Chapter 6: Spatial and technological considerations when implementing building-integrated agriculture[3]

1. Introduction

Urban agriculture (UA) is implemented globally in diverse contexts; ranging both in scale, community demographics, as well as the spatial conditions. Its flexibility and diversity in application, as discussed in Chapter 2, has been noted by a series of authors as a land-use type with high climate change adaptation (CCA) potential. Its ability to be implemented on varied scales in the urban context, is considered as one of the principal benefits of UA (Lovell 2010). Successfully implementing this flexible land-use type requires a place-specific response that considers location and its integration with existing social, economic and ecological structures (Matos & Batista 2013). Furthermore, as noted in Chapter 5, the many formal urban environments present diverse spatial conditions that can be retrofitted for CCA purposes. In the Hatfield context, these largely represent *open roof level* spaces, and the analysis documented a range of spatial scales and qualities that allow for multiple BIA applications.

UA projects have various benefits. Successful UA projects have been noted to respond to specific contextual economic crises (Partalidou & Anthopoulou 2017), allowing historic conflicts to influence its function and management processes to improve social cohesion (Corcoran & Kettle 2015), as well as addressing environmental threats such as climate change (De Zeeuw et al. 2011, Padgham et al. 2015). While UA is often considered in terms of its food provisioning role, it is important to acknowledge its diverse contributions to the local community, such as its deeply personal impact on female farmers in vulnerable communities, as identified by Battersby and Marshak (2013), and its means of cultural expression, as noted by Krikser et al. (2016). This heterogeneous nature of UA results in a variety of garden types performing multiple functions, and often results in cross-programmed or multifunctional spaces (Napawan, 2015). As a result, considering the spatial and technological implementation of these farms in terms of their multifunctional roles will provide more insight into how the built environment can promote this land-use form.

As part of this multifunctional role that UA plays in the urban environment, a multitude of technologies and forms thereof have developed in the last few years. One such form of UA

[3] An article was developed from this chapter and is currently under review:
Hugo, JM, du Plessis, C & van den Dobbelsteen, AAJF. Differentiating Zero-Acreage Farming: a Spatial and Technological Comparison of Urban Agriculture Farms.

that has been identified is building-integrated agriculture (BIA), as agriculture systems that "… exploit synergies between buildings and agriculture" (Thomaier et al. 2014:44). This form of architecture has long been proposed by Despommier (2010) as an important development needed to achieve more sustainable food networks, improved urban environments and resource-efficient architecture.

This chapter considers both UA and BIA in terms of their resultant spatial and technological manifestation in the urban context to highlight their differences and similarities. This chapter addresses the second research objective, to define the spatial and technological considerations of BIA as retrofitting strategy by interviewing a range of UA farmers and specialists, and documenting a series of BIA (including UA farms) through an observational analysis.

This chapter is divided into two sections. The first section discusses the general spatial, material and technological aspects of UA and BIA. This section considers a broad range of examples and farms to develop a broad overview of UA and BIA within the various countries. It starts by considering the various spatial parameters and continues to focus on the technological requirements. The second section considers specific BIA examples and identifies the various trends notable in these selected projects. These BIA examples included farms implemented on top of, within or adjacent to existing buildings and were documented in all four countries, as discussed in Chapter 3.

2. Spatial and technical trends documented in UA and BIA projects.

Building on the BIA farm types developed by Goldstein et al. (2016), this analysis identified a series of eight farm types ranging from low-technological solutions to highly developed automated technological solutions (Table 27 and 28, in Section 2.3). These farm types were defined along spatial conditions, technological and resource use, and microclimatic control. While the contextual implementation of these farms varies considerably, the farm-types differ in their spatial and technical articulation and also have diverse requirements. This inadvertently has an impact on the resultant flexibility and required spatial and technological inputs to implement these farm types.

The eight farms types include:

a) **Ground-based unconditioned**: These are often community farms or allotments for personal use.
b) **Ground-based conditioned:** These are low technological farms that commercial and community farms use, often focusing on organic farm practices.

c) **Integrated unconditioned:** These farms are integrated with buildings, but often have aesthetic and cultural functions and are less concerned with produce output.
d) **Integrated conditioned:** This farm type is considered as the basic BIA project, often uses hydroponic systems (Goldstein et al. 2016), function as commercial enterprises, and involve some level of microclimatic control.
e) **Integrated conditioned in-situ circular resources:** While considered experimental in nature a series of these farms have been developed. These farms currently function as aquaponic farms that recirculate nutrients within the farm itself.
f) **Integrated conditioned ex-situ circular resources:** These farms consider resource circularity within the greater community or neighbourhood. While a number has been developed, these farms are still highly experimental in nature.
g) **Indoor conditioned:** Basic hydroponic farms that function as food factories, as result the indoor air and lighting quality, as well as the nutrients are highly controlled (Graamans et al., 2018).
h) **Indoor conditioned automated**: This farm type is considered the avant-garde of UA, in these examples the farms are entirely automated, and control all the nutrient and microclimatic conditions without any human interaction.

While there are many overlaps between these farm types, the farms have different spatial and technological requirements. As a result, the differentiation between the farm types can be made and is discussed in sections 2.1 and 2.2.

2.1. Spatial parameters of urban agriculture and building-integrated agriculture projects

While the definition "urban agriculture" denotes a specific locality of food production, Matos and Batista (2013) argue that it is not the locality of the farms themselves but rather its integration on social, economic and ecological levels that present its leverage potential. Furthermore, Napawan (2016) concludes that potential implementation of urban agriculture cannot be ascertained through a mere land survey process, but rather require a specific contextual and spatial understanding of its integration with the urban context.

The collated spatial parameters of these eight farm types were documented see Table 27 in section 2.3. The analysis considers programming, parameters to assign the location, layout tactics, spatial scale, spatial and structural integration, space use, urban integration, and retrofitting feasibility as spatial characteristics specific to the eight identified farm types. These parameters manifested differently in the various farms and are associated with particular farm types.

2.1.1. Programming

The multifunctional programming of UA is actively promoted by a number of theoreticians in the discourse. As noted by Wiskerke (2001 in Ploeg & Roep 2003), the multifunctional and value–adding role of urban agriculture farms that i) provide additional services to improve the local well-being of users, and ii) produce local products, effectively differentiates UA from conventional industrial farming practices. Wiskerke (2001 in Ploeg & Roep 2003) argues, therefore, it is not the location of the farm but rather the farming practices and the role that it plays in the local community that is important to consider. While not all will agree with such a definition, Wiskerke identifies an opportunity that UA can exploit in its development as a farming strategy.

In practice, more multifarious approaches to programming have been noted. While the limited implementation of multifunctional programming cannot be associated with a specific context or country, different opinions related to multiple programming of urban farms were documented. During an interview with one of the farmers located in Johannesburg, South Africa, a specific production orientated approach to running an urban farm was revealed:

> *… Yeah, when I started I [would] bring people around… [but] there's too much administration, it's a mess. You know, I'm having tourists coming here… going through your business model... sending e-mails… it's not part of my business modelling… But now once you start doing something, you know, practically, that see that nah… I've called off a lot of interviews with media. I don't do site visits anymore… I'm not being arrogant or being cocky, but that's not why I came here…*

(Respondent 9, 12/04/2018).

This statement reveals a specific opinion towards multifunctional programming, noting a concern regarding the administration and financial returns that it presents to the farmer.

In contrast, many farmers in Singapore, the Netherlands, and selected cases in Belgium argued that including additional programmes in farming business models allow for additional revenue streams and improve awareness around the sustainability of our current food networks. As a farmer who manages a farm in Den Haag noted:

..this moment the sharing between our hospitality revenue and our sales revenue is 50-50; of course then it becomes a little bit harder to track, because we sell a lot of produce to the outside but we also transform a lot of produce on the inside…

(Respondent 12, 23/04/2018)

We see therefore, urban farms that manage to identify the additional programmes as alternative revenue streams advocate for multiple programming. This was also confirmed by farmers in Singapore: “Obviously we are a farm, but we are also looking to agrotourism to help us and sustain us” (Respondent 1, 15/01/2018). Multiple programming presents financial models that can enable these farms to compete financially in the food network.

Not all multifunctional programming of urban farms is financially driven; the study also documented a series of farms where social spaces, and active spaces such as gyms – in one case a BMX pump track – were included on the farms. Unfortunately, as the farms become more product orientated and technologically advanced, the farms actively isolate themselves from the public focusing only on food production, as noted in Figure 28.

Figure 28: Technologically more advanced farms in Belgium that are isolated from the public, and only allow limited interaction.

In conclusion, while most of the farm types present levels of multifunctional programming, and many farmers advocate for that, not all farms actively pursue multifunctional programming. As the farm types move towards more technologically sophisticated models, less integration of the farms with alternative programmes were documented (Table 12).

Table 12: Comparison of the programmatic responses related to the various farm types.

	Farm Types	A	B	C	D	E	F	G	H
Programming	Mono-functional		√		√		√	√	√
	Multifunctional	√	√	√	√	√	√		
	Farm type definitions:								

A – Ground-based unconditioned; *B – Ground-based conditioned*; *C – Integrated unconditioned*; *D – Integrated conditioned*; *E – Integrated conditioned in-situ circular resources*; *F – Integrated conditioned ex-situ circular resources*; *G – Indoor conditioned*; *H – Indoor conditioned automated*

2.1.2. Location parameters

During the documentation of the various farms the optimisation of the microclimate and a specific focus on increased exposure to sunlight were noted as a critical concern. This has been especially evident in South African farms where artificial lighting is not used. In these cases overshadowing is a critical limiting factor to consider during the identification and location of a site. This often results in a farm layout that responds to specific solar-exposure requirements. As one of the South African respondents that grows organic produce in an unused land parcel stated during an interview: “I believe a major impact, that makes a large portion of this channel (soil surrounding the channel) less appropriate, is the high trees that are growing on both sides” (translated, Respondent 21, 11/05/2018). Similarly, a farmer growing produce on the roof of an existing building using nutrient film technique (NFT) hydroponic systems, confirmed these concerns. In addition to solar exposure, the farmer (Respondent 9, 12/04/2018) noted that higher wind speeds and periods of overheating resulting from the increased thermal capacity and emissivity of the surrounding building materials significantly impact the produce output.

The importance of favourable microclimates was also discussed by farmers that use alternative technologies to ameliorate the microclimate. This was evident in the documentation of the Dutch and Belgian farms where even though artificial lighting and heating are installed in the greenhouses (Figure 29), farmers still noted that sunlight is the most cost-effective input in agriculture.

Figure 29: Farms in Den Haag and Brussels using artificial lighting and heating to optimise the microclimate.

The site visits also included farms that function as completely enclosed growing chambers. In these cases the electricity, water and internet connectivity are critical resource inputs, to achieve optimum humidity, temperature and lighting conditions (Figure 30). This increasing dependence on external resource inputs to achieve controlled growing conditions, result in high levels of flexibility in terms of location parameters and produce types.

This level of locality flexibility has been lauded by many as one of the main benefits of UA (Lovell, 2010; Senes et al., 2016). As noted during an interview with an expert in the UA and food network discourse. “…the phenomenon of urban agriculture manifests itself in many shapes and forms…” (Respondent 10, 18/04/2018). As a result, UA’s flexibility in terms of location parameters is arguably one of the main sustainable features of this land-use form.

Figure 30: Completely enclosed growing chamber the Netherlands; interior and exterior views.

