Solutions from Above: Using Rooftop Agriculture to Move Cities Towards Sustainability

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Abstract: Cities present many opportunities to improve socio-ecological sustainability through efficiencies of scale and access to resources and services. These benefits are often compromised by rapidly increasing urban populations demanding energy, water, resources and food that are sourced, produced and transported from rural areas in unsustainable ways. A systems level approach to understanding the complex challenges cities face is required to strategically plan for the future. Rooftop agriculture is one measure that can help address many sustainability problems cities are currently faced with. Our research aims to identify the role rooftop agriculture can play in moving society towards sustainability, the challenges it currently faces that may prevent it from being widely implemented, and how to overcome these challenges. To structure our research, we used the Framework for Strategic Sustainable Development (FSSD), a scientifically rigorous and peer reviewed model designed to manage the complexity of planning and decision-making towards sustainability. The culmination of this paper was the creation of a Sustainable Rooftop Agriculture Guide, a practical resource that can help city stakeholders determine how to best use rooftop agriculture in their movement towards sustainability.

Keywords: Rooftop Agriculture, Urban Agriculture, Sustainability, Green Roof, Framework for Strategic Sustainable Development, City/Food Nexus

Statement of Contribution

The research and writing of this thesis was a collaborative effort between Joshua Foss, Aaron Quesnel and Nina Danielsson whose individual perspectives, strengths and expertise culminated to produce this paper.

The team developed close personal relationships throughout the research and writing processes that helped to make the work more efficient and rewarding. The experiences shared throughout the project have contributed greatly to each individual's personal and professional development. The production of this paper provided the opportunity for the team to refine skills in group dynamics, explore an exciting concept in a thorough manner, and strengthen their presentation abilities.

Each group member offered a unique and beneficial presence to the success of the project. Joshua provided the continuous out-of-the box and creative insight which enabled the project to reach great heights. Aaron ensured the project was comprehensive, complete and met the rigorous standards set forth by the MSLS program. Nina took on the responsibility of maintaining balance and perspective within the group while instilling the importance of fika in our host nation.

Throughout the thesis, the three members supported and challenged each other with enthusiasm. This collaboration undeniably resulted in a much richer experience than if projects were completed individually and in isolation.

Nina, Joshua and Aaron are grateful to have enjoyed a productive, positive, and fulfilling venture.

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Executive Summary

Introduction

About two-thirds of the ecosystem services which society depends upon are being degraded or used in ways that cannot be sustained (World Watch Institute 2006). The rapid development of the world's cities is a significant driver of this degradation, housing a growing urban population that is expected to rise from 3.3 billion today to 6.4 billion in 2050 (United Nations Population Division 2008). At present, modern cities are responsible for the consumption of 75% of the world's resources on less than two percent of the global land area (UNEP 1996; Toronto Food Policy Council 1999).

In order for cities to become sustainable they need to eradicate their dependence on the unsustainable management of water, materials, energy, and food. A measure to reduce the unsustainable management of these resources is to redesign how existing spaces are being used. One of the most underutilized spaces in modern cities is rooftops, which make up between 15 to 35% of an urban footprint (Lawlor et al. 2006). A developing concept aimed to take advantage of these spaces is rooftop agriculture.

Rooftop agriculture (RA) is the production of fresh vegetables, herbs, and edible flowers on rooftops for local consumption. This innovative use of rooftops has been shown to create green jobs, increase local food production, and provide substantial ecological benefits e.g. by expanding available areas for food production in a world where this is a growing sustainability concern. To this point, three primary types of RA have been utilized throughout the developed world. These include:

Agricultural green roofs (AGRs) integrate edible crops into a soil-based growing medium on top of a waterproofing membrane. They often include additional layers such as a root barrier, drainage layer and an irrigation system.

Rooftop container gardens involve planting vegetables, herbs, and wildflowers in pots or raised beds which contain soil-based growing media.

They can range from simple pots to more elaborate systems and are capable of covering a large portion of a rooftop.

Rooftop hydroponic systems are methods of growing plants using water-based nutrient solutions in place of soil. They require ongoing energy inputs and are often located in greenhouses, which help to boost their yields through extended growing seasons.

