed that 46% (FOI_{total} n=93) (PSI - 48%; 110,497 m^2) and 55% (FOI_{total} n=111) (PSI - 58%; 133,517 m^2) have no tree or vegetation coverage respectively. Only 10% (FOI_{total} n=20) of the sites have a tree coverage of 75-100%, while 22% (FOI_{total} n=44) of the sites have between 75-100% vegetation coverage. The sites with the least proportionate vegetation coverage are the *open roof level, attached ground level* and *enclosed ground level* spaces. This revealed a high quantity of spaces that are highly exposed to solar irradiation and accommodate little vegetation that can reflect excessive solar irradiation, ameliorate heat build-up or facilitate stormwater infiltration (Holm 1985; Jonsson 2004).

In terms of material use, the study undertook a holistic overview and not a detailed representation of the various identified spaces. Urban spaces typically comprise of diverse material types that present difficulties in documenting accurately. The study therefore considered the use of materials based on the presence of high thermal mass or lightweight structures. Notably, the local built environment generally uses masonry or concrete framed structures with brick infill, as a result limited lightweight framed structure were documented. The material use analysis of the structures enveloping these spaces found that 72% (FOI_{total} n=145) have at least one edge constructed from high thermal mass materials, such as masonry or concrete with glazing. Only 4% (FOI_{total} n=8) have completely glazed edges. On the other hand 24% (FOI_{total} n=49) of these sites are open with limited existing structures and therefore the ground surface material plays an important role.

The study used vegetation as an indicator of ground surface treatment type. It was noted that 67% (FOI_{total} n=136) of all the space do not have any vegetation. *Open roof level* spaces and *open ground level* spaces make up a large portion of these spaces contributing to 43% (PSI_{total} = 98,987m^2) of the total surface area of the analysed spaces. These spaces typically consist of impermeable surfaces with high thermal mass materials such as concrete, paving or tarmac.

Concurrently these spaces do present opportunities for retrofitting and adaption to contribute to the local CCA strategies. In terms of their edge definition 77% (FOI_{total} n=156) of the spaces have two or less boundaries. While *open roof level* spaces make up 26% (FOI_{total} n=52) of those spaces, covering 31% (PSI 71,055 m^2) of all the unused and underutilised space, 51% (FOI_{total} n=103) of all the spaces are located on ground level and have a maximum of two undefined edges. This means that these spaces can be developed with relative ease and are located such as to positively contribute to the public realm.

Although 74% (FOI_{total} n=150) of the spaces have controlled access (including private and public space), it is important to note that 73% (FOI_{total} n=148) of these spaces are located on public property. While spaces located on public property will be easier to transform, this will require bottom-up and top-down coordination to achieve tangible and effective results. Yet as these spaces are located on public property and are often maintained with public funds, the argument can be made that retrofitting these spaces can provide additional public good to the local neighbourhood. The spaces located on private property (PSI_{total} - 27%; 62,154 m^2) can be easier to transform due to less bureaucratic control, yet it will require personal investment and as a result, they often require a tangible return on investment for the owners.

Finally, in terms of retrofitting these spaces, it was already noted that 69% (PSI_{total} 159,147 m^2) (Table 8) of the total area coverage is located on ground level and can be retrofitted with relative ease. Alternatively, the analysis of existing urban agriculture precedents revealed roof spaces are often retrofitted for alternative uses (Goldstein et al. 2016; Chapter 6); the remaining 31% (PSI_{total} 71,055 m^2) constituting of *Open Roof level* spaces also hold potential to be retrofitted.

In terms of the materials and structural systems enveloping these spaces, it was found that only 4% (FOI_{total} n=8) of all the space instances have glazed or light-frame structures. While 24% (FOI_{total} n=49) of the spaces do not have any existing structures that can be considered as structural elements, the remaining 72% (FOI_{total} n=145) are heavyweight structures that are often considered robust and can accommodate retrofitting strategies.