As a spatial parameter, access to the farms was documented as a critical factor to ensure project viability. While access to soil-based urban farms is generally easy to manage and often controlled, access to rooftop farms is in many cases problematic. All the rooftop farms that were documented only have a single access point for both the delivery of goods and access for visitors. While the limited access can be considered as both a cost saving benefit and improved access control, the observational study often noted lengthy and difficult access to the various rooftop farms, as a result affecting the ease of deliveries.

As a result, the location and its associated constraints are important to consider. The farms that have less control over their microclimate are heavily dependent on pre-existing favourable microclimatic conditions, specifically the exposure to sunlight and the thermal conditions. As a result, these farms are less flexible in the implementation and organisation of their planting areas (Table 13). On the other hand, the more technologically developed farms, using artificial lighting and indoor climate control, are completely flexible and only require space for implementation (Table 13). All farms are planned and adapted for some form of access and delivery, yet in most cases this aspect is challenging and poorly resolved.

Table 13: Comparison of the location requirements related to the various UA farm types.

	Farm Types	A	B	C	D	E	F	G	H
Location parameters	Access points	√	√	√	√	√	√	√	√
	Microclimate concern	√	√	√	√	√			
	Location of resources						√		√
	Flexible location						√	√	√

Farm type definitions:

A – Ground-based unconditioned; B – Ground-based conditioned; C – Integrated unconditioned; D – Integrated conditioned; E – Integrated conditioned in-situ circular resources; F – Integrated conditioned ex-situ circular resources; G – Indoor conditioned; H – Indoor conditioned automated

2.1.3. Layout procedure

During the observational study, a high level of incremental development of the various farms was noted (Table 14). In many cases, this has resulted in farms developing organically over time and point towards the use of self-made technologies to accommodate these changes (Campbell 2017). The incremental development of these farms is commendable; as this allows individuals to participate in the development of the farms and slowly grow it over time. Unfortunately, as noted in the photographs taken of urban farms in Singapore and the Netherlands, this often results in haphazard development and reveals health and safety concerns (Figure 31).

Figure 31: Organic development of urban agriculture farms in Singapore and the Netherlands.

The soil-based farms that are not integrated with any built structures presented examples of spontaneous, organic development. While the farms that are integrated with buildings, typically constructed as rooftop hydroponics or soil-based roof gardens, have some sense of organic planning and experimentation, the implementation of these farms is highly dependent on the inputs from specialists to optimise the farming system. As mentioned by a South African urban farmer, this flexible quality that allows for experimentation is important to retain, as inflexible infrastructure can impede the optimisation of the farming conditions (Respondent 7, 11.04.2018).

Table 14: Comparison of the layout procedures and requirement related to the various farm types.

	Farm Types	A	B	C	D	E	F	G	H
Layout procedure	Organic layout	√	√	√	√			√	
	Professional input needed		√	√	√	√	√		
	Predetermined - no flexibility							√	√
	Farm type definitions:								

A – Ground-based unconditioned; *B – Ground-based conditioned*; *C – Integrated unconditioned*; *D – Integrated conditioned*; *E – Integrated conditioned in-situ circular resources*; *F – Integrated conditioned ex-situ circular resources*; *G – Indoor conditioned*; *H – Indoor conditioned automated*

In the case of the integrated aquaponic farms (farm type: integrated conditioned in-situ circular resources), specialist assistance is critical and spontaneous changing and adjusting of the farms are not advised. A specialist that developed aquaponics systems in the UK warned that the ad-hoc development of building-integrated aquaponics systems poses significant risks.

"… I've seen so many ad-hoc systems where you have massive fish tanks built on roofs that aren't meant to hold that. When I'm looking at them I'm just cowering with dread because that's going to fail." (Respondent 24, 17/05/2018). Installing these systems requires significant resource inputs and making any changes to these systems once implemented are more difficult.

The indoor farms and automated farming options are developed as complete modular entities and present very little flexibility in terms of layout options. Although these are modular and can be implemented in multiple conditions, adjusting for changes in spatial and crop requirements are limited (Figure 32). Any subsequent change after implementation will require input from the product suppliers or specialists.

Figure 32: Highly mechanised farms make any adjustments to these difficult once implemented. Location: Belgium.

2.1.4. Spatial scale

All the farms that were documented are anthropomorphically scaled (Table 15). They are specifically developed to be managed by humans, resulting in the planting systems, tray sizes, and planter heights designed for the human body. Many farmers argue that this is an important benefit of urban agriculture, as noted by Belgian urban farmers that developed a BIA farm: "[It] is a nice thing that you don't work with big machinery like a farmer. You don't have big tractors… there is no big machinery…" (Respondent 17, 26/04/2018). This anthropomorphic quality of the urban farms results in diverse workers being employed. This was documented in the Singaporean farms where minority groups such as physically and mentally disabled individuals are included in the workforces to promote more inclusivity.

Table 15: Comparison of the spatial scale relates to the various farm types.

Farm Types		A	B	C	D	E	F	G	H
Spatial scale	Anthropomorphic	√	√	√	√	√	√	√	
	Produce optimised				√	√	√	√	√

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
C – Integrated unconditioned
D – Integrated conditioned
E – Integrated conditioned in-situ circular resources
F – Integrated conditioned ex-situ circular resources
G – Indoor conditioned
H – Indoor conditioned automated

In the case of farms that are more produce orientated and technologically developed, typically BIA farms, methods of space optimisation were documented. Automated farms move beyond human-centred design, as these do not require any human interaction. These farms exhibit spatial articulation that completely optimises the growing spaces (Table 15). As noted in Figure 33, access is completely limited and the management of the produce is mechanised. This results in new spatial configurations that only focus on maximising the growing space. Ergonomic principles and access to each plant are negated.

Figure 33: Optimised growing conditions within a shipping container in Belgium. Access to the crops is limited.

As a result, space optimisation presents a new form of industrial-scale that is not necessarily larger in scale, but the nature of the spaces is different and more intensely used. The study therefore documented in a specific shift in scale as the technological application increases. Discussions with a group of urban farmers that were considering automation voiced concerns regarding the loss of human-plant interaction. "…you need to see if the plant is healthy or not, because so far there are no production sensors available that can tell you how the plant is doing. That is something you need to see in person…" (Respondent 17, 26/04/2018). Complete farm automation must therefore be considered with care.

2.1.5. Structural integration

The study documented farm types that range in their structural integration with the existing context or building (Table 16). The soil-based community and commercial gardens often have very little critical structural elements constructed or included. In the case of the commercial farmers, pre-manufactured growing tunnels were documented. Yet the risk of damage to other structures during installation, and the required structural integration with other structures to ensure structural stability, are minimal (Figure 34). The BIA examples and indoor agriculture are often closely integrated with the built fabric and their structural planning must be closely aligned with the existing structures (Figure 35). In these cases, the study documented a series of instances where the layout was adjusted to suit the structural point loads of the existing building. This often led to a series of constraints on the farms' production efficiency. Surveying automated indoor farms and farms circulating resources revealed the development of pre-manufactured self-contained units. While these self-contained units require assessing the associated structures or spaces before implementing them, adjusting these pre-manufactured farms to suit the building structure is limited (Figure 36).

Table 16: The range of structural integration related to the various UA farm types.

	Farm Types	A	B	C	D	E	F	G	H
Space layout integrated to structural needs	Structural integration			√	√	√	√	√	
	Pre-manufactured structure - no integration needed		√				√		√
	No structures installed.	√	√						
	Farm type definitions:								

A – Ground-based unconditioned; *B – Ground-based conditioned*; *C – Integrated unconditioned*
D – Integrated conditioned; *E – Integrated conditioned in-situ circular resources*; *F – Integrated conditioned ex-situ circular resources*
G – Indoor conditioned; *H – Indoor conditioned automated*

Figure 34: Soil-based urban agriculture that requires little structural integration or coordination. Location: South Africa.

Figure 35: Building-integrated agriculture that requires close alignment with the built infrastructure. Location: South Africa, Belgium and the Netherlands.

Figure 36: Contained farming units that are modular and easy to move and install, yet difficult to adapt to specific contexts. Location: Belgium.

2.1.6. Space use tactics

In terms of space use, the urban farms all differ in property size. The study revealed high levels of modularity and flexibility that allow these farms to grow and optimise the available space. Although the farms differ extensively in scale, ranging from 12 – 4000 m^2, the lack of space and difficulty to compete in the commercial food industry has been a sentiment documented throughout the industry. As a South African urban farmer who farms on an unused balcony in Johannesburg noted: "… because you can't compete with commercial farmers who are sitting on a thousand hectares. You know, let's be honest. So, volume can never be your value proposition. Because they'll always crush you…" (Respondent 9, 12/04/2018). In response to the space concern, farmers often optimise their space-use efficiency to increase the production of their farms.

To achieve this, the farmers follow a series of tactics. The first tactic involves moving functions or activities that can happen off-site from the farm area to more appropriate locations. As a

Belgian rooftop farmer noted: “That is one of the issues, things like plant boxes, if you need five pallets of cold boxes to put your tomatoes in, there’s nowhere to put them, so you have to put them somewhere else. You have to use another space to store that…” (Respondent 16, 26/04/2018). A second approach is a specific technological solution where stacking is used to increase the farm’s growing area is (Figure 37). While stacking can increase the produce output, concerns regarding the overshadowing of the produce were noted.

Figure 37: Stacking of farm growing systems and produce. Location: South Africa and the Netherlands.

A third spatial tactic that was documented is spatial and temporal flexibility. The study documented farms of diverse sizes, implemented in various spatial conditions, based on diverse tenure arrangements. This reveals certain flexibility in application and ability to optimise space-use which require a high level of adaptability and modularity. One of the South African farmers, farming on a series of dormant properties adjacent to existing stormwater infrastructure noted: “I did not receive permission per se to use the property. I am not renting it. I do use the property with the municipality’s knowledge, and I am sure that they approve of me using the space” (Translated; Respondent 21, 11/05/2018). Notably, in cases where farmers do not own the land or have any formal agreement to use the land, specific risk-averse layout strategies were documented. Here the farmers employed low resource input strategies that are demountable and flexible, while also investing as little as possible in the property.

In terms of modularity, the more technologically advanced farms start revealing technologies that can be implemented in farms as small as 8m^2 to large scale complete indoor farms (for example Aerofarm in Newark, New Jersey) (Figure 38). As a result a series of farms, specifically the more technologically advanced farms, revealed the use of pre-manufactured parts or components, as well as the use of a kit of parts from which the final farm can be constructed.