To guide this research, the following questions were addressed:

RQ1: *What can be the role of agricultural green roofs, rooftop container gardens, and rooftop hydroponic systems when moving towards a sustainable society?*
RQ2: *What are the challenges of implementing rooftop agriculture in cities of the developed world and how might they be overcome?*
RQ3: *What can assist cities of the developed world to better understand how rooftop agriculture can address their sustainability problems?*

Methods

Our research was designed around a series of six distinct phases formulated to help answer the research questions. In the first phase, *FSSD,* we used the Framework for Strategic Sustainable Development (FSSD) to consider food and cities to guide our research from a systems-based model. A thorough *literature review* on RA was done next, encompassing a hybrid study of green roof technologies and urban agriculture initiatives, both of which helped supply us with data to build a baseline understanding of RA. We then reached out to various experts for the third phase, *interviews*, to collect additional data from a total of 37 stakeholders with applied knowledge in RA and corresponding fields. For the *data interpretation* phase, each research question utilized the collected data in a customized fashion, incorporating elements from the FSSD description of food and cities, literature review and expert interviews. To ensure that information was accurately presented, we sent a summary of findings to our interviewees for *expert feedback*. Finally, a *Sustainable Rooftop Agriculture (SRA) Guide* was developed to apply an understanding of the key concepts identified from the research in an accessible format aimed to help city stakeholders better understand and implement RA.

Results

RA and the FSSD. The FSSD was used as a guiding framework to identify how RA can strategically move society towards sustainability. At the *systems* level, we designated the 'city/food nexus' as our system of study – i.e. an integrated functionality between cities on the one hand, and the need for food to feed city populations on the other. This nexus was defined as the connection or series of connections linking the system of a city with how it produces and consumes food. At the *success* level we created a vision of an ideal city/food nexus which complied with the conditions for a sustainable society as defined by the FSSD. At the *strategic guidelines* level we determined the strategic role of RA as to help move the city/food nexus towards success through backcasting from the vision of a sustainable nexus. The *actions* level puts focus on the concrete actions strategically informed to move the entity towards success within the city/food nexus. Rooftop agriculture was studied in this context as a means aimed to better utilize roof spaces, which have traditionally contributed to various sustainability problems in urban areas. The *tools* level was used to identify appropriate methods, techniques, and instruments used to implement actions towards success within the defined system. In parallel to the research of RA in the context of a successful city/food nexus, we designed the study to allow the development of a guide that can help a city determine how RA could be a compelling action for their strategic plans towards sustainability.

Research Question 1: The Role of RA in a Sustainable Society. In this research, it was determined that RA can provide substantial environmental, social and economic benefits to cities moving towards sustainability. The literature review and dialogues with expert stakeholders helped us identify 10 prevalent sustainability problems which RA could help to mitigate. These include: stormwater runoff, urban heat island effect, biodiversity loss, greenhouse gas emissions, community apathy, public health repercussions, food insecurity, disconnect from nature, outsourced economies, and underutilized development opportunities. We found that each of the three primary types of RA can be effective at mitigating the 10 sustainability problems at varying levels.

By using the FSSD to analyze RA from a systems level, we recognized that the different types are not in and of themselves sustainable. We identified a series of sustainability challenges which need to be taken into consideration for AGRs, rooftop container gardens and hydroponic systems to comply with the vision of success established by the FSSD. These challenges included the use of unsustainable materials for construction such as plastics, and the need for continuous inputs during operation of the RA system such as energy and fertilizers.

Research Question 2: The Challenges of Implementing RA. In theory, RA can provide significant benefits to move the city/food nexus towards sustainability. In application however, many environmental, social, and economic challenges currently exist that have contributed to RA's minimal implementation throughout cities of the developed world. The majority of challenges identified were socially constructed, citing a lack of overall awareness of the concept, an assumption of high upfront costs and policy barriers that prevent RA from being easily developed.

Research Question 3: Assisting Cities to Better Understand RA. A city looking to utilize RA requires a comprehensive and systems understanding of how it can relate to their city/food nexus. Without a clear definition of success and a strategic approach on how to achieve it, it is not guaranteed that RA will be the most compelling action when moving a city towards sustainability. Industry experts have suggested that there is a gap in accessible information regarding RA and its relationship to sustainable development. We developed a Sustainable Rooftop Agriculture Guide in an attempt to fill this gap.

Discussion

The FSSD provided our research with a strategic sustainability lens, helping to guide our analysis of RA and provide us with a clear definition of success within the city/food nexus.