5.3. Overall findings of the vulnerabilities and opportunities ingrained in these space types

From the overall analysis of the various spaces, the study documented a number of them increasing the local vulnerability of the neighbourhood. Concurrently, these very spaces also present opportunities to be redressed and improve the local climate change resilience. It was often found that spaces present multiple retrofitting opportunities and provide alternative adaptation capability.

Based on the most pertinent climate change-related risks identified in section 4 (Chapter 5) and section 3 (Chapter 2) this analysis considered the specific spatial and material characteristics that:

- contribute to the local UHI (medium to high levels of impacts),
- increase the risk of local flooding and stormwater impacts,
- have high photovoltaic generation potential,
- contribute to food production as private or public entities, and
- embody retrofitting potential.

The analysis revealed that only 5% (FOI_{total} n=11) of all the spaces contain no significant retrofitting opportunity. Furthermore, 48% (FOI_{total} n =96) of all the spaces inherently retain multiple spatial and material characteristics that can contribute to a series of CCA response measures.

Table 9: Overall comparison of the spaces with high potential to contribute to the local CCA measures in the built environment.

Spatial response potential and strategy	Number of incidence	Percentage of incidence (FOI)	Total area covered	Percentage of area covered (PSI)	Proportion of study area
Spaces contributing to the local UHI.	183	91%	210,264 m^2	91%	10%
Spaces contributing to stormwater quantities.	120	59%	152,625 m^2	66%	7%
Spaces with high PV potential.	87	43%	124,979 m^2	54%	6%
Spaces with high UA potential (public realm).	44	22%	66,152 m^2	29%	3%
Spaces with high UA potential (private realm).	41	20%	54,846 m^2	24%	3%
Spaces with high retrofitting potential.	84	42%	86,262 m^2	37%	4%
Spaces with high retrofitting potential – no structures and extensive vegetation.	24	12%	54,452 m^2	24%	3%
Total	202		230,202 m^2		11%
Total Site			2,150,000 m^2		

Table 9 compares the frequency of incidence (FOI) and potential spatial impact (PSI) of the spaces that negatively impact the climate change vulnerability of the built environment due to their spatial and material attributes. The analysis of the spaces with UHI contributory factors considered the sky view factor, solar exposure, and level of overshadowing due to the surrounding urban context. It also considered the vegetation and tree cover and noted the incidence of high thermal capacity construction materials used. The findings revealed that 91% (FOI_{total} n=183) of the spaces that were documented contribute to the local UHI impact in moderate to high levels. This constitutes 10% of the total study area and amounts to 210,264 m^2 of coverage.

The study revealed a correlation between spaces contributing to the local UHI and stormwater quantities. The use of impervious materials, lack of tree and vegetation cover, and exposure to the natural elements were considered to define the stormwater impacts of spaces. This revealed that 66% (PSI_{total} 152,625 m^2) of all the unused and underutilised spaces have attributes that increase the local stormwater quantities and flooding risks. These spaces make up 7% of the total study area.

These spaces do not only represent adverse vulnerable spaces in our cities, but as noted in Table 9, these spaces also present several opportunities to contribute to the surrounding neighbourhood. While a number of the spaces are exposed to significant levels of solar irradiation, high sky view factors, limited overshadowing and low levels of vegetation, taking these factors into account, along with considering the orientation of the sites, the study revealed that a total of 43% (FOI_{total} N=87) of the spaces present opportunities to implement photovoltaic energy-generating modules. This constitutes 6% (PSI_{total} -124 979m^2) of the total study area. As these spaces are highly exposed, subject to 1700 kWh/m^2/a (DEA, 2019), this represents a total generating capacity of 31.9 GWh per annum, at a 15% energy generation efficiency ratio for the photovoltaic panels.