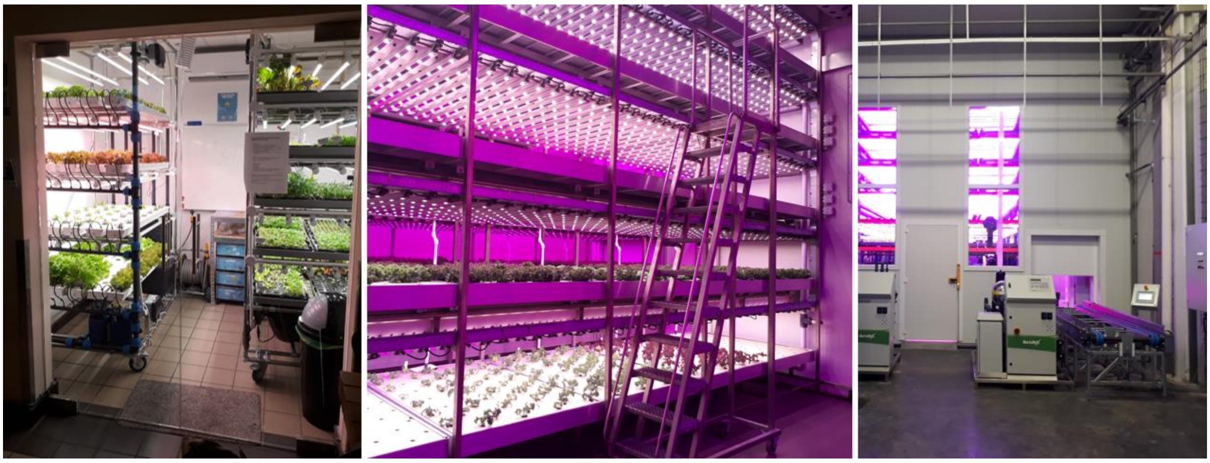

Figure 38: Farms ranging from 16m2 to larger installations, often using similar technologies or components. Location: Netherlands and Belgium.

Importantly the flexibility in the spatial application of all the different urban farm types must be emphasised (Table 17). This has been documented in all different levels of technological application and urban contexts.

Table 17: The space tactics used by the various UA farm types.

	Farm Types	A	B	C	D	E	F	G	H
Space use tactics	Large range of property sizes	√	√	√	√	√	√	√	
	Modular flexible implementation	√	√	√	√	√	√	√	√
	Farm type definitions:								
A – Ground-based unconditioned	*B – Ground-based conditioned*	*C – Integrated unconditioned*							
D – Integrated conditioned	*E – Integrated conditioned in-situ circular resources*	*F – Integrated conditioned ex-situ circular resources*							
G – Indoor conditioned	*H – Indoor conditioned automated*								

2.1.7. Urban integration

The integration of UA with the rest of the city is critical, as it provides us with the opportunity to reconsider the nature of our public spaces but also that of urban productive spaces (Bohn & Viljoen 2011). On the other hand, concerns around the feasibility of integrating urban agriculture projects with the urban environment have been noted (Napawan, 2016). Notwithstanding, as noted in the previous section, its modularity and scalability allow UA to be implemented in multiple spatial conditions, as a result enabling easier integration if needed.

During the interviews with farmers and specialists the spatial and programmatic roles of urban agriculture were often discussed. As a typical example, a Singaporean farmer noted the larger scalable opportunity that their farm presents in the urban environment.

"So for example this rooftop, before we came up it was unused land it was basically for your water tanks, for your telecommunication equipment, and for your condenser units, and for your aircon. It is basically just anti-land. By allowing us to come up here you have basically converted it into a productive piece of land where people can come to work and you can actually provide food for people around here…"

(Respondent 2, 16/01/2018).

This awareness of the greater role that both the farms and farmers play in the urban environment has long been noted in the discourse (Krikser et al. 2016; Samangooei et al. 2016). Interestingly farmers that participate in projects that contributed to local urban regeneration processes also often noted this ideal.

Ironically in practice a more varied application of this land-use form and the integration thereof were identified. As a group of specialists, German and Dutch landscape architects that have implemented many urban farms, argued during an interview.

"… you need to think about the ways you're going to separate your delicate greens from the users. In our vision it was always a combination of urban agriculture and recreation, and use of the spaces for other things because we didn't want to take away parks from the people and make them into urban agriculture farms…"

(Respondents 25, 26/05/2018).

This reflects a typical concern regarding achieving food safety, whilst exploiting the proximity and access of these productive spaces to the public community.

Two important factors contributing to more isolated urban agriculture projects are the security of equipment and infrastructure, and food safety. As depicted in Figure 9, farms that are located in more impoverished neighbourhoods have experienced theft of their equipment and as a result farmers are isolating their farms from the greater urban context and limiting access to the farms.

Figure 39: Highly secure urban farm located in South Africa with extensive security measures undertaken to ensure the equipment is safe.

In terms of food safety, many commercial farmers identified the safe production of produce as a principal driver of isolated growing chambers. As a specialist that develops automated food factories acknowledged.

> *… As far as my knowledge goes, we have the only publicly communicated robotics within the growth environment for planting and harvesting. And the main reason for adding that to the plant factory is risk management. Meaning that humans are the highest risk factor when it comes to bringing bacteria and other insects and stuff into the growth room. And if you're growing pesticide free that's the last thing you'd like…*

(Respondent 19, 27/04/2019).

This approach to growing spaces in UA results in additional isolation of the farms from the urban context. Many cases of complete isolation of farms were documented.

The study also observed completely accessible urban farms, resulting in a range of urban integration and accessibility. Community gardens often present the highest level of integration with public spaces (Figure 40). While community gardens that are entirely accessible were documented, in some cases farmers prefer defining access through the use of small gates. In cases where farms are managed as commercial entities (often the condition under which BIA functions) access is restricted to include only patrons of the entity (Figure 40). In these cases access is restricted to a certain degree. As the farms become more technologically developed, the farms become more isolated to maintain controlled growing conditions. In these examples the emphasis is placed on production output. As a result, the spaces are often isolated but still visually accessible (Figure 41). In all the completely isolated examples, the farms implemented highly developed technological systems such as automated growing systems, artificial lighting systems, and hydroponic systems (Figure 41).

Figure 40: Range of accessibility - completely open (top row) to selective accessibility (bottom row) of the farms. Location: Netherlands.

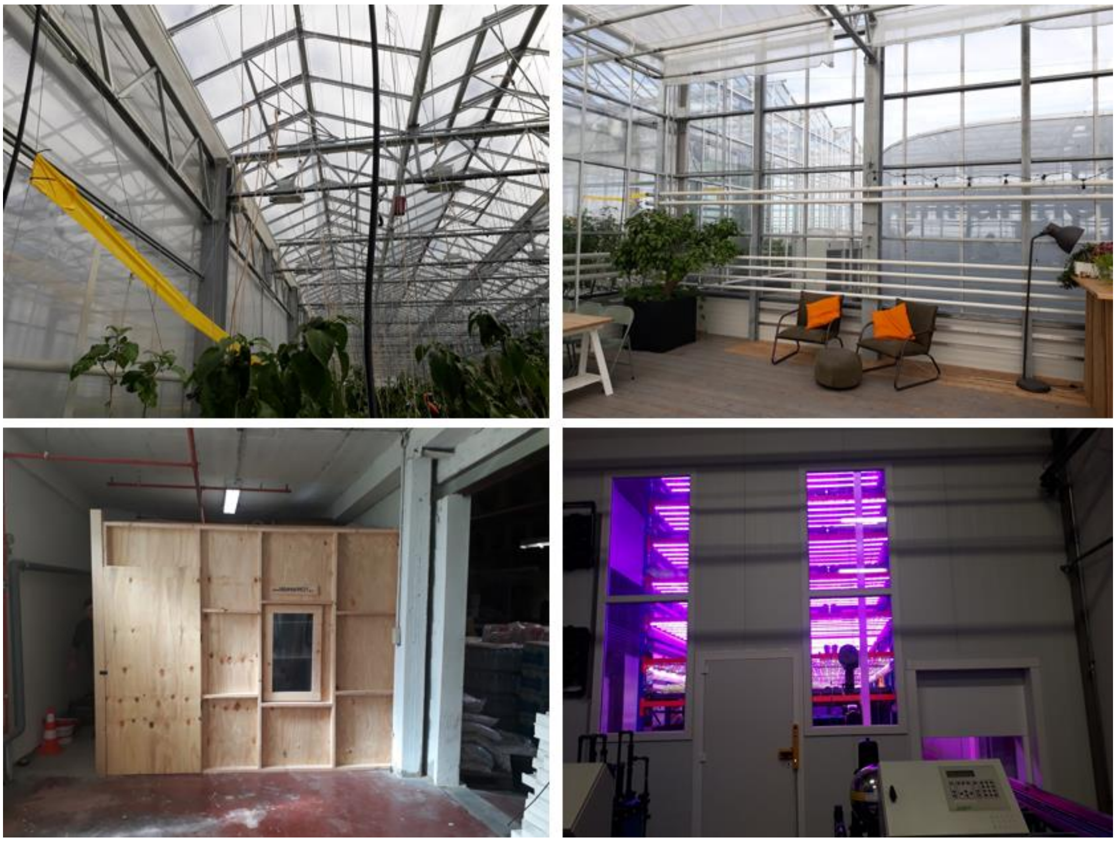

Figure 41: Range of accessibility, from visually accessible (top row) to completely isolated farms (bottom row). Location: The Netherlands and Belgium.

As a result, the study documented urban integration as a contentious aspect where the theoretical ideals differ significantly from the practical application in reality (Table 18). Furthermore, food safety and regulatory restrictions also influence the resultant implementation and urban integration of urban farms.

Table 18: The range of urban integration related to the various farm types.

	Farm Types	A	B	C	D	E	F	G	H
Urban integration	Integrate with public space	√							
	Integrated with patrons only	√	√	√	√	√		√	
	Isolated visual access					√		√	
	Isolated no access				√		√	√	√
	Farm type definitions:								

A – Ground-based unconditioned	*B – Ground-based conditioned*	*C – Integrated unconditioned*
D – Integrated conditioned	*E – Integrated conditioned in-situ circular resources*	*F – Integrated conditioned ex-situ circular resources*
G – Indoor conditioned	*H – Indoor conditioned automated*	

2.1.8. Retrofitting capacity

The analysis of the different examples revealed that all the farm types presented varying levels of retrofitting capacity (Table 19). The documented examples included retrofitting buildings, activating empty unused sites, and in certain instances attaching or contributing to infrastructure. This phenomenon has also been documented in other studies that consider UA's potential as urban regeneration strategies (Matos & Batista 2013; Galt et al. 2014). All the farms that were documented corroborated these arguments as all of them present high levels of retrofitting capacity.

Table 19: The retrofitting capacity related to the various UA farm types.

	Farm Types	A	B	C	D	E	F	G	H
Retrofitting capacity	Retrofit infrastructure	√	√				√		
	Reuse empty / unused sites	√	√			√	√		√
	Retrofit buildings			√	√	√		√	

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
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G – Indoor conditioned
H – Indoor conditioned automated

During the interviews it was evident that farmers have an intimate knowledge of the context and are very effective in identifying spatial opportunities that can be retrofitted. As noted in figure 42, farmers in South Africa identified both unused land parcels next to infrastructure and empty spaces in buildings as production spaces. In some cases this retrofitting strategy resulted in farmers identifying complete buildings as project opportunities, as stated by this Singaporean farmer: "So Panjara means jail in Malay – so fifty years ago this was a remand centre… It has been unused and when we saw that this place is only available for nine years, we thought that we should take this chance…" (Respondent 1, 15/01/2018). Similarly, a project undertaken in the Netherlands retrofitted an old Phillips factory as part of an urban regeneration effort. The intervention aims to redevelop the unused building through a series of food production programmes, and as a result hopes to improve the local surrounding neighbourhood (Respondent 12, 23/04/2018).

Figure 42: Retrofitting portions of infrastructure or parts of buildings. Location: South Africa.

Importantly, the nature of the space that is to be retrofitted often defines what type of technological application that can be implemented. The study found that open flexible soil-based farm types are easily implemented as part of larger infrastructural redevelopment measures, yet through technological advances research is being undertaken to integrate aquaponics systems as part of neighbourhood circular waste water strategies (Respondent 18, 27/04/2018).

