Chapter 10: Conclusion

1. Introduction

As an inquiry into the climate change adaptation (CCA) capacity of the urban environment, this study specifically considered inland Southern African cities, in this case Tshwane, and how climate change response measures can be undertaken in a resource scarce context. While cities, and their associated urban structure and material use, have been neglected in many of the local CCA policies, Seto & Shepherd (2009) remind us that our vulnerability is both affected by externalised hazards and internally driven through the urban form itself. The research, therefore, evaluated the potential of using the current urban built environment and its ingrained capacity to be retrofitted with building-integrated agriculture (BIA), a form of urban agriculture (UA), to contribute to the local CCA response measures.

As a study positioned within the pragmatism paradigm, it aimed to rigorously present reality in the research findings. It endeavoured to consider the current land-use practices executed in the BIA industry and its reciprocal interaction with the built environment in formalised South African neighbourhoods. As a result, it considered the potential of BIA as a retrofitting strategy to improve the performance of the built environment as proposed by Despommier (2010) and Specht et al. (2014). Responding to one of several future climate change-driven hazards identified for the given context, the inquiry analysed the potential to improve the modulation of the indoor thermal environment as a possible co-benefit from retrofitting the roof spaces of buildings with rooftop greenhouses (RTGs). This analysis considered the potential in several ways, it analysed the urban capacity to implement BIA farms as a retrofitting strategy, it furthermore documented the spatial and technical considerations needed to implement BIA farms, and finally simulated the resultant impacts of these RTG farms on the performance of the built environment.

2. Summary of findings

The research project was guided by the following research question:

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

This question was divided into the three sub-questions and the pertinent findings for each of the sub-questions are as follows.

2.1. Sub-question A

What are the spatial and material characteristics of the unused and underutilised spaces located in Hatfield, Tshwane?

This research phase established criteria to identify and define unused and underutilised spaces that both contribute to the local climate change vulnerability, and, once retrofitted, improve the local climate change resilience. From the mapping and analysis process, five space types were defined that communicate the spatial and material conditions of the various unused and underutilised spaces. These include *open roof level*, *open ground level*, *attached ground level*, *in-between ground level*, and *enclosed ground level* spaces. The analysis revealed that 48% of the identified unused and underutilised spaces negatively affect local climate change resilience and can potentially facilitate multiple climate change response strategies.

In terms of the food production capacity of the unused and underutilised spaces in Hatfield, *open roof level* and *open ground level* spaces were found to have the largest implementation potential. This is due to the amount of space available in these two categories, their optimal microclimatic conditions, levels of exposure and space control, and their ingrained retrofitting capacity.

As a result, *open roof level* and *open ground level* spaces embody 46% of all the unused and underutilised spaces in the Hatfield neighbourhood. They represent 5% of the entire neighbourhood and cover a total of 109,346 m^2 that can be retrofitted. These spaces range in size and present several spatial opportunities that can facilitate both farmers focused on produce output, as well as alternative spaces that integrate public and productive spaces as proposed by Viljoen (2005). The findings corroborated that several latent spaces exist in the urban context that perpetuate climate change vulnerability and simultaneously present opportunities to limit the local exposure to climate change hazards.

2.2. Sub-question B

What are the spatial and technological parameters of BIA when used to retrofit the existing built environment?

The study corroborated conclusions from Thomaier et al. (2014) and Goldstein et al. (2016) that BIA is a distinct land-use form in the UA field. Building on the work of Goldstein et al. (2016), the study identified eight farm types, six of which are specific to the BIA industry. Furthermore, while the diverse application of the BIA land-use form did not reveal specific prescribed spatial and technological parameters, several signature characteristics related to the manifestation of BIA were identified.

The interviews and observational analysis revealed a highly flexible and adaptable land-use form, which often adjusts to specific diverse spatial conditions and organically develops to suit these contexts. This results in a highly modular land-use form. A select number of farm technologies and systems, often more specifically in UA examples, allow farmers to adapt the technology themselves. Finally, an inverse relationship between the technological sophistication and the spatial-microclimatic needs was identified – as the technology improves the farmers are less reliant on optimum microclimatic conditions.

Observations of the various farms revealed that farmers are highly effective in appropriating the latent spatial potential in the urban environment for food production purposes. However, many farmers share a sentiment that there is a lack of space available for farming, and as a result it is difficult to participate in the food industry.

Finally, while a flexible and highly adaptable land-use form that presents significant CCA opportunities was identified, several developments were also revealed. Many BIA farms are located in secluded urban conditions and are actively isolating themselves. Unfortunately, the technological advances in the BIA industry result in constrained flexibility and adaptability once implemented, and increased vulnerability to resource and infrastructure disruptions.

2.3. Sub-question C

What is the cooling and heating load impact on a building when retrofitted with BIA?

The thermal performance of RTGs located in Johannesburg and Tshwane was considered. This involved collecting microclimatic data from these sites and the analysis of this data revealed the following:

a) The RTGs provide limited thermal modulation.
b) Farmers have little control to change the thermal conditions in the RTGs.