A quick overview of the food production capabilities ingrained in the urban environment considered the solar exposure, levels of overshadowing, accessibility and edge definition of the spaces. This revealed a total food production capacity of 120,998 m^2, constituting 6% of the total study area. Importantly, this also provides a series of smaller space opportunities allowing for a network of farmers to contribute. As noted in Table 9, a total of 44 spaces (FOI_{total} =22%) with high public exposure and 41 spaces (FOI_{total} =20%) in private property settings were identified. This makes up 42% of all the spaces analysed. In the subsequent section, Section 6, the food production capacity of the study area will be discussed in greater detail.

In terms of the retrofitting potential, a total of 84 spaces (FOI_{total} 42%) were identified to be easily retrofitted for alternative functions. To identify these spaces, the study considered the material use (whether the structure can be easily adjusted or added to), whether existing structures or surfaces exist to attach alternative structures to, the availability of infrastructure and resources on the site, and accessibility to the sites. The analysis revealed that 37% (PSI_{total} 86,262 m^2) of the total potential spatial impact could easily be retrofitted for alternative functions in the urban environment (Table 9). This means that a high number of spaces can effectively contribute to the CCA capacity of the neighbourhood. If one considers the existing spaces with vegetation and tree coverage (above 25%) and the number of existing structures to retrofit, then an additional 54,452 m^2 (3%) of the total area is included. This amounts to a total of 108 spaces (FOI_{total} = 54%) within the neighbourhood.

The analysis of the spatial and material characteristics of the unused and underutilised spaces within the neighbourhood revealed the impact that certain design decisions and responses have on the urban environment's exposure to negative climate change impacts. Furthermore, these spaces present a series of opportunities to generate additional avenues to harness local resources or waste streams whilst addressing local vulnerabilities in the urban environment. As argued in the work of Shaw and Hudson (2009) and Galt et al. (2014), using the left-over spaces allow for alternative imaginative uses to be implemented, effectively broadening the functional scope of the urban environment. As revealed in the analysis, these spaces can positively contribute to the local CCA strategy.

6. Findings - Food production potential

Considering the research focus, the study further evaluated the material and spatial nature of the existing unused and underutilised spaces in order to understand the current retrofitting potential of the neighbourhood to enable local food production. The discussion focuses on the microclimatic conditions, and spatial attributes limiting access and control to these spaces. The availability of these productive spaces is discussed, after which the findings consider the nature of these spaces and their retrofitting potential. Finally, the overall frequency of incidence (FOI) and potential spatial impact (PSI) is compared to the whole site, in order to understand its implementation potential within the whole of the Hatfield neighbourhood.

6.1. Analysis of the implementation potential considering the spatial and material attributes

In terms of solar exposure, the first stage of analysis considered the SVF of these spaces. As the morphology of the city generally embodies a low, spread-out built environment, and these spaces are often in neglected open spaces, the mean SVF of the unused and underutilised spaces is 0.84. This means that these spaces are predominantly exposed to high solar irradiation. In addition, 68% (FOI_{total} n=138) of all the spaces have a SVF of more than 0.75 (Figure 25).

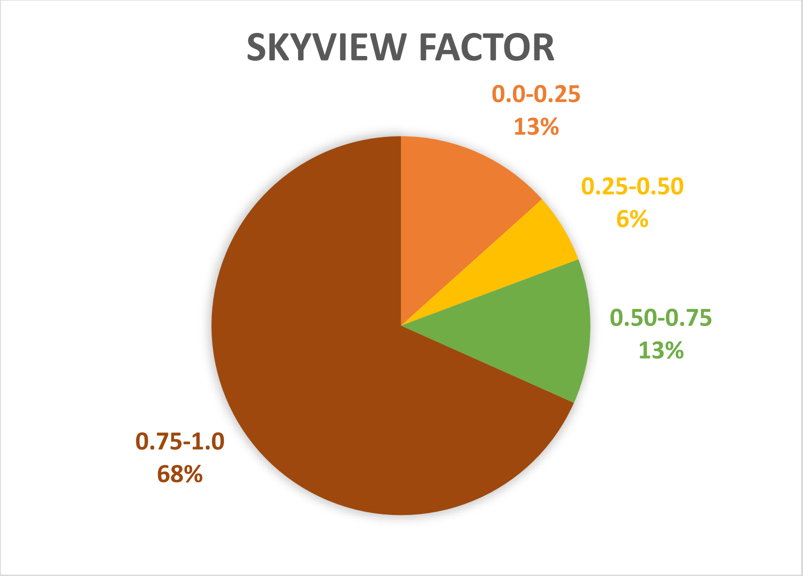

Figure 25: Analysis of the SVF of the unused and underutilised spaces in Hatfield.