RA Best Applied. Throughout our results, we identified various ways in which the three primary types of RA can contribute to mitigating the 10 identified sustainability problems. Agricultural green roofs and rooftop container gardens have shown tremendous potential in tackling various environmental and social problems within the city/food nexus, while hydroponic systems may be better suited to develop local economies and strengthen a region's food security.

We found that social and economic challenges proved to be the toughest hurdles for the implementation of RA in cities of the developed world.

However, our experts were able to suggest several ways to overcome these challenges.

Overall, our key findings suggest that RA has a high probability of being utilized throughout many cities of the developed world in the not-too-distant future. Several significant projects have been recently developed throughout North America that will lay the groundwork for how the concept can move forward.

Strengths, Weaknesses and Limitations of Research. The predominant strength of the study was the analysis of RA from the strategic sustainability perspective. The FSSD provided a robust framework to work from, ensuring that investigation of RA was done in a manner that put RA into a structured perspective large enough in time (backcasting) and space (universal sustainability principles). The insight provided by key industry experts was another research strength. Relevant data and ideas from some of the leading researchers in green roofs, urban agriculture, and rooftop agriculture were harvested in this study. We created a Sustainable Rooftop Agriculture Guide to try and fill a pronounced gap in information available to city stakeholders, but limited by time, this guide was never field tested with our experts.

Recommendations for Future Studies.
The RA industry would benefit from interdisciplinary collaboration and consolidation of research efforts within the fields of green roofs and urban agriculture. While some studies have investigated the potential for urban agriculture to contribute to a regional food system, similar studies for rooftop agriculture could garner public interest and support for the concept. Future research may also investigate emerging technologies which were not analyzed in this study such as aeroponics and aquaponics.

Conclusion

This research identified that while currently in a nascent stage, rooftop agriculture has the potential to be a strategic action to move a city of the developed world towards sustainability. We determined that while RA can contribute key benefits to the city/food nexus in isolation, its strengths lie in its ability to address environmental, social and economic sustainability problems simultaneously.

Glossary

Agricultural green roofs (AGR): A rooftop which integrates edible crops into a soil-based growing medium on top of a waterproofing membrane. It often includes additional layers such as a root barrier, drainage layer and an irrigation system

Backcasting: A planning procedure by which a desired future is imagined, followed by the question: 'What do we need to do today to reach this desired future state?' (Dreborg 1996)

Biocapacity: Measures the bioproductive supply, or biological production of an area, and that area's ability to absorb wastes and pollution

Biodiversity: The variety of life forms within a given ecosystem, biome, or region

Biodynamic agriculture: A method of farming which views farms as unified and individual organisms, emphasizing the balance of holistic development and interrelationships between the soil, plants and animals which creates a self-nourishing system without the need for external inputs

Biosphere: The part of the earth's system in which there are the necessary conditions to support life; including the surface, the atmosphere, and the hydrosphere

Community supported agriculture (CSA): A socio-economic model of agriculture production and food distribution where a consumer buys a share in the farm by purchasing a season's supply of groceries and paying for it at the beginning of the season, thus sharing any seasonal risks with the farmer

City/Food nexus: A connection or series of connections linking the system of a city with how it produces, consumes, and disposes of food

Ecosystem services: The goods and services that the environment produces. These include, but are not limited to, clean water, clean air, carbon regulation, pest control, pollination and food

Food insecurity: When individuals do not have access to sufficient, safe, nutritious food to maintain a healthy and active life. The concept includes both physical and economic access to food that meets people's dietary needs as well as their preferences

Funnel metaphor: Is representative of the socio-ecological system in which society exists and represents a decreasing capacity of the Earth's systems to support society in relation to time. This is driven by the systematic depletion and degradation of natural resources and ecosystem services against a rising global demand for these resources (Robèrt 2000)

Framework for strategic sustainable development (FSSD): A five-level framework used to understand and plan progress towards a sustainable society. It is built upon a generic framework for planning and decision making in complex systems utilizing a whole-systems approach and science-based Sustainability Principles.
It is comprised of five distinct, non-overlapping levels: (1) System, (2) Success, (3) Strategic Guidelines, (4) Actions, and (5) Tools (Robèrt 2000)

Greenhouse gases: Gases which can absorb longwave (infrared) radiation in a planetary atmosphere and reduce the loss of heat into space, thus contributing to warming of the atmosphere

Green roof: A roof that is partially or wholly covered with vegetation in a soil based growing medium on top of a waterproofing membrane. It often includes additional layers such as a root barrier and drainage boards