The resultant poor performance of the RTGs can be ascribed to the types of materials and technological systems used in their construction, the lack of contexual design resolution, as well as the impact of the existing context and microclimate.

A series of simulations were run from these findings, testing the impact of completely retrofitting a theoretical office building in Hatfield, Tshwane, with RTGs. The simulations tested the performance of two buildings, a poorly insulated building with high levels of infiltration (SANS 10400XA non-compliant) and a highly insulated building that adequately seals (SANS 10400XA-compliant), under current and 2100 climatic conditions (A2 business-as-usual scenarios).

The findings revealed that retrofitting the RTGs to buildings have small, but varied impacts. In terms of the temperature variations, the highly insulated building simulation revealed a lower indoor temperature once retrofitted. In this case an average lower temperature of 0.8 K was documented. In contrast, the poorly insulated building simulation concluded that the retrofitting results in higher indoor temperatures: an average increase of 0.52 K was noted. Unfortunately, under climate change affected conditions, the higher temperatures resulted in all the simulations being negatively affected by the additional RTGs. Furthermore, in the highly insulated building simulation the use of air-conditioning resulted in cooler indoor environments (max 25°C), which increased the thermal conductance from the residual heat in the RTGs. This effectively increased the total energy consumption by 3.4% and 3.8% under current and future (A2 climate change conditions) climate conditions, respectively. The largest impact was documented on the top floor of a poorly insulated building, where the annual cooling load increased with 17.6% under current climatic conditions.

As a result, the analysis revealed that fully retrofitting a building in Tshwane with passively controlled non-integrated RTGs leads to varied results. By not developing the appropriate solution and controlling the residual thermal energy in the RTGs, long-term adverse impacts on the indoor thermal environment under climate change affected conditions can be expected.

2.4. Main research question

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

In order to consider the main research question the final synthesis phase expanded on the CCA definition as established by the IPCC (2014a). The expanded criteria of considerations include the following conditions that must be achieved by the given CCA solution:

a) The fitness to the context and problem.
b) The capacity to be implemented.
c) Ability to promote deep structural changes.
d) Its future impacts.
e) Continued flexibility to be adjusted.

In terms of the fitness of the solution, the findings unfortunately revealed that the BIA farms studied in this research, specifically passively controlled non-integrated RTGs, are inappropriate solutions to the context and the forecasted climate change impacts. Retrofitting buildings with this particular form of RTG can therefore be considered a mal-adaptation to the current and future climate conditions. Unfortunately, this land-use form with its current technological implementation exacerbates the higher thermal impacts already experienced in the context.

This does not mean that all forms of BIA farms are climate change mal-adaptations as the land-use form has many qualities that can facilitate effective CCA strategies. While the neighbourhood has the spatial potential to implement BIA farms, and as these spaces must be retrofitted to limit the inhabitants' exposure to climate change hazards, the findings point to the importance of developing appropriate technologies to address it. To improve the thermal performance of RTGs, by extension BIA farms, technological adjustments are needed. This calls for technology that conforms to the following:

a) The solution is adjusted and appropriate to the local context and conditions.
b) It takes cognisance of the end-user and their capacity to adapt it as needed.
c) The solution is tested in terms of its performance both in the short- and long-term.
d) It allows for continued changes and adjustments to changing spatial, functional or user conditions.
e) The BIA technological solutions must be fully integrated with the building and the greater urban context.

In conclusion, the current form of BIA technology that is implemented in the Johannesburg and Tshwane context increases the local vulnerability of both the building occupants and the farmers alike. As a result, the BIA farms do not provide any potential to modulate the indoor thermal environment. While the energy consumption cost to the neighbourhood as a whole is negligible, an increase of less than 0.05% for the added benefit of increasing local functional intensity and food production, this study hopes that adjusting the current technologies can result in tangible co-benefits as well.

If correctly designed these BIA farms can potentially provide opportunities to store and harness the residual heat in the urban environment. This will effectively adjust the energy balance of the microclimate and capture residual heat for alternative uses. As the study noted periods of significant overheating and the high exposure to direct short wave radiation, lining greenhouse structures with thin-film photovoltaic cells can potentially manage the excessive solar exposure and heat associated with it, whilst also acting as small-scaled energy-generating plants. This will ultimately require optimising the crop choice, managing the thermal heat, and coordinating the building's energy needs. The design and optimisation of the farm technology and integration with the built environment can potentially result in significant co-benefits.

3. Summary of contributions

The study contributes to the climate change and urban agriculture discourses and hopes that the findings and recommendations from the study can inform changes in both the built environment and the UA industry.

a) Climate change and climate change adaptation strategies

- The study contributes to the CCA discourse by developing a framework to document and assess the spatial and material structure of cities and their potential for CCA. This framework can be further developed and used to read cities in terms of their current spatial and material condition, and identify potential points of intervention.
- On a more practical basis, the study considered the resultant impact of one land-use type (passively controlled non-integrated RTGs) as CCA strategy in the climatic conditions of specific cities in the South African interior. The results can inform both the choice of BIA projects being implemented, and possible changes needed to ensure that they are appropriate to their context.
- Finally, while CCA is often considered and developed as macroscale initiatives or city-wide projects (Mukheibir & Ziervogel 2007), this project rather considered CCA strategies on a smaller networked basis that can be implemented by individuals or smaller entities.

b) Building-integrated Agriculture as novel land-use type in the Urban Agriculture industry.