While we can assume that these spaces are subject to high levels of solar exposure, the study also considered the overshadowing potential of these spaces. This involved considering the spatial definition, the site orientation and the structures that can potentially overshadow these spaces. The overshadowing potential was observed during the transect walks and not modelled during the desktop study, as a result the method and findings was developed as a heuristic response to identify potential spaces. The analysis revealed that 62% (FOI_{total} n=126) of the sites will experience limited to very little overshadowing (Figure 26). This can be attributed to a high number of the sites being accessible roof spaces (*open roof level spaces)*, but at least 74 of the total number of spaces are positioned on ground level, which presents opportunities to easily address the public realm. As these spaces receive high levels of sunlight, limited added additional light or changes to improve the microclimate will be needed for food production purposes.

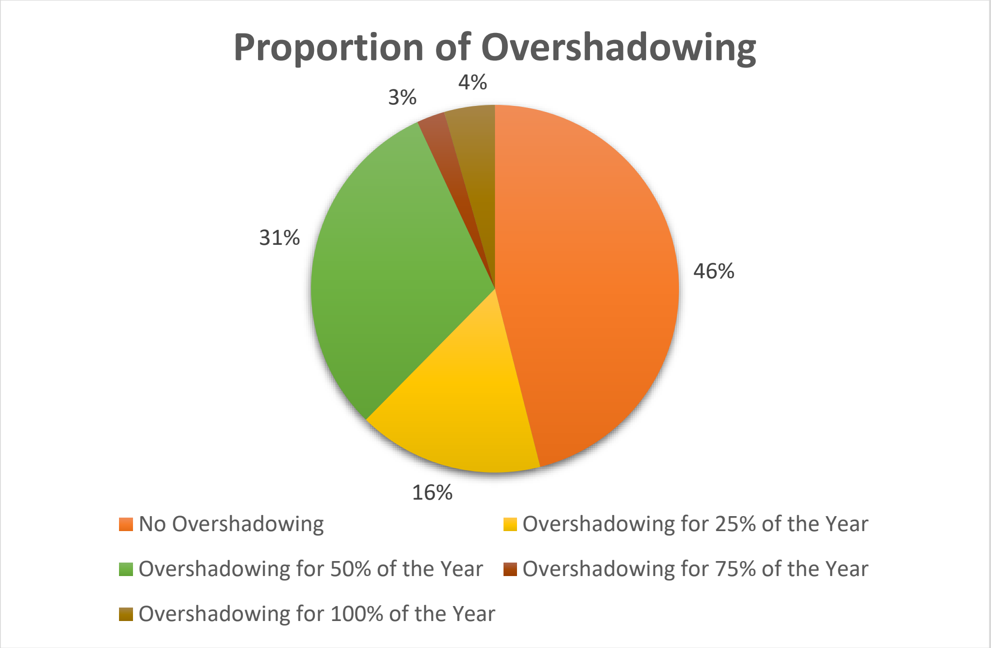

Figure 26: Analysis of the potential overshadowing of the unused and underutilised spaces in Hatfield.

The edge definition of these spaces is an important factor to consider in terms of their accessibility, ability to ensure access control, and security for goods and produce. It is important to note that some farm typologies require high accessibility for the public, while other urban agriculture projects prefer isolated spaces to ensure food safety (see Chapter 6). This analysis therefore did not designate specific value to the spaces, but rather identified a diversity of spaces available.