Resilience: The ability of a system to anticipate risk, limit impact and recover readily from any misfortune

Rooftop agriculture: The growing of fresh vegetables, herbs or edible flowers on rooftops for local consumption

Rooftop container gardens: The planting of vegetables, herbs, or edible wildflowers in rooftop containers or raised beds which contain soil-based growing media. They can range from simple pots to more elaborate systems and are capable of covering a large portion of a rooftop, but are generally independent of the roof structure

Rooftop hydroponic systems: A method of growing plants using water-based nutrient solutions in place of soil. Systems can be exposed to the air, or contained in a glass or plastic greenhouse

Sustainability Principles: In a sustainable society, nature is not subject to systematically increasing:

SP1. ...Concentrations of substances extracted from the Earth's crust;

SP2. ...Concentrations of substances produced by society;

SP3. ...Degradation by physical means;

and, in that society,

SP4. *...People are not subject to conditions that systematically undermine their capacity to meet their needs*

(Ny et al. 2006)

Systems-thinking: An approach to problem solving that assumes that the individual problem is part of a much larger system. The intent is to solve the problem in a way that does not create further problems down the road

Technosphere: A system which is built or modified by humans and is a sub-system within the biosphere

Urban agriculture (UA): The growing, processing, and distribution of food and other products, through intensive cultivation in urban and peri-urban areas

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1 Introduction

1.1 The Sustainability Challenge and Urbanization

Human development in its current form is unsustainable and the evidence is everywhere; climate change, species extinction, pollution and social inequality are deteriorating the capacity to sustain our ways of life. It is estimated that about two-thirds of the ecosystem services upon which human society depends are being degraded or used in ways that cannot be sustained (World Watch Institute 2006). This degradation is occurring at an alarming rate from a global time scale, yet the majority of society has not comprehended the socio-ecological impacts for which it has been predominantly responsible.

Figure 1.1 is representative of the socio-ecological system in which society exists and is referred to as the 'funnel paradigm' (Robèrt 2000). It is a visual metaphor which represents a decreasing capacity of the Earth's systems to support society in relation to time. Increasing human populations which demand ecosystem services have led to increasing resource consumption, while access to these resources and the health of ecosystems upon which society relies have been in decline. This path of development which humans have chosen will inevitably lead to the breakdown of the socio-ecological system.

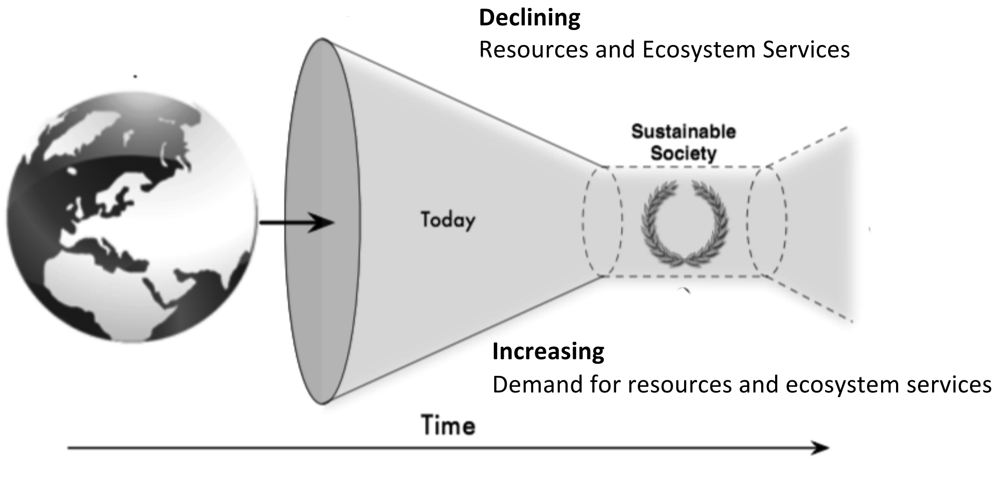


Figure 1.1 The Funnel paradigm (derived from The Natural Step 2008)

1.1.1 Urban Development

One of the key drivers of humanity's movement through the funnel has been the alarming increase in global population over the past several decades. The number of humans on the planet in 1970 was 3.7 billion and projections show a population of 9.2 billion by 2050 (United Nations Population Division 2007). The majority of this population increase has occurred in urban areas and is projected to continue to do so. Estimations anticipate urban populations will grow from 3.3 billion today to 6.4 billion in 2050, about a 90% increase (United Nations Population Division 2007). In other words, the number of people living in urban areas in 2050 will be close to the entire world population today.