Retrofitting of empty and unused sites has been undertaken using several technological solutions ranging from simple soil-based farm types to highly sophisticated automated solutions. In terms of retrofitting buildings themselves, hydroponic systems are often used as weight is an important consideration, while advances in artificial lighting have resulted in several indoor applications being tested and developed (Figure 43). It is important to note that vertical agriculture examples, which were successfully integrated with building facades, were not identified at the time of the study.

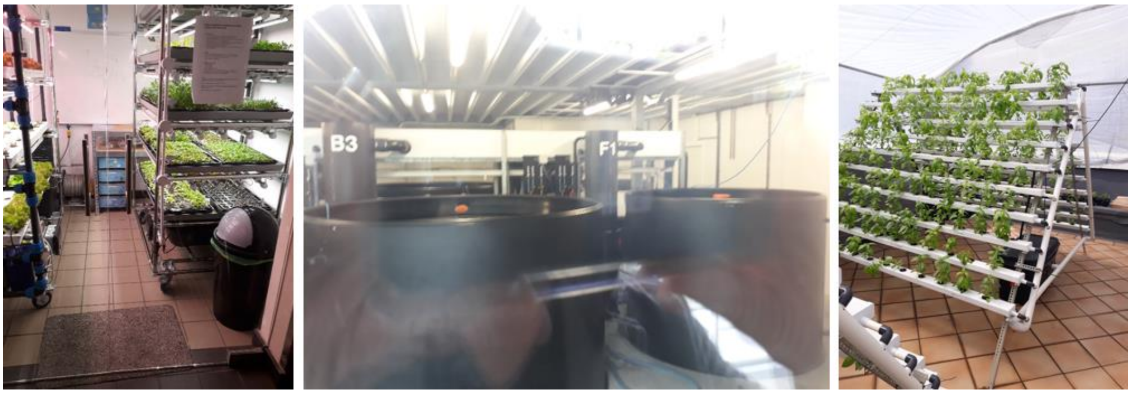

Figure 43: Aquaponic and hydroponic systems used as retrofitting strategies of existing buildings. Location: Netherlands and South Africa.

2.2. Technical parameters of urban agriculture and building-integrated agriculture farms

While industrial agriculture has over the years experienced significant technological development, little work on how these systems are implemented on smaller-scaled, diverse urban farming conditions exist. Only recently have Goldstein et al. (2016), Jenkins (2018), and Roggema (2017) started to consider the technological implementation requirements of urban agriculture, specifically BIA farms. Goldstein et al. (2016) developed a taxonomy of BIA farm types based on their spatial conditions; their analysis of the various farm types points to a specific relation between the spatial configuration and the technological implementation in the farms, arguing that specific technological systems are needed in BIA. Ngumbi (2019) acknowledges that vertical agriculture presents significant opportunities to improve resource consumption and produce efficiency. Goldstein et al. (2016) further argue that the closer integration between agriculture and the built environment increases both land-use types' resource efficiency. Furthermore, Ngumbi (2019) calls for the development of context-specific solutions that are appropriate for African conditions. She argues that more research into the technological implementation and development of vertical agriculture is needed (Ngumbi 2019).

As a result, this section specifically considered the various technological characteristics of both UA and BIA, as well as methods of technological adaptation to local conditions and project requirements. Table 28 considered the various technological parameters documented in the study and how these relate to the various farm types. These are discussed under the themes of resource inputs, infrastructure, material use, growing spaces, planting strategies, and microclimate amelioration.

2.2.1. Resource inputs

During the observational study it was noted that the resource inputs intensify as the technological sophistication of the farms increases (Table 20). At the most basic level, water is a critical resource input in all the farm types. The water quality is an essential factor, as noted by Perrin et al. (2015), and the FAO (2012) revealed an alarmingly high rate of farmers using contaminated water to grow their produce in several African cities. As one of the South African farmers that farm next to a canalised river in Pretoria noted: “The water in the channel is not clean at all, residents (next to the channel) drain their swimming pools and washing machines into the river… even sewerage pipes leak into the river” (translated, Respondent 21, 11/05/2018). As a result, the farmer installed her own irrigation system, with water supplied from a nearby home. Ensuring therefore that clean potable water is available to grow the produce is critical and considered a basic prerequisite for all farm types.

In terms of the choice of growing medium, farmers that are focussed on growing organic produce require good quality soil. As the farms move towards more technologically advanced growing methods the combination of inert growing mediums with appropriate nutrient mixes is needed. As soil plays such an essential role in soil-based farms, farmers actively regenerate the soil of their plots through composting and crop rotation methods. As a South African urban farmer argued: “I am very passionate about what we eat…. I am specifically concerned about how we use our soils. People are irresponsible and do the worst things with their soils” (translated, Respondent 21, 11/05/2018). As illustrated in Figure 44, soil-based farmers use multiple tactics to ensure the long-term sustainability of the soil on their farms.

Figure 44: Farmers using mulch to cover soil during winter periods, rotational cropping ensuring the sustainability of the farms, and incorporating compositing methods by either composting on-site or taking it offsite to compost. Location: South Africa and the Netherlands.

On the other hand, when employing more technologically advanced solutions, the extensive use of lightweight growing mediums with liquid nutrient mixes was documented. These technologies are not overly complex, as one of the Singaporean urban farmers noted: "… the technologies are all already out there. There is nothing really fancy… it is actually very simple technology" (Respondent 1, 15/01/2018). It does require some innovation and experimentation from the farmers to ensure that the technology is appropriately applied. As the same farmer continued: "We are trying out a few systems as well. We have stabilised two of them now, more or less. That will keep us going, but we are going to be building more systems out there." (Respondent 1, 15/01/2019). All hydroponic farms, regardless of their scale, require a tank to house the nutrient mix, a pump and reticulation system to circulate the nutrients. The plants themselves require growing medium to both stabilise the plant and hold some nutrients for the plant's root structure to absorb (Figure 45).

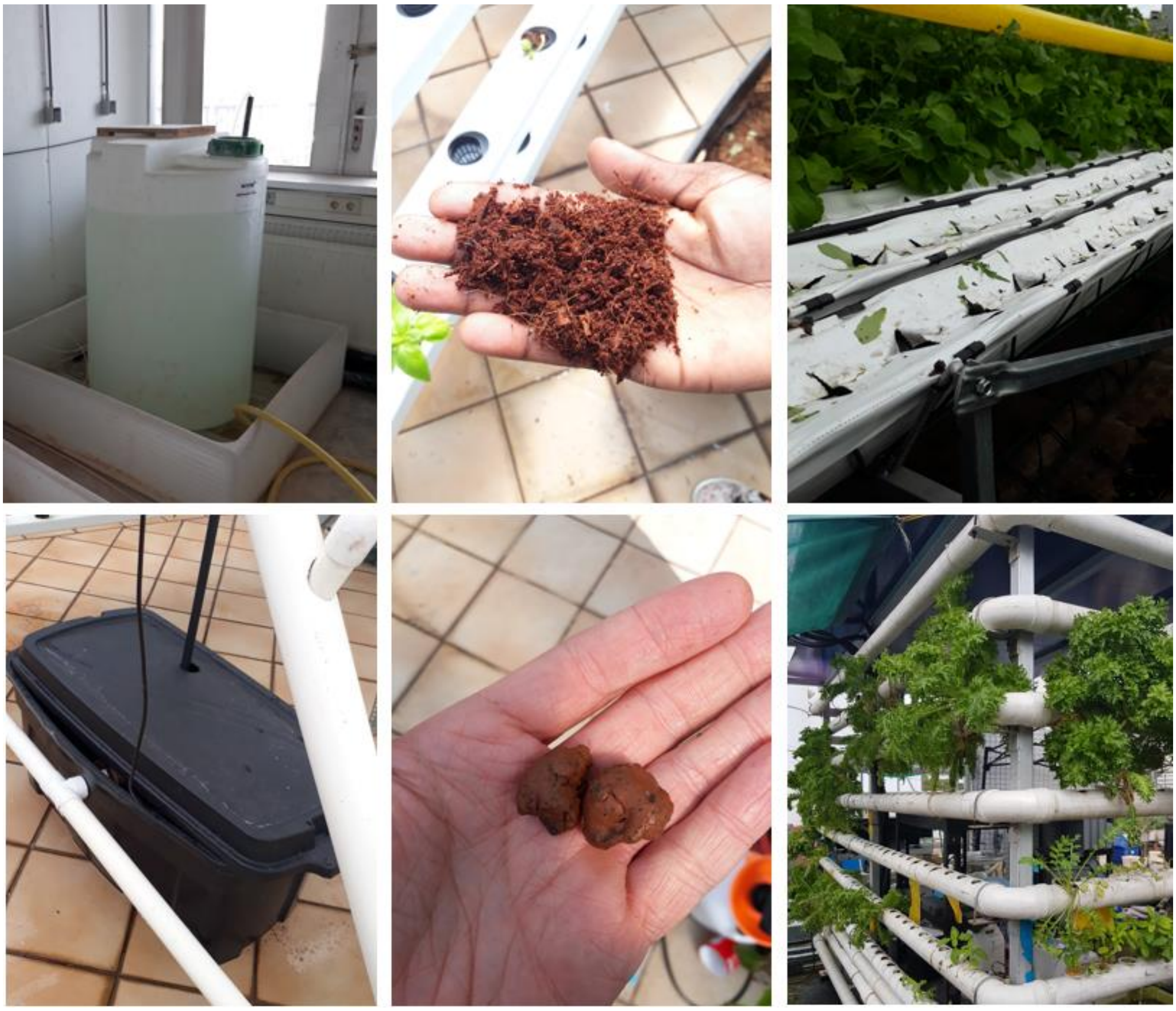

Figure 45: Various components of a hydroponic growing system and the implementation options. Location: Singapore, South Africa, the Netherlands.

Electricity as resource input is associated with the lighter, more technologically advanced growing systems. This requires additional infrastructure as well as stable resource provision to ensure that the plants do not lose nutrients or dry out due to the low absorption capacity of a typical NFT or ebb-and-flow system. While electricity is often readily available in building-integrated agriculture farm sites, the infrastructure costs can result in being more expensive to install than soil-based farms (Figu46).

Figure 46: Reticulation of electricity throughout a typical South African rooftop greenhouse (BIA). Location: South Africa.

During the interviews with product developers of automated farming systems the additional telecommunication infrastructure was identified as essential. These automated growing systems require three resource inputs – water, electricity and internet connectivity (Respondent 19, 27/04/2019). As result, it is important to be cognisant of the additional resource inputs and their required stability as the growing technology becomes more sophisticated.

On the other hand, the increased technological inputs and resource requirements provide additional opportunities to improve resource circularity and harness waste as a resource. As argued by a Belgian urban farmer while discussing the resource circularity opportunities that their farm presents: “the farm is very much integrated with the building…because of the heat value that we get from the building. So one of the ways that the fish is chosen, is how much energy is the building producing that we can capture…” (Respondent 16, 26/04/2018). The study identified the use of higher technological solutions increasing the resource efficiency of both the buildings and farms. In the completely isolated, automated urban farm types, resource circularity has been developed to the point where the excess water is collected from the dehumidification undertaken by the air-conditioner unit and used in the growing system itself (Respondent 19, 27/04/2018).