As indicated in Figure 27, sites with two or less defined edges constitute 76% (FOI_{total} n=154) of all the spaces documented. These spaces can enable public access; the spaces with two edge conditions allow for spatial control opportunities and make up 26% of the total number of identified spaces. In addition to these spaces, roof spaces typically have no edge condition and can be considered open, yet access to these sites is usually limited. This spatial condition is often considered beneficial to farmers that are focused on produce output (see Chapter 6). These spaces contribute 25% (FOI_{total} n=52) to the total area (Table 10).

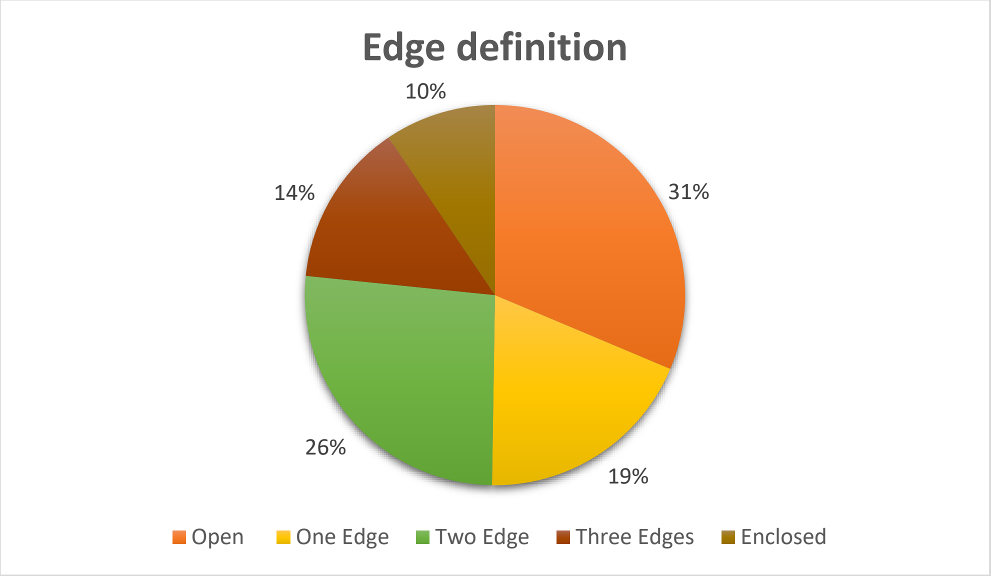

Figure 27: Analysis of the edge definition of the unused and underutilised spaces in Hatfield.

Furthermore, the analysis also considered the position of these spaces and whether the spaces that have been documented can be considered open, have controlled access, or no access at all. The study revealed that a total of 29% (FOI_{total} n=58) of the spaces are open for public access. This results in 27% (FOI_{total} n=54) of the spaces not being open for public access at all (unless design interventions are undertaken), while the remaining 45% have controlled access.

By collating the various data sets, one can with more accuracy define potential spaces that can be used for food production. In this analysis the access to the site, SVF, overshadowing potential, and the existing edge conditions were considered. The analysis revealed that 39% (FOI_{total} n=80) of the spaces have good potential for food production but have varied levels of accessibility.

Table 10: Comparison of the existing spaces and their potential to be used for urban food production.

	Total number of sites	**Frequency of incidence**
Potential spaces with good relation to public realm.	29	14%
Potential spaces on ground level that are inaccessible.	6	3%
Potential spaces located on easily accessible roofs.	17	8%
Potential spaces located on inaccessible roofs.	35	17%
Sites with low food production potential.	115	58%
Total number of spaces identified.	202	100%

As noted in Table 10, the sites with potential for food production present a variety of spatial conditions. While 14% of the sites are located at ground level and have a direct relation to the urban realm, 52 of the spaces are structural, flat concrete roofs that provide a good alternative location for food production. The accessibility of the roofs is more varied and the structural implication of such a farm on top of an existing roof will require consideration by a specialist. Nonetheless, the study identified a total of 39% of the unused and underutilised spaces available for food production in the city.