1.1.2 Opportunities in Urban Development

Cities can offer efficient ways to address many of the social and environmental problems associated with population growth. With good governance and leadership, they are able to deliver education, health care and other services more efficiently than rural areas as a result of their advantages of scale and proximity (United Nations Population Fund 2005). The potential to generate jobs and income has been another key advantage cities have been shown to provide (United Nations Population Fund 2005). Furthermore, energy conservation and efficiencies can be achieved from increased building density and an integrated human-scale transport infrastructure (Eaton et al. 2007).

1.1.3 Challenges of Urban Development

While cities have great potential to minimize the resources used per capita, the reality is that their footprints currently far exceed their biocapacities or biological production of an area, and that area's ability to absorb wastes and pollution by up to 150 times within a specific region (Doughty and Hammond 2004). This is due in part to infrastructure development e.g. inefficient land-use, urban sprawl, poorly planned transport systems etc., and partly because urban residents, through their demands, drive unsustainable ways of resource extraction, manufacturing processes and transport within urban areas as well as far beyond city boundaries. At present, modern cities are responsible for the consumption of 75% of the world's resources on less than two percent of the total global land area (United Nation Environment Programme 1996; Toronto Food Policy Council 1999).

In addition to resources, most cities rely on importing energy from distant and environmentally degrading sources. When examining the current global energy portfolio, 85% is derived from non-renewable fossil fuels in the form of coal, oil or natural gas (International Energy Agency 2010). Urban areas require 67% of the global energy demand while housing only half of the global population (International Energy Agency 2008). Fossil fuel use has increased substantially over the past half century, from 1.7 billion tonnes of oil equivalent in 1950 to 8 billion tonnes in 1999 (Girardet 1999). This alarming increase in fossil fuel usage has catalyzed urban development throughout the world and brought many people out of poverty, but at the same time has placed cities in a vulnerable position regarding their future energy security. Conservative international governmental sources estimate that both oil and natural gas reserves will run out by 2050 (Scheer 1999). The oldest and arguably most environmentally problematic source of energy, coal, is expected to expire for commercially meaningful purposes well before 2100 (Droege 2002). These projections suggest that there may be significant challenges ahead for urban areas in terms of their energy security into the future, particularly when global population trends are considered.

Tied directly to this energy volatility and urbanization is the agriculture industry, which has become increasingly reliant on significant energy inputs. The vast majority of food is no longer produced within close proximity to city centers, with the average food item on a store shelf in North America having travelled 2,000 km from its point of harvest to the consumer (Brown and Carter 2003). Trucks, airplanes, and ocean vessels are now required to deliver the majority of the food consumed by city dwellers, disconnecting them from food production and increasing their vulnerability to disruptions in the global food system. Most people have little more than a few days of food supply at their homes and limited or no access to the essentials they need to sustain themselves (Hall 2000). To develop regional resilience, it is increasingly imperative that cities utilize strategies to minimize their reliance on importing food, energy and other resources.

1.2 Promoting Resilience in Cities through Urban Agriculture and Green Roofs

Two of the most effective actions to help build resilience into a city include increasing local food production within urban and peri-urban areas

(Mullinix et al. 2009) and rethinking how existing spaces such as rooftops can be used in productive ways.

1.2.1 Urban Agriculture

Urban Agriculture (UA) is the production, processing, and marketing of food in urban and peri-urban areas, through intensive production methods to yield a diversity of crops and livestock (Smit et al. 1996). UA operations have the potential to boost the food output of regions in productive and efficient ways (Brown and Carter 2003), and because of this has garnered increased attention throughout cities of the developed world in recent years. Heimlich and Bernard (1993) noted that commercialized operations within a city can yield up to 13 times more food per hectare when compared to conventional industrial agriculture found in rural lands. This in part is due to the ability of increased intensities and implementation of season extending technologies that can be integrated into urban agriculture activities.

One prominent benefit of localizing food production in urban areas is the strengthening of a region's food security, or the availability of food and one's ability to access it (Hall 2001). Experts suggest that to prepare for emergencies (either natural or human induced) every community should be able to produce or supply at least a third of the food required by its residents (Brown and Carter 2003). At present, most cities produce less than five percent of their food needs on average (Brown and Carter 2003). An additional benefit UA provides to urban resilience is the development of local economies when inner-city residents gain the ability to grow and market their own food, and when urban farmers markets provide new opportunities for commercial farmers and entrepreneurs (Brown and Carter 2003). Furthermore, environmental impacts can be drastically reduced when food is produced in close proximity to urban populations, minimizing the reliance on fossil fuels for production and transportation (Smit et al. 1996).