One final opportunity that the increased sophistication of growing technologies presents is integrating low and high technological systems. As discussed by a group of urban farmers in Belgium: “The main objective was to use high tech and low tech, which means natural technology, to combine them in one very, very productive system which optimises production per square meter…” (Respondents 18, 27/04/2018). As a result these farmers are experimenting with the use of wetlands, aquaculture and hydroponic systems to reuse existing effluent water with safe, consumable produce as output. We see, therefore, resource circularity being developed in multiple ways, highlighting new opportunities that technological advances present to urban farms.

In conclusion, all farm types require water and a growing medium to grow the produce. The growing medium ranges from the soil itself to lightweight forms such as coconut peat and vermiculite. It is important to note that as the farms become more technologically advanced the function of the growing medium moves from nutrient provisioning element towards basic stabilising medium. The study revealed that as the projects become more technologically advanced and increase their focus on production efficiency, more diverse resource inputs are needed (Table 20). On the other hand, these technologically advanced solutions also provide more opportunities for resource and energy circulation.

Table 20: The resource input requirements associated with the various farm types.

	Farm types	A	B	C	D	E	F	G	H
Resource inputs	Water	√	√	√	√	√	√	√	√
	Soil	√	√						
	Growing medium			√	√	√	√	√	√
	Electricity				√	√	√	√	√
	Nutrients				√	√	√	√	√
	Recirculated - thermal energy					√			
	Recirculated nutrients					√	√		√
	Internet connectivity								√

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
C – Integrated unconditioned
D – Integrated conditioned
E – Integrated conditioned in-situ circular resources
F – Integrated conditioned ex-situ circular resources
G – Indoor conditioned
H – Indoor conditioned automated

2.2.2. Infrastructure needs

As documented in the observational study, it was noted that there is a direct relationship between the complexity of infrastructural requirements and the level of technological sophistication. The study also revealed that farms that are integrated with the built environment are increasingly more technologically sophisticated (Table 28). As discussed in Figure 47 and Table 21 these trends have been documented throughout the various contexts and farm types.

Similar to the discussion on resource needs, the infrastructure requirements increase as the projects move from soil-based community garden types to automated indoor farms (Table 22). The study also noted an increased need for infrastructural stability once hydroponic systems are implemented. As the farms move indoors, they start depending on artificial lighting and indoor air-quality controls. This results in significant increases in energy and infrastructure inputs. Once the farm functions as an automated entity, it relies on constant stable resource supplies using more sophisticated infrastructure. At its highest level of sophistication, the indoor automated farms require a constant, reliable water supply system, electrical networks, growing systems of trays and pumps, monitoring systems, and piped nutrition supply systems. It also requires a drainage system connected to a larger waste water drainage system, artificial lighting infrastructure, air-condition units that include ducts, air handling units and condensers, and finally internet connection and a computer monitoring system and software (Figure 47).

Table 21: Infrastructural needs associated with the specific farm type.

← Increasing technological sophistication

Farm Type	Typical Example	Infrastructural needs
Ground-based unconditioned	Community garden Personal garden	Soil management
Ground-based conditioned	Soil-based commercial farm Organic farmer	Soil management Water Reticulation Cold Storage Growing Tunnel
Integrated unconditioned	Soil-based rooftop farm	Soil management Water Reticulation
Integrated conditioned	Rooftop hydroponics farm	Water Reticulation Electrical network Growing Chamber Growing System Resource Reticulation Drainage system
Integrated conditioned in-situ circular resources	Rooftop aquaponic farm	Water Reticulation Electrical network Growing Chamber Growing System Resource Reticulation Nutrient Reticulation Drainage system
Integrated conditioned ex-situ circular resources	Rooftop aquaponics farm Integrated aquaponics growing chambers.	Water Reticulation Electrical network Growing Chamber Growing System Resource Reticulation Drainage system Artificial lighting Air-conditioning
Indoor conditioned	Food factory Indoor farms	Water Reticulation Electrical network Growing Chamber Growing System Resource Reticulation Drainage system Artificial lighting Air-conditioning
Indoor conditioned automated	Automated food factory	Water Reticulation Electrical network Growing Chamber Growing System Resource Reticulation Drainage system Artificial lighting Air-conditioning Management Software Automated machinery

← Increasing infrastructural requirements

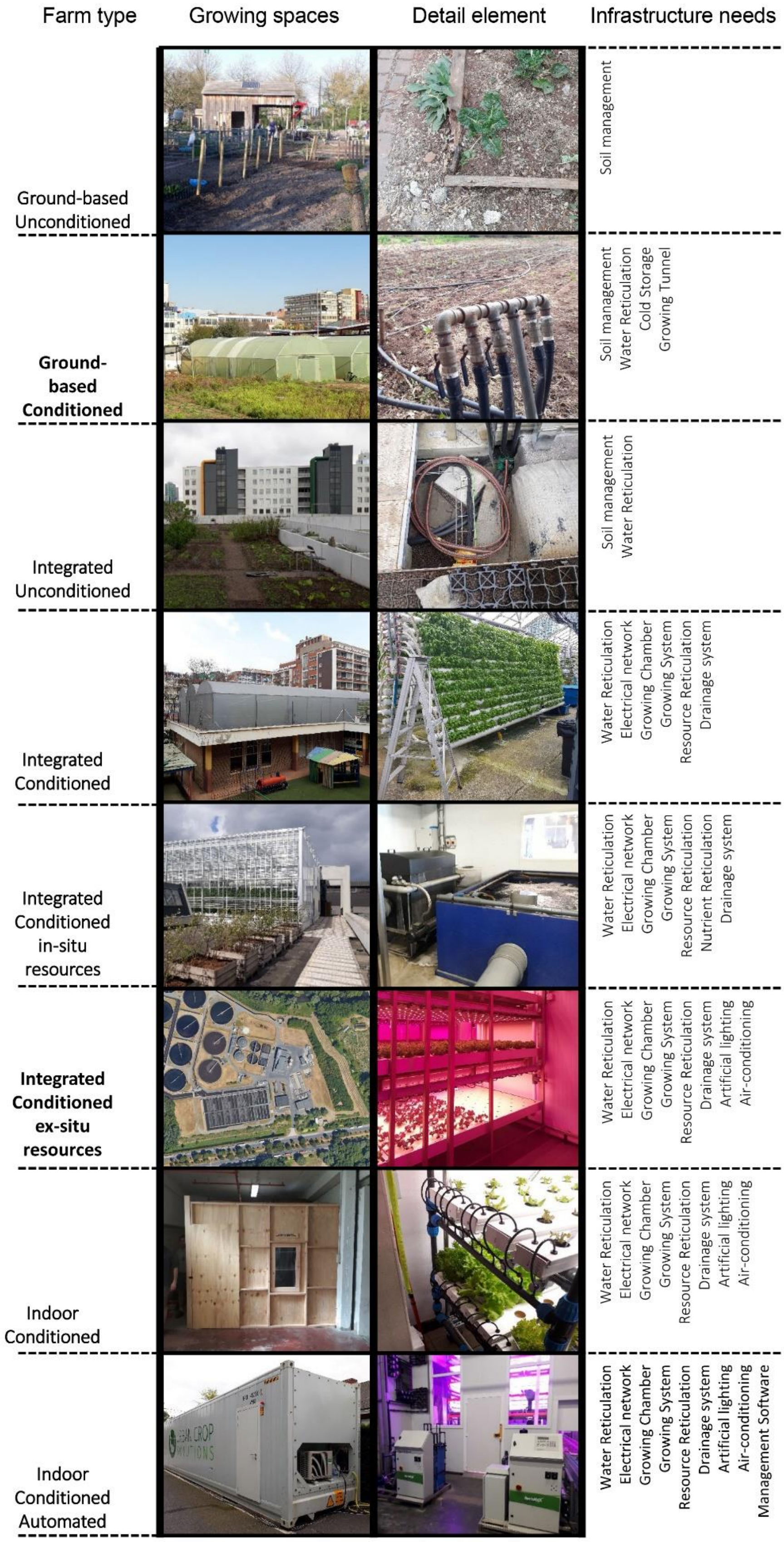

Figure 47: A selection of typical overall view and detail photographs of the various farm types that were documented. Note the increasing infrastructural needs associated with the more sophisticated farm types (Source: Aerial photograph: Google Earth).

Table 22: Infrastructural needs associated with the various UA farm types.

	Farm types	A	B	C	D	E	F	G	H
Infrastructure needs	Soil management	√	√	√					
	Water reticulation		√	√	√	√	√	√	√
	Electrical network				√	√	√	√	√
	Cold Storage		√			√			
	Growing tunnel		√		√	√	√	√	√
	Growing system				√	√	√	√	√
	Localised nutrient reticulation				√		√	√	√
	Integrated nutrient reticulation					√			
	Drainage system				√	√	√	√	√
	Air-conditioning							√	√
	Management software								√

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
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The study revealed that as the infrastructure needs increase, so does the reliance on stable resource inputs (Table 22). While soil-based farms can modulate between events of resource abundance and scarcity (rainy seasons vs droughts), sophisticated indoor farms require stable constant supplies to ensure continued automated functionality. As a result, while indoor automated farms present high levels of modularity and flexibility, concurrently their vulnerability to rapidly changing conditions and resource supply interruptions increases.

2.2.3. Technology choice and material use

During the observational study and the interviews, the use of diverse technologies and material use were documented. This diversity in material and technology was at times found within single farms, as noted by this South African urban farmer when questioned regarding their choice of growing systems: “Three (growing technologies). So we have the NFT (nutrient film technique), we have deep water culture and we have the gravel beds” (Respondent 7, 11/04/2018). While some farmers experiment extensively with diverse growing technologies and material use, the study also observed farms where very specific singular objectives are explored. As an urban agriculture specialist responded to the question regarding their focus into a specific growing technology: “What we currently see is that aquaponics and others work, don’t get me wrong, but we have focused on the economic viability of it too…” (Respondent 19, 27/04/2018). The study therefore identified the objectives and drivers of a project being closely linked to the material and technology use of a project. Commercial projects with a single focus on produce output often choose to optimise one growing technology.

In terms of the material choices the study documented three trends. Many farms actively focus on only using natural materials; secondly a series of farms specifically explore reusing and re-appropriating materials; and finally some farms only use industrially manufactured equipment (Figure 48). The interviews with farmers that are focussed on produce and commercial success often mentioned efficiency and food safety as critical concerns. During an interview with an urban farming specialist focussed on developing automated indoor farming solutions, it was clear that the use of industrially produced equipment allows for highly controlled farming conditions. This approach optimises labour efficiency and limits health or contamination risks (Respondent 19, 24/04/2018).

Figure 48: The three approaches to material use associated with the various urban agriculture farm types (left: natural materials, centre: reused or found objects, right: industrially manufactured equipment). Location: South Africa, The Netherlands and Belgium.

A second approach uses only natural materials within the farming context. This approach was documented in exclusively soil-based solutions, and often in these instances the farms have specific sustainability project drivers. While the choice of materials was not discussed; the objective of the farms as sustainable models to grow food was often cited during the interviews. As an older Dutch urban farmer and retired professor noted: “I think urban agriculture has the potential to make a substantial contribution to a more sustainable system. Not so much from the food provision angle but much more in greening the city” (Respondent 10, 18/04/2019). In these examples the farms actively set out to improve sustainability on social and ecological levels, and as a result the choice of materials often reflects that intention (Figure 49).