6.2. Analysis of space types available for food production

By categorising the data generated through the analysis according to spatial typologies, it is clear that *open roof levels* (roof spaces) and *open ground level* spaces present the highest potential. This was noted both in terms of the frequency of incidence (FOI) and potential space impact (PSI) of these two space types. As a collective these spaces can transform 5% of the total study area, yet in terms of the documented unused and underutilised spaces these represent 46% (109,346 m^2) of all the spaces (Table 11). They also present 66 (FOI$_{total}$ =32%) space opportunities that can be developed as smaller farm entities.

Table 11: Categorisation of the various space types with spatial and material food production opportunities.

Space Type		**Number of incidence**	**Percentage of incidence**	**Total area covered**	**Percentage of area covered**	**Proportion of study area**
Open roof level	Public accessible	26	13%	43,290 m^2	18%	2%
	Private no access	25	12%	27,610 m^2	12%	1%
Open ground level	Public accessible	14	7%	35,079 m^2	15%	2%
	Private no access	1	<1%	3,367 m^2	1%	<1%
Attached ground level	Public accessible	9	5%	5,701 m^2	2%	<1%
	Private no access	0	0%	0 m^2	0%	0%
In-between ground level	Public accessible	2	1%	3,363 m^2	1%	<1%
	Private no access	2	1%	1,408 m^2	<1%	<1%
Enclosed ground level	Public accessible	3	1%	1,022 m^2	<1%	<1%
	Private no access	3	1%	6,223 m^2	3%	<1%
Total		202		230,202 m^2		11%
Total Site				2,150,000 m^2		

In terms of the potential to retrofit the neighbourhood with BIA, *open ground level* spaces are typically not related to any built structure, and only represent open unused spaces. The study revealed that BIA can be implemented on *open roof level* spaces (both publicly accessible and inaccessible) (Table 11). A small yet important opportunity lies in developing *attached ground level* spaces that are accessible to the public (Table11). Although the *attached ground level* spaces only present 9 (FOI$_{total}$ 5%) space opportunities, these equate to 5,701 m^2 (PSI$_{total}$ 2%) in coverage. The respective spatial coverage of this space type constitutes 2% (0-50 m^2), 63%

(50-500 m^2), 25% (500-2000 m^2), and 10% (>2000 m^2). In comparison to the sites observed (see Chapter 6), many these sites are adequately sized for small to large BIA farms.

The analysis revealed three types of space typologies available for retrofitting. *Open roof level* spaces can be used for intensive production, *open ground level* spaces present opportunities to use productive spaces as alternative public spaces, and *attached ground level* and *open roof level spaces* can be used to change the resource efficiency performance of the associated built environment (Thomaier et al. 2014; Goldstein et al. 2016).

This analysis further concluded that *open roof level*, *open ground level*, and *attached ground level* spaces have the highest potential to be retrofitted for food production. *Open roof level* spaces also present the highest opportunity for potential space impact, with the total space available amounting to 70,900 m^2. By further analysing the typical area coverage of these roofs it is noted that 23% of the spaces (n=12) have a spatial coverage of 50-500 m^2, a further 54% are between 500-2000 m^2 (n=28), and finally, 21% has a space potential of more than 2000 m^2 (n=11). The largest space is 8866 m^2; this means that 75% of these roof spaces have significant potential for BIA projects.

6.3. Retrofitting potential of these spaces for food production

As an initial parameter, the study considered the retrofitting requirements of all the spaces that were documented. The analysis concludes that 79 (FOI 39%) and 65 (FOI 32%) of the spaces are associated with heavyweight structures or heavyweight framed structures, respectively. This means that these spaces are typically associated with a structure that can, through a layered retrofitting technique, enable easy fixing (see Chapter 6), and furthermore these cases consist of highly legible structures to which the retrofitted farming infrastructure can be attached. Only 58 (FOI 29%) of the spaces require alternative means of retrofitting, in some cases requiring complete structurally contained interventions for open spaces or glazed facades.