1.2.2 Green Roofs

Green roofs integrate vegetation in a soil-based growing medium on top of a waterproofing membrane and often include additional components such as a drainage layer and root barrier. The concept promotes environmental, social, and ecological resilience by taking advantage of rooftops, which can make up a significant portion of a city's footprint. Lawlor et al. (2006) estimates that 15 to 35% of an urban footprint is comprised of roofspaces.

Green roofs are increasingly being utilized as methods to manage stormwater runoff (Clark et al. 2008; Lee 2004), reduce building energy consumption (Rowe 2010; Bass and Baskaran 2003) and serve as a platform to bolster biodiversity (Castelton et al. 2010). They have also been proven to protect the roofing membrane against ultra-violet (UV) radiation, extreme temperature fluctuations and puncture or physical damage from recreation or maintenance (Rowe 2010). In addition, green roofs can contribute to the economic resilience of an urban area by increasing amenity value for building tenants (Peck and Callaghan 1999), improving property values and increasing worker productivity for those with views of green spaces (Osmundson 1999; Peck et al. 1999).

1.3 Addressing Sustainability Challenges through Rooftop Agriculture

Combining the key components of green roofs and urban agriculture is a concept known as rooftop agriculture (RA). RA is the production of fresh vegetables, herbs and edible flowers on rooftops for local consumption. RA is a nascent industry throughout the developed world, but is gaining traction as an emerging element to urban landscapes. There have been several large-scale projects recently constructed in North America, helping to shape and better define the concept. While future projects may take on new designs, most existing rooftop projects can be placed into three main categories; agricultural green roofs, rooftop container gardens, and rooftop hydroponic systems.

1.3.1 Agricultural Green Roofs

An agricultural green roof (AGR) integrates edible crops into a soil-based growing medium on top of a waterproofing membrane. It often includes additional layers such as a root barrier, drainage and an irrigation system. AGRs can vary substantially, but can be divided into two general subcategories, extensive and intensive:

Extensive. This manifestation of AGR is comprised of a lightweight substrate depth ranging between five and 15cm (Rowe 2010). While there were no large-scale agricultural projects operating at the time of writing, several studies were underway to determine the viability of such a system (Bass 2011; Williams 2011).

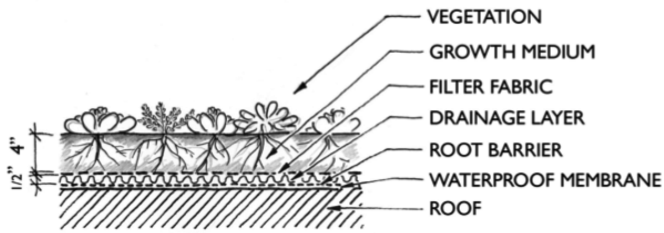


Figure 1.2 Cross section of an extensive green roof (Holland et al. 2007)

Intensive. This type of AGR is comprised of 15cm+ of growing media (Carter and Keeler 2008). In recent years there have been a handful of intensive rooftop agriculture projects popping up on the eastern seaboard of North America including the *Eagle Street* and *Brooklyn Grange* farms in New York City (City Farmer 2011).

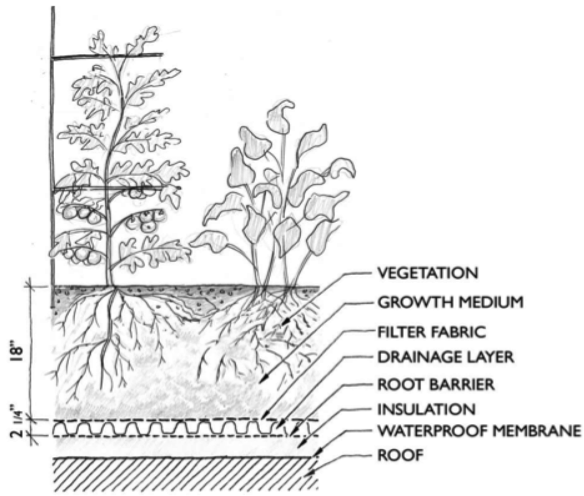


Figure 1.3 Cross section of an intensive green roof (Holland et al. 2007)

1.3.2 Rooftop Container Gardens

Rooftop container gardens involve planting in pots or raised beds which contain soil-based growing media (Coffman 2007). These systems have been popular with individuals growing herbs and flowers and can be found in many variations. They can range from simple pots to more elaborate systems which cover a large portion of a rooftop. The depth and expanse of the system will depend on the goals and budget of a project.