Figure 49: The use of natural materials in the various urban farms. Location: The Netherlands and South Africa.

The third approach that was documented is the re-appropriation and reuse of materials. These strategies were often documented in conventional community gardens and also in soil-based commercial urban farms. In these cases, farmers noted cost saving as one of the drivers of this approach. As noted by a South African farmer:

> *… Everything here has been made on site except, so, you have to buy hydroton or lyca or clay balls… the growing medium, that needs to be bought because you can't make that, but in our gravel beds we use a gravel rock, we don't use that in our gravel beds either because it's just too expensive…"*
>
> (Respondent 7, 11/04/2018)

While cost saving can be considered as one of the principal motives of self-made equipment, the researcher also postulates the intention to limit the environmental impact of urban farms as one of the reasons for the material choices. This was never confirmed during the interviews with the farmers, but the use of found and reused objects was documented extensively in soil-based urban farms.

These trends in material use have resulted in a series of fixing methods used to construct the farms. The main trends that were documented during the observational study have been i) weaving and binding methods with no mechanical fixing (Figure 50), ii) temporary demountable methods (Figure 51), iii) layered retrofitting methods (Figure 52), iv) innovative new material connections and products (Figure 53), and plug-and-play solutions (Figure 54).

Figure 50: Photographs of non-mechanical fixing of natural materials. Location: The Netherlands.

Figure 51: Examples of temporary fixing of farming equipment. Location: South Africa..

Figure 52: Layered fixing of farm structures and equipment to minimise damage to the existing structures. Location: Belgium.

Figure 53: Innovative use of materials and development of multifunctional farming components. Location: Singapore and the Netherlands.

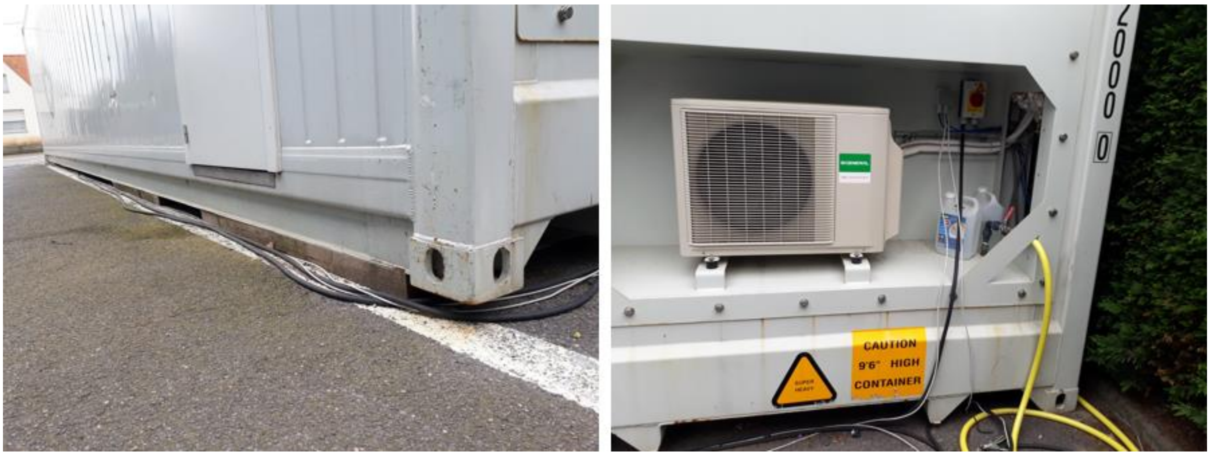

Figure 54: Examples of plug-and-play farming systems. Location: Belgium.

The study documented a high level of diverse material and assembly solutions in the industry that are closely aligned with the objectives of each farm. The observation of the various farms revealed a high level of flexibility and adaptability as one of the key intentions in the technological development of the farms. Furthermore, the layered and temporal fixing methods assist the farmers in limiting their risks during construction as well as sudden tenure changes or technology adjustments. As one of the farmers confirmed due to the nature of their farm, infrastructure adjustments and improvements are nearly impossible, negatively impacting their produce efficiency (Respondent 7, 11/04/2018). The flexibility and adaptability to change and adjust farming systems on a continuous basis are vital. The development of the plug-and-play solutions can be considered as the ultimate flexibility in application. This allows for the establishment of farms in diverse remote areas whilst limiting any adverse local impacts (Figure 54). However, adjusting these growing conditions is more complex and requires specialist input.

Table 23: The material use strategies and technology choices related to the various UA farm types.

	Farm types	A	B	C	D	E	F	G	H
Material Use	Appropriated or reuse	√	√	√					
	Natural material	√	√	√					
	Industrial				√	√	√	√	√

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
C – Integrated unconditioned
D – Integrated conditioned
E – Integrated conditioned in-situ circular resources
F –Integrated conditioned ex-situ circular resources
G – Indoor conditioned
H –Indoor conditioned automated

In conclusion, the material use shifts entirely from natural, reused and re-appropriated materials in the soil-based farms, to industrially produced components and elements in more technologically advanced farms (Table 23). This is often aligned with the project drivers and intentions of the various farms.

2.2.4. Growing spaces

As UA and BIA are persistently grappling with limited available growing spaces; a series of measures to optimise growing spaces have been documented. This was evident in both soil-based farms, where the identification of diverse growing opportunities was noted. Similarly, in more technologically advanced farm types a clear shift towards the produce intensification was observed.

Multiple farmers often voiced concerns regarding the limited space available to farm. As a result, many farmers do not see their initiatives as disruptive to the current food network but rather complementary to it, as argued by a Belgian farmer developing an aquaponics model: "… but again our aim is not to be against, to kill fishery on sea, but if we can take pressure off the ocean by providing a land based alternative" (Respondent 18, 27/04/2018). This sentiment does not negate the difficulty that urban farmers have to participate in the global food network. As a result, quality becomes the main sales pitch of the farmers. One of the urban farmers in Johannesburg unpacked his business model stating: "… 'Cause you can't compete with commercial farmers who are sitting on a thousand hectares. You know, let's be honest. So volume can never be your value proposition…" (Respondent 9, 12/04/2018). This farmer continued arguing that extended shelf-life, quality in taste, and produce fragrance are his main selling points. As a result the quality of the farming produce is critical. Nonetheless, while quality is important, the study still identified a range of methods to optimise the various growing spaces.

At the most basic level, soil-based urban farms often consider space optimisation by identifying and using all the available land, and limiting their capital inputs. Farmers, therefore, either limit their financial inputs by limiting infrastructure investment or resource inputs, even if it results in lower produce output. In addition, most soil-based farms focus on producing organically grown products, by extension focusing on soil-based growing methods (Figure 55). As noted in one of the examples in Johannesburg, where the farmer reused an old bowling club and transformed it into an urban farm. The farmer used all the space available as growing areas, but retained basic conventional soil-based farming methods. As a result, beyond using all the available land, the choice to grow organic produce has limited space optimisation opportunities. It is important to note that these farms still often employ crop-rotation methods and let portions of their farms rest for certain growing seasons. As a result, the observational study reveals limited opportunities to otherwise optimise their growing spaces.

Figure 55: Soil-based growing spaces with limited optimisation strategies undertaken. Location: The Netherlands and South Africa.

In contrast, hydroponic systems provide more opportunities for production optimisation. As a result, a series of vertically and horizontally stacked growing systems have been documented. Sunlight is still a limiting factor in these cases and is optimised as noted by one of the Belgian farmers developing indoor food factories: "… the big cost is the LEDs. That is if you would make a distribution of the cost the LEDs would easily be 70% of the investment" (Respondents 17, 26/04/2018). As a result the BIA farms that use hydroponic systems often still optimise the growing spaces to expose the crops to as much sunlight as possible (Figure 56).

Figure 56: Horizontal and vertical stacking of growing beds - note the optimisation of sunlight exposure. Location: The Netherlands and South Africa.

Finally, as the crops start moving indoors and artificial lighting is used, the vertical stacking of growing beds was documented. In these cases limited exposure sunlight is not a problem, but access and maintenance by staff members are considered, as well as ensuring adequate air-movement between the various trays (Figure 57). In the examples where automated growing systems are used, the extensive stacking of produce was documented. In these cases the farms are up to ten times more efficient in terms of growing space versus surface coverage (Figure 58).

Figure 57: Indoor agriculture where extensive optimisation of the growing beds is developed. Location: The Netherlands.

Figure 58: Growing space optimisation of automated indoor farms. Location: Belgium.

As noted there is a progression of growing space optimisation as the farms become more technologically advanced (Table 24). The organic farms retain soil-based methods and as a result have limited scalable options to increase their produce output. With the introduction of hydroponic growing methods, a series of options to increase the produce efficiency are available to the farmers but require increased infrastructure inputs.

Table 24: Growing space strategies documented at the various UA farm types.

	Farm types	A	B	C	D	E	F	G	H
Growing Space	Soil-based	√	√						
	Growing bed - single layer				√	√			
	Growing bed - stacked				√		√	√	√
Parameters									

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
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F – Integrated conditioned ex-situ circular resources
G – Indoor conditioned
H – Indoor conditioned automated

2.2.5. Planting and plant nutrition strategies

The interviews and observational study revealed a progression in terms of planting and plant nutrition strategies, ranging from a natural open system involving a level of stewardship to highly controlled administering of carefully formulated nutrition recipes. The community gardens and soil-based commercial farms all use organic planting methods such as companion planting, crop rotation, mulching and minimal weeding. The farmers that specifically focus on organic planting methods, do so both from a personal conviction and increased financial returns, as indicated by a South African organic farmer:

“I am passionate about what we eat and we have to be aware about what [we] give to our children [to eat]. Furthermore, I am specifically very concerned about how we use our soil. People are inconsiderate about how they impact the soil.

(Translate, Respondent 21, 11/05/2018)

In addition to a value-driven approach to choosing farming methods, using organic farming methods also enable farmers to obtain organic farming certification and access a smaller food network where their farming practices are valued and adequately remunerated. As a result, the main focus of these farmers is to ensure that the soils are adequately preserved, as was argued by a South African farmer following organic planting methods in Johannesburg: “All is the soil. I do natural planting. Strictly organic.” (Respondent 20, 08/05/2018).

The singular focus on organic planting strategies was not documented in the hydroponic or aquaponic farming systems. Yet farmers are still acutely aware of the negative impacts of industrial farming and prohibit the use of artificial pesticides and herbicides in their hydroponic and aquaponic farms. As argued by a Belgian farmer developing indoor farms:

… here in Europe we have a lot of problems already with microplastics in fish, and everything that is grown is already polluted because we are so densely populated. So that’s why people are more and more in favour, of the agreement of isolating or producing it in isolation environment, although it is not considered as natural…

(Respondent 18, 27/04/2018).

These farmers, therefore, see the benefit of isolated farms that limit the use of artificial pesticides and herbicides, and optimise resource consumption (Figures 56 & 59). In terms of nutrient inputs, the hydroponic farms all use additional nutrients which are specifically formulated to suit the crop type and conditions.

Aquaponic systems and integrated resource farm types aim to optimise the use of organic nutrient resources with a large portion of their nutrient inputs being provided through resource circulation from within the system. Unfortunately, as these farms are soilless they still need limited additional minerals to facilitate growth and retain an adequate PH balance. In this study, one of the surveyed projects explored using an alternative resource circularity approach where the aquaponics system provides the basis to include alternative nutrition and mineral sources to grow produce. In this instance the project explores the use of municipal effluent as resource input.