- This study builds on the current discourse by further differentiating BIA as a novel land-use type, as well as categorising a number of farm types that have developed in the industry.
- This study identified the limited and negative impacts that passively controlled, non-integrated RTGs in warmer temperate South African conditions have on the indoor thermal environment. Unlike what is argued by many authors (Despommier 2010; Thomaier et al. 2014; Goldstein et al. 2016), this study concluded that this land-use form has a limited CCA potential. The recommendations from the study will hopefully inform the required changes to BIA projects and their designs in the Southern African context.
- The study developed a quantitative model to assess the thermal impacts of passively controlled non-integrated RTGs on the South African build environment and hopes that this contributes to future work undertaken in this topic.

4. Reflection on the research protocol and its application.

By critically reflecting on the study and the research protocol that was followed, recommendations for future improvements have been noted.

Research objective A tested the use of existing tools and a mapping process to capture an alternative reading of the urban environment. It attempted to develop a heuristic approach to quickly, and effectively, gain an in-depth ground level understanding of the city. While the use of multiple research assistants allowed for incorporating many readings or perspectives of the neighbourhood to identify a typically ambiguous spatial condition, the study could have included a wider diversity of assistants (respondents) to document it. This would provide more diverse readings of the given neighbourhood and if it includes the appropriate stakeholders can become an advocacy opportunity to initiate small scale CCA projects in the neighbourhood.

Due to the time constraints of the study, research objective B had to produce a quick overview of the spatial and technological characteristics of various UA and BIA farms. One can consider undertaking a longitudinal study to document the spatial and technological changes over several years and align this with specific farms' production output and function. This will provide more insight into the spatial and technological adjustments that the farmers undertake. Ultimately providing data on the adaptive capacity of urban farmers and the flexibility that these land-use forms present.

Reflecting on the outcomes of the final research objective, research objective C, the choice of building function had an impact on the resultant performance of the RTGs and indoor environment. Modelling a residential building might have had alternative results, as their occupancy schedules are normally different from that of office buildings and in the South African context residential buildings are less dependent on mechanical cooling. As a result, the thermal energy misalliance might have been less severe. Nevertheless, the study highlights the need to design and integrate RTGs with the built environment to enable resource circularity.

5. Suggestions for further research

From this mixed method study a number of areas for further research were identified.

a) In terms of the CCA mapping undertaken in research objective A, further research is needed to expand the group of respondents to include a diverse community of both local residents and specialists. This can inform the use of space reading heuristics and how the reading of city spaces differs between respondents. Furthermore, extending this mapping process to multiple contexts and comparing the resultant identification of unused and underutilised space opportunities can potentially reveal the relationship between the availability of unused and underutilised space types and the given context. Finally, developing an improved database that can disaggregate the collected and analysed data to develop interactive, layered mapping documents can improve the research outcomes. This can potentially communicate the various spaces' adaptation potential and improve the viability of using the data for implementation.

b) Building on the findings from research objective B, further research into the relationship between technological flexibility and the local context-specific adaptation capacity is needed. Future studies can investigate the conditions and constraints of developing urban farming technologies and spatial organization that promote the adaptation of farms to the local conditions and needs. The findings from such studies can inform the development of other building types and technologies to promote adaptive capacity in the built environment.

c) Finally, in terms of the performance modelling of BIA farms conducted in research objective C, further research into developing the appropriate RTG types is needed. This requires the development of RTGs that are fully integrated with the built environment, as suggested by Sanye-Mengual et al. (2018), and lower the indoor thermal exposure under increased climate change-driven temperatures. RTGs could be architecturally and technically designed to make them solar heat absorbers and useful energy producers, while also performing as stormwater or rainwater collectors to mitigate water insecurity.

6. Recommendations for implementation

The research project identified a land-use form that on a spatial level is highly responsive to the climate change risks confronting many cities. Unfortunately, the application and development of the specific BIA typology considered in the study are less successful within the research context to improve the local adaptive capacity, leverage change, and accommodate contextually appropriate solutions.

The industry can potentially improve its technological resolution of the various farm types, in this instance rooftop greenhouses, by developing and testing solutions for farmers located in rapidly growing Southern African urban contexts. As noted in Section 2.4, this can allow for the design and manufacture of appropriate farming technologies, such as rooftop greenhouse, for the local warmer temperate climatic conditions. Furthermore, this can also enable the development of systems that function as flexible modular entities. These solutions must be considered in terms of their continued responsiveness to changing needs, allow farmers access to the technology, and ensure that individuals can adjust it as needed. Finally, the long-term effectiveness of these solutions must be tested for the specific context in question.

Only once the fitness of the technology for the developing and fluctuating South African urban contexts is proven, can further development of policies and the integration of this land-use form in larger precinct and urban planning be advanced. While the integration of productive spaces with the greater urban context is important, the efficacy of BIA as a CCA solution must be ascertained beforehand.