1.3.3 Rooftop Hydroponics

Hydroponics is a method of growing plants using water-based nutrient solutions in place of soil and differ from AGRs and container gardens in that they require ongoing energy inputs (Discount Hydro 2011). The rooftop hydroponics in today's marketplace can be separated into two sub-categories, exposed hydroponic systems and hydroponic greenhouses.

Exposed Hydroponic System. These are hydroponic technologies used in open-air settings.

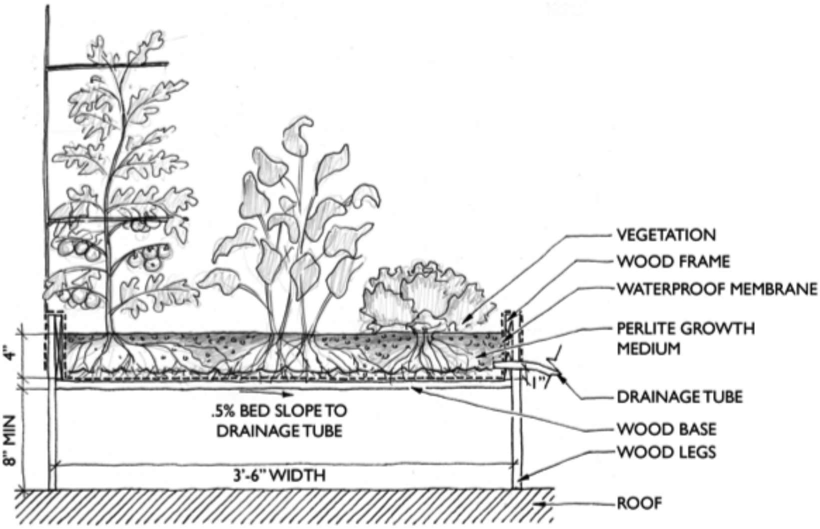


Figure 1.4 Cross section of a hydroponic vegetation system (Holland et al. 2007)

Hydroponic Greenhouse. A hydroponic system that uses glass or plastic casing to regulate growing conditions and shelter the hydroponic technologies from the external environment. Two large-scale hydroponic greenhouses are currently being constructed in eastern North America. *Lufa Farms* is a 2,880 square meter commercial operation in Montreal and *Gotham Greens* is a 1,400 square meter farm being developed in Queens, New York (City Farmer 2011).

1.3.4 Defining Characteristics of RA

Each of the three types of RA have unique characteristics that affect their ability to be implemented on rooftops. Figure 1.4 is a summary of the key distinguishing factors of each of the three primary types of RA, highlighting the major components, installed weight range and basic cost breakdowns.

	Major Components	Weight Range (in kg/m2)	Cost (in CAD/m2)
AGRs_ Extensive	-5-15 cm soil substrate[1,2,3] -Drainage layer -Leafy greens & herb production	50-200[1]	$120-300[1]
Intensive	-15+cm soil substrate[1] -Drainage layer -Variety of produce	200-1000[1]	$450 and up[1]
Container Gardens	-Range in substrates[1,2,3] from 10-60cm -Customizable planter options -Variety of produce	50-1000[1]	Highly variable
Hydroponics	-Growing container[4,5] -Reservoir container -10cm nutrient rich substrate -Variety of produce	20+[4]	$380 and up[5] + operations

Sources: 1) Xero Flor International 2011, 2) Zinco 2011, 3) Soprema 1996, 4) Holland et al. 2007, 5) Discount Hydro 2011

Figure 1.5 Defining characteristics of the three types of rooftop agriculture

1.4 Purpose of Study

The socio-ecological problems we are faced with are unprecedented in their scale. A new "whole-systems" way of thinking, planning, and living requires breakthrough solutions that step outside of the limitations of the current mental model (Senge and Carstedt 2001).