Figure 59: The use of insects as natural pest-control measure. Location: The Netherlands.

As the farms move towards more technologically advanced and sensitive systems, artificial nutrients are often used. This approach ensures that the technological system functions optimally and allows for more control of the growing conditions. As a result, any variations in the growing conditions are limited, therefore enabling automation. As noted by a specialist developing automated farms when questioned about their singular focus on hydroponic systems: “We see that it’s the most efficient way of producing plants, and allows for the most flexibility. What we currently see is that aquaponics and others work… but we have focused on the economic viability of it too.” (Respondent 19, 27/04/2019). As a result, the highly automated farming systems exclusively use artificial nutrients as part of their planting strategies and exclude resource circulation methods such as aquaponics systems.

Table 25: The various planting strategies related to the UA farm types.

	Farm types	A	B	C	D	E	F	G	H
Planting Strategy	Organic planting	√	√						
	Optimised - natural nutrients					√	√		
	Optimised - artificial nutrients				√			√	√
Parameters									

Farm type definitions:

A – Ground-based unconditioned | *B – Ground-based conditioned* | *C – Integrated unconditioned*
D – Integrated conditioned | *E – Integrated conditioned in-situ circular resources* | *F – Integrated conditioned ex-situ circular resources*
G – Indoor conditioned | *H – Indoor conditioned automated*

In conclusion, as farms shift towards more technologically advanced entities, the options to use natural and organic farming methods are increasingly more difficult to implement (Table 25). The technologically advanced farms rather opt for a more controlled approach using artificial planting and nutrition strategies.

2.2.6. Microclimate

From the observational study and interviews, three primary approaches to enhancing and using the microclimate were documented. The first approach chooses the correct site and optimises the solar exposure; the second starts ameliorating the thermal conditions and available sunlight; and the third approach creates a completely artificial microclimate and controls all the parameters.

Community gardens are often located such as to optimise the sunlight and frequently use additional strategies to improve thermal conditions (Figure 60). As discussed by this South African urban farmer: “I am limited by the seasons. In the winter, the one side (of this farm) is virtually useless and other side I can plant my winter crops” (translated, Respondent 21, 11/05/2019). As a result, farmers often respond to the seasonal variation by changing their crop types or resting portions of their farms. In some cases farmers use smaller growing chambers for seedlings or, if the funds allow, use greenhouses. In these instances the farmers mentioned that the greenhouses provide longer growing seasons, and to a limited degree, pest control.

Figure 60: Community farm with little additional improvements to the microclimate. Location: The Netherlands.

While many rooftop hydroponic, soil-based commercial farms, and integrated aquaponic farms optimise their solar exposure (Figure 61), these farms start using growing tunnels to adjust the thermal conditions and extend the growing seasons. In these cases several strategies are used ranging from cooling growing tunnels to heating the indoor air temperature. These strategies include the use of radiators to heat up the greenhouses or the nutrient mixes, the opening of screens to optimise ventilation, and in hotter climates the lack of evaporative cooling resulted in farmers using fans to increase ventilation-assisted cooling (Figure 62) as well as using ice blocks to cool the nutrient mixes of the hydroponic systems. Exposure to sunlight still plays a critical role as illustrated in Figure 61, where the greenhouse located in Johannesburg is positioned as far as possible from the southern façade of a potentially overshadowing structure. In addition to thermal control, the installation of greenhouses on rooftops also limit wind damage caused by higher wind speeds, and can provide pest control to a limited degree (Respondent 6, 11/04/2018).

Figure 61: Positioning of the urban farm to optimise insolation. Location: South Africa (Aerial photograph source: Google earth).

Figure 62: Additional measures to cool or heat the greenhouses. Location: South Africa.

The indoor agriculture, indoor automated, and integrated resources farms, all control the microclimate completely by isolating the growing chambers (Figure 63). In these cases the air temperature, humidity, carbon dioxide levels, light quality and airflow are controlled. All these parameters are used to optimise the growing conditions to suit the specific crop type. This allows the farmers to grow plants in any climatic condition, such as a case mentioned by one of the specialists developing urban farming technologies, where banana plants are grown in Leuven in Belgium for research purposes (Respondent 19, 27/04/2018). To achieve such controlled growing conditions artificial lighting, air-conditioning systems to manage temperature and humidity, and water and nutrients are carefully managed. This increased optimisation of growing conditions to suit a single crop type limits the ability of farmers to grow multiple crops at a time, and at times negatively impacts the financial success of farms, as noted by an urban farmer in Den Haag (Respondent 12, 23/04/2018).

Figure 63: Controlling the indoor environment using various systems and measures taken. Location: Singapore and the Netherlands.

In conclusion the analysis revealed that increased technological complexity allows for many opportunities to optimise the microclimate (Table 26). The optimisation of the microclimates presents the potential to improve crop diversity, but as mentioned by a specialist during an interview, this also increases the resultant embodied energy of the produce output (Respondent 11, 19/04/2018).

Table 26: Levels of microclimatic amelioration noted at the various UA farm types.

	Farm types	A	B	C	D	E	F	G	H
Microclimate amelioration	Open - sunlight optimised	√	√		√	√			
	Adjusted thermal & sunlight optimised		√		√	√			
	Control and optimised						√	√	√
Parameters									

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
C – Integrated unconditioned
D – Integrated conditioned
E – Integrated conditioned in-situ circular resources
F – Integrated conditioned ex-situ circular resources
G – Indoor conditioned
H – Indoor conditioned automated

2.3. Concluding the spatial and technological analysis of urban agriculture

In conclusion, the analysis of the farms and interviews with the farmers revealed a number of aspects. By collating the findings from the spatial and technological parameters a series of related to specific farm types were identified (Tables 27 & 28). While a number of farms share certain technological and spatial characteristics, in some aspects clear differences were noted.

First of all, UA must be developed and integrated on an urban level. This is critical to ensure that it links to existing networks and aligns with local urban development frameworks. Only once it is considered as a network of farms can this be extended and aligned to achieve additional benefits and provide sufficient food quantities.

A concerning finding is the fact that UA farms and networks do not often get designed but rather develop organically. This allows for more control for the farmers themselves; however it leads to the development of farms in isolation. This approach does not further the UA industry as a scalable transformational land-use practice that can function as a network of entities.

From the analysis it is clear that UA and BIA can be implemented in a number of spatial conditions and sizes. While these farms are flexible, all the farmers voiced their concern regarding the implementation scale of these farms. In most cases the farmers acknowledged that their role is only to augment the current food network and not replace the food industry. This can be attributed to the lack of space available for these farms.

Table 27: Comparison of the spatial trends and its relation to the farm type (Hugo et al. under review).

Parameters		A	B	C	D	E	F	G	H
	Farm Types	A	B	C	D	E	F	G	H
Programming	Mono-functional		√		√		√	√	√
	Multifunctional	√	√	√	√	√	√		
Location parameters	Access points	√	√	√	√	√	√	√	√
	Microclimate concern	√	√	√	√	√			
	Location of resources						√		√
	Flexible location						√	√	√
Layout procedure	Organic layout	√	√	√	√			√	
	Professional input needed		√	√	√	√	√		
	Predetermined - no flexibility							√	√
Spatial scale	Anthropomorphic	√	√	√	√	√	√	√	
	Produce optimised				√	√	√	√	√
Space layout integrated to structural needs	Structural integration			√	√	√	√	√	
	Pre-manufactured structure - no integration needed		√				√		√
	No structures installed.	√	√						
Space use tactics	Large range of property sizes	√	√	√	√	√	√	√	
	Modular flexible implementation	√	√	√	√	√	√	√	√
Urban integration	Integrate with public space	√							
	Integrated with patrons only	√	√	√	√	√		√	
	Isolated visual access					√		√	
	Isolated no access				√		√	√	√
Retrofitting capacity	Retrofit infrastructure	√	√				√		
	Reuse empty / unused sites	√	√			√	√		√
	Retrofit buildings			√	√	√		√	

Farm type definitions:

A – Ground-based unconditioned
B – Ground-based conditioned
C – Integrated unconditioned
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E – Integrated conditioned in-situ circular resources
F – Integrated conditioned ex-situ circular resources
G – Indoor conditioned
H– Indoor conditioned automated

While most farms are flexible in their application, the BIA examples that were documented all made use of roof spaces or indoor environments. The options to use building facades have not yet been explored extensively in the industry. This could be due to practical and cost constraints to implementing farms on building facades.

Produce space optimisation is an important practice documented in all the farms. This has often led to less comfortable spaces for the farmers themselves. As a result, the health and safety of these farms have been noted as a concern, especially in the South African farms. This is concerning as many of the farmers endeavour to employ marginalised members of the community. While this is a commendable and important benefit, the universal access around these farms is often of poor quality.

Table 28: Comparison of the technological trends and their relation to the farm types (Hugo et al, under review).

	Farm types	A	B	C	D	E	F	G	H
Resource inputs	Water	√	√	√	√	√	√	√	√
	Soil	√	√						
	Growing medium			√	√	√	√	√	√
	Electricity				√	√	√	√	√
	Nutrients				√	√	√	√	√
	Recirculated - thermal energy					√			
	Recirculated nutrients					√	√		√
	Internet connectivity								√
Infrastructure needs	Soil management	√	√	√					
	Water reticulation		√	√	√	√	√	√	√
	Electrical network				√	√	√	√	√
	Cold Storage		√			√			
	Growing tunnel		√		√	√	√	√	√
	Growing system				√	√	√	√	√
	Localised nutrient reticulation				√		√	√	√
	Integrated nutrient reticulation					√			
	Drainage system				√	√	√	√	√
	Air-conditioning							√	√
	Management software								√
Material Use	Appropriated or reuse	√	√	√					
	Natural material	√	√	√					
	Industrial				√	√	√	√	√
Growing Space	Soil-based	√	√						
	Growing bed - single layer				√	√			
	Growing bed - stacked				√		√	√	√
Planting Strategy	Organic planting	√	√						
	Optimised - natural nutrients					√	√		
	Optimised - artificial nutrients				√			√	√
Microclimate amelioration	Open - sunlight optimised	√	√		√	√			
	Adjusted thermal & sunlight optimised		√		√	√			
	Control and optimised						√	√	√
Parameters									

Farm type definitions:

A – Ground-based unconditioned | *B – Ground-based conditioned* | *C – Integrated unconditioned*

D – Integrated conditioned | *E – Integrated conditioned in-situ circular resources* | *F – Integrated conditioned ex-situ circular resources*

G – Indoor conditioned | *H – Indoor conditioned automated*

The farms often revealed high levels of experimentation and adjustment of the growing systems during their use. In cases where this is impossible, farmers have complained about the negative impact it has on the produce output and management of the farms. Post-implementation flexibility and adjustability are essential to include in the planning process.

Notwithstanding, the level of modularity of the farm technologies is high and allows them to grow into the various spatial conditions as needed. While soil-based farms and hydroponic farms can easily grow and shrink over time, in the case of integrated aquaponics systems the integrated nature of the farm limits their flexibility and adjustment if needed.

While the multifunctional nature of UA farms has been advocated and welcomed by many, in technologically sophisticated examples the inclusion of multifunctional programming is becoming increasingly limited. In many cases these technologically advanced solutions are advocating for isolated growing chambers. While this leads to safer produce; creating opportunities to promote awareness of smaller compact food networks, by integrating the consumers and producers, are more difficult to achieve.