If one considers the *open roof level, open ground level* and *attached ground level* spaces in terms of their retrofitting characteristics; *open roof level* spaces consistently represent high-mass framed structures and therefore provide opportunities to layer or fix existing structures to the horizontal roof plane. A simple layered method is often used to protect the existing waterproofing and rooftop services (see Chapter 6). Unfortunately, it leaves one with few vertical structures to which the infrastructure and structure can be attached. In addition, access to these spaces and the existing structural integrity must be considered.

Open ground level spaces, on the contrary, are often not associated with built structures; in 66% (FOI_{total} n=23) of the cases the ground plane has no existing structures, 31% (FOI_{total}

n=11) has a high-mass ground plane that is typically concrete or asphalt. This reveals opportunities for soil-based and hydroponic farming systems that can easily be accommodated in these spaces, as the additional weight of growing systems is not a concern.

Finally, 15% (FOI_{total} n=7) and 56% (FOI_{total} n=27) of *attached ground level* spaces are abutting mass and high-mass framed structures, respectively. This means that should the microclimate or technology be appropriate, these spaces can incorporate the existing structure and attach a new food production intervention to it. This lends itself to more vertically orientated technologies, yet its application as attached façade is yet to be successfully developed.

Notably, the available existing spaces and typical farming typologies align with the findings as will be discussed in Chapter 6 (Sub-question B). In Chapter 6 it is concluded that the *Open roof level* spaces are most often used as building-integrated agriculture (BIA) project sites, and as noted in the Hatfield analysis, this space type has the highest potential for CCA.

While a total of 5% of the study area is available to be retrofitted for food production, only 2% of the total area can be easily transformed with BIA typologies. It is important to note that 2% of the ground level spaces can become more community-orientated farming solutions, while the 1% *attached ground level* space typology can be transformed into vertical agriculture, once the appropriate technology is cost-effective to implement.

7. Conclusion

In response to the climate change-induced impacts identified in the AR5 Report (IPCC 2014a), the study considered the existing vulnerabilities and opportunities related to these concerns. The study set out to consider the adaptation potential ingrained in the urban environment and specifically calculated the potential to improve the food production capacity of the Hatfield neighbourhood.

As the study identified the need to transform the existing urban environment to achieve deep-seated climate change adaptation (Mapfumo et al. 2017;O' Brien 2012), it explored the use of unused and underutilised spaces of the urban environment to do so. It set out to specifically move beyond using vacant sites that are formally defined as undertaken in the work of Németh and Langhorst (2014), but rather identified and defined often hidden and neglected space opportunities. Using multiple research participants in the study, the research method allowed for multiple readings of the city to identify a vaguely defined urban condition. This resulted in a more in-depth, thoroughly documented context analysis, beyond what was deemed achievable with a desktop study.

The findings from the analysis address the optimistic assumption that a significant amount of space is available to retrofit. Using the mapping method, many spaces deemed feasible from a desktop study, proved to be different in reality once the research assistants documented the spatial and material conditions on site. Furthermore, the findings also reveal existing inefficiencies in terms of space use due to formalistic responses, material use, and spatial definition. The study confirmed that multiple spaces in the urban environment exist that can potentially be retrofitted to address the ingrained vulnerabilities and access resource potentials in the city.

This stage of the study set out to define and document the spatial and material quality of local unused and underutilised spaces in the Hatfield neighbourhood in terms of its food production potential. The aim was to uncover the spatial and material characteristics of a generally vaguely defined spatial condition. The findings point towards *open roof level* spaces, *open ground level* spaces and *attached ground level* spaces as potential leverage spaces to retrofit the neighbourhood. *Open roof level* spaces have the highest potential in terms of optimum microclimatic conditions and ease of retrofitting. The next chapter discusses the spatial and technological parameters to implement BIA farms in the urban environment. Having established the characteristics of the existing urban context, and understanding the spatial and technological considerations when implementing BIA farms, further contributes to our understanding of the urban environment and its potential to be retrofitted.