There is a relative abundance of information that explores the benefits which green roofs (Currie and Bass 2008; Rowe 2010; Schrader and Boning 2006; Banting et al. 2005; Castleton et al. 2010; Carter and Keeler 2008; Peck et al. 1999) and urban agriculture (Holland Barrs Planning

Group, Lees + Associates, Sustainability Ventures Group 2002; Holland Barrs Planning 2007; Brown and Carter 2003; Nasr et al. 2010; Satterthwaite et al. 2010; Veenhuizen and Danso 2007) provide for a city. When these two actions are combined into the concept of rooftop agriculture, there has been minimal academic research to date. The concept of RA has been explored in various manners by past academics including Kortright 2001, Nowak 2004, Coffman 2007, Kaill-Vinish 2010, Engelhard 2010. None of these research projects however looked at rooftop agriculture's unique relationship to strategic sustainable development (SSD). Our research team felt there was a need to analyze RA in an SSD context to better understand the role it can play in moving the socio-ecological system towards sustainability.

This study aims to provide information on how a city can use rooftop agriculture to address potential sustainability problems through a strategic manner using the Framework for Strategic Sustainable Development (FSSD). The FSSD is a scientifically rigorous and peer reviewed model for the management of complexity in planning and decision-making towards sustainability (Robèrt 2000). It can be applied to a variety of systems; global, national, regional, municipal, communal, organizational and individual, with equal rigor, providing a structured and systematic way of approaching sustainability (Robert et al. 2002; Ny et al. 2006). The FSSD also provides an ideal future of what a defined system can look like from a lens of socio-ecological success. For our study, we created an ideal model of how rooftop agriculture can contribute to this success, thus creating a vision and guide for what society can strive towards when considering sustainability.

1.5 Scope

This study will focus on the nexus[1] between a city as a system and how food interacts with that system, which will be referred to as the 'city/food nexus'. This study will first take a birds-eye view to identify the role RA can have in a sustainable society, and then analyze ways in which RA can be better understood and applied. This study is not designed to be a

1 Nexus is a connection or series of connections linking two or more things

technical performance analysis of RA systems. Our research was focused in North America and Western Europe, as this is where rooftop agriculture projects are beginning to be explored on commercial levels. While different forms of rooftop agriculture are possible, this study was limited to agricultural green roofs, rooftop container gardens, and rooftop hydroponic systems.

Our primary audience is officials and policy makers within a city or municipal government. We also aim to present information that would be relevant to additional stakeholders including businesses, building owners and others. A full list of stakeholders can be found in Figure 2.3.

1.6 Research Questions

The following questions were used to guide our research:

RQ1: *What can be the role of agricultural green roofs, rooftop container gardens, and rooftop hydroponic systems when moving towards a sustainable society?*

RQ2: *What are the challenges of implementing rooftop agriculture in cities of the developed world and how might they be overcome?*

RQ3: *What can assist cities of the developed world to better understand how rooftop agriculture can address their sustainability problems?*

2 Methods

Our research was designed around a series of six distinct phases formulated to help us answer our three research questions (RQ). We progressed naturally from one phase to the next, but many aspects of the phases overlapped chronologically and functionally in non-linear ways. For example, phases one through four were all utilized simultaneously at various points of our research process. Figure 2.1 below shows how each of the six phases relate to the research questions.

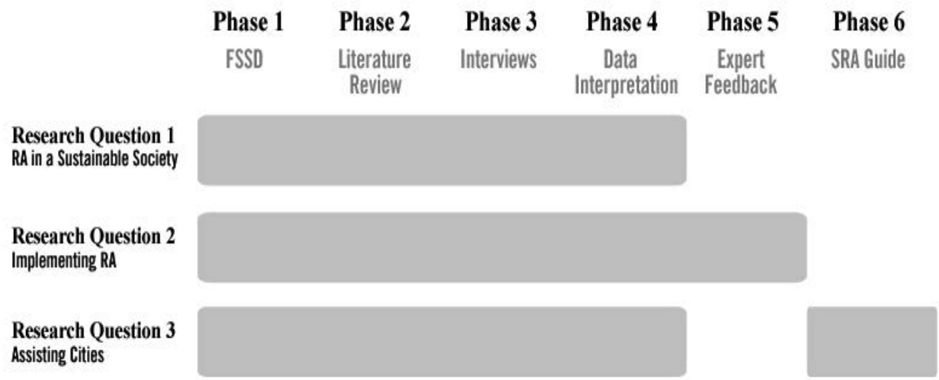