The use of growing tunnels or greenhouses has been identified as a highly effective method to optimise the growing season and yield of the farms. However, optimising the growing conditions for a single crop type results in less diverse produce availability and limits the ability of the farms to provide alternative solutions to the food industry. This requires either the use of smaller greenhouses, the adjustment of the food network, or a system to allow multiple urban farms to function as a network of suppliers to ensure that a diverse range of food types are supplied.

In many instances the development of anthropomorphic scaled farms and the inclusion of human labour were documented. This results in specific spatial and technological solutions to accommodate the labourers. The automation that is currently underway in the industry is concerning, as this could possibly remove the human-plant interaction that is valued by many farmers.

The technological drive that has been developing in the UA and BIA industry is concerning as it is often produce orientated. It does not bring about significant paradigm changes or systemic changes to consumption patterns. The optimisation of produce through technologies effectively perpetuates the consumption orientated food network that is currently in place. Many theorists argue for deeper systemic changes to bring about an improved food network.

The retrofitting capacity of UA and BIA farms are noteworthy. Many farms have retrofitted existing buildings successfully and provide a wide array of solutions that can be undertaken. This reveals a high level of flexibility in its implementation and contextual responsiveness. Yet in all the cases access and the movement of goods from the various spaces are difficult. In many of the examples only a single access point is provided for all types of movement - be it goods or customers' access.

Finally, in terms of the CCA role of UA, conflicting opinions were raised. While many suggest that UA can contribute in terms of water security, water resilience, and limiting localised flooding (Astee & Kishnani 2010; Lupia & Pulighe 2015; Moglia 2014), this will only be effective in the case of soil-based agriculture farms that use empty lots or transform existing impermeable surfaces.

Dealing with temperature increases and urban heat island conditions are more difficult. While many state that urban agriculture can lower the local temperatures (Lovell 2010; Matos & Batista 2013; Thomaier et al. 2014; De Zeeuw 2011), others argue the increased need for sunlight can potentially result in less street or urban trees being planted, resulting in increased local urban temperatures. Only in the case of urban arboriculture can the cooling effect of urban farming be assumed (Corburn 2009). Unfortunately, few such examples as commercial urban farms exist.

In terms of CCA potential towards improved food security, a concern around capacity is identified. While all the farms provide additional food resources close to consumers, and as a result present a degree of climate change mitigation (CCM) potential, a number of farmers stated that UA cannot replace the current industrial farming system due to capacity constraints. UA therefore provides added food resources in close proximity, but with limited quantities.

This analysis presents an overview of the technological and spatial considerations of UA and BIA in a series of contexts. The next section focuses on BIA examples to identify specific trends associated with this land-use form.

3. Building-integrated agriculture – Spatial and technical trends

Following the analysis of both UA and BIA farms, trends in the spatial and technical implementation of BIA examples were considered. The criterion for the BIA examples strictly focused on projects that are undertaken either on top of, within, attached to, or directly adjacent and in close relationship to a built structure (Thomaier et al., 2014).

While this excluded some sites, twelve of the sites that were visited qualify under the criterion. These sites still presented a wide array of solutions, and are located in all four countries that formed part of the sample group. Furthermore, these examples still present a high level of flexibility in their application, and are adapted to multiple contexts and spatial configurations.

While a variety of technological solutions are employed in these projects, specific technological trends were noted.

3.1. Trends documented in Building-integrated Agriculture

a) Trend 1: Towards a more controlled environment

The documentation of BIA farms revealed an increasing shift towards controlled environments where the microclimate is optimised for a specific crop type. The study found a number of highly controlled growing conditions with a low diversity of crop types grown in these isolated growing chambers.

b) Trend 2: Increased isolation

These BIA farms are often located in more isolated conditions making it increasingly difficult to access. Some projects also specifically isolate the growing chambers due to security or food safety concerns. Finally, in cases where these spaces are publically accessible, they function as pseudo-public spaces (Landman 2016) where only patrons of the establishment are welcomed.

c) Trend 3: Flexible in application and farm size

Due to the increased use of technologies these farms revealed a high level of flexibility in terms of its spatial and microclimatic requirements. As a result, these BIA farms are implemented in a variety of spatial conditions and sizes.

d) Trend 4: Structural Integration

All the BIA farms need to retain the structural integrity of the existing buildings, and are integrated and adapted to these specific structural constraints. This requires input from multiple professionals and intimate knowledge of the structure that is to be retrofitted.

e) Trend 5: Lightweight construction

As the structural implications of these farms are significant, many of the projects use lightweight construction methods to limit the impact of their weight. These lightweight structures often include industrial materials to limit their structural impacts.

f) Trend 6: Technology-driven planting solutions

Planting technology plays a significant role in these farms to ensure crop output optimisation, economic feasibility, and their implementation in diverse contexts. The development and implementation of higher technological solutions allow for the application of BIA in a diverse series of spaces and achieves higher produce output.

g) Trend 7: Crop optimisation as spatial driver

The farms are increasingly focused on produce output, as a result spatial and technological systems focus on crop output optimisation. This often becomes the main spatial driver in several of the farm layouts or greenhouse designs.

h) Trend 8: Industrial material use

The analysis revealed a clear shift in material choice, opting to use pre-manufactured elements made from industrial materials rather than natural materials or reused elements. This can be ascribed to the need for lighter components, ensuring food safety, and the technological solutions dictating the component types.

i) Trend 9: Human scaled design and construction

All the farms retain an anthropomorphic scale to their spatial layout and technological articulation. In most of the cases using human labour is advocated.

3.2. Variations in farm implementation

While the research revealed a series of trends, a select number of variations were also documented during the analysis. In these cases, the analysis did not reveal a universal consensus, but rather diverse outcomes.

a) Variation 1: Resource consumption approach – circularity, towards resource efficiency

The projects revealed a wide range of approaches to dealing with resources. This included cases of complete optimisation and resource neutrality to farms where resource consumption is not considered at all. The trend towards resource efficiency is a significant development to note, but is not yet widely implemented nor considered important by many farmers.

b) Variation 2: From Multifunctional towards mono-functional

While many respondents argue for the benefits of multifunctional urban farming, farms ranging from complete multifunctional programming to strictly produce-orientated (mono-functional) were documented. It has been noted that the level of mono-functionality increases as the project becomes more technologically advanced.

3.3. Concerns regarding the spatial and technological resolution

The development of BIA is considered as a positive addition to the current UA industry and is actively being promoted by many in the field (Despommier 2011; Thomaier et al. 2014). However, the following concerning developments have been documented in the BIA industry.

a) Concern 1: Limited crop diversity

Due to development in technologies and the possibility of controlling the microclimate within the greenhouses or growing chambers, farmers are forced to grow a smaller selection of crop types. This has been evident in smaller farms that cannot afford a series of greenhouse structures or do not have access to space to grow multiple crop types. In many cases the industrial monoculture farming practices are retained.

b) Concern 2: No certification to differentiate farming practices

All the BIA farmers endeavour to grow their produce as organically as possible within their constraints. While the more isolated growing methods ensure that no artificial pesticides and herbicides are used, the growing methods (hydroponic or aquaponics systems) are not considered as organic farming practices. While the farms are clearly not organic in nature, their limited use of pesticides and herbicides are important benefits to the food network. Unfortunately this form of farming practice is not recognised as valuable to the food network and consumers (Respondent 15, 25/04/2018).

c) Concern 3: Less integration in the urban environment than intended

While the farmers all argue for better integration with their customers and the surrounding environments, the analysis revealed an increase in isolated farming conditions as the farms become more integrated with architecture and technologically sophisticated.

d) Concern 4: Cost of produce and technology

As noted by one of the academics in the urban agriculture discourse, the cost of the produce is still concerning. The focus on technology development does highlight a concern regarding the affordability of the technology. The technology inputs are increasingly higher in the case of BIA farms than in soil-based examples. Its affordability to be implemented in developing countries must be considered.

e) Concern 5: Access to high technological solutions in developing countries

The technological development, specifically the development of turnkey solutions, highlights the concern regarding the access, long term sustainability and agency that these projects bring to communities in poorer developing contexts. The success of implementing turnkey BIA solutions in community settings still need to be tested.

f) Concern 6: Increasing vulnerability of the systems

The increasing technological sophistication of the planting systems points towards a concern regarding the high vulnerability of these systems to external disruptions. As the projects become more automated their ability to adjust to sudden major impacts such as a loss of electricity, water, and communication disruptions must be considered.

g) Concern 7: Limited flexibility once implemented

While some projects manage to continually experiment and evolve after their initial implementation, there are cases where integration with the existing structures, resources on site, and type of produce allow little further adjustment. Maintaining flexibility to adjust over time is critical.

h) Concern 8: Worker comfort not valued

In all the cases the workers' comfort is neglected. As many farms focus on employing marginalised members of society, their comfort and safety are important factors that need attention.

i) Concern 9: Food network still concerning

While many projects are innovative in their use of space and the variety of conditions within which they are implemented, more development regarding the overall food network is needed. Most of the projects are still isolated or simply aim to function in the existing food network. If societies would like to shift towards more sustainable food networks, the food network must be addressed.

j) Concern 10: Climate change adaptation

While BIA farms present a series of climate change response strategies, defining these strategies and assessing their resultant impact is needed. As mentioned earlier, the greater resource inputs and dependence on stable conditions may counter the resultant benefits such as stormwater control and urban cooling, as argued by Dubbeling and De Zeeuw (2011).

4. Conclusion

While an extensive range of spatial and technological parameters of BIA was documented, this study confirms the argument by Specht et al. (2014) and Thomaier et al. (2014) that BIA can be identified as a specific land-use form in the urban environment. Consequently, while this land-use form, similar to UA, has retained a flexible and adaptable quality, its close relation with the built environment sets it apart from other forms of agriculture. Unfortunately, its flexible application makes specific parameters and spatial rules less discernible. The study, therefore, argues that rather than defining specific parameters and rules to implement this land-use form, a series of trends and approaches specific to BIA are developing. These trends were highlighted in this chapter.

While a wide variety of examples were documented in this analysis, the final research objective focused on the applications of BIA farms in South Africa. The unused and underutilised space mapping of Hatfield (Chapter 5), identified *open roof level spaces* (predominantly flat concrete roofs) and *open ground level spaces* as the most prevalent space types identified in the study. These spaces make up 69% of all the unused and underutilised spaces documented in Hatfield and also comprise of spatial and material qualities that can accommodate UA. From this analysis it was noted that UA, and BIA in particular, is a highly flexible land-use form and can be implemented in various spatial conditions. Notable rooftop greenhouses that employ hydroponic systems, defined as *Integrated conditioned* and *Integrated conditioned in-situ resources* farm types, were the most widely implemented BIA farm types at the time of the study, as confirmed by Goldstein et al. (2016). As a result the study considered the performance of rooftop greenhouses implemented in the South African conditions as CCA response strategies. This was appropriate as the mapping of unused and underutilised spaces in Hatfield identified *open roof-level spaces* as spatial conditions that are both widespread and suitable to retrofit. In Chapter 9, Section 3.2, the relation between the predominant farm types and space typologies (Chapter 5) is discussed in further detail. The next two chapters consider the efficacy using of passively controlled non-integrated rooftop greenhouses to improve the indoor thermal environment as a CCA retrofitting strategy.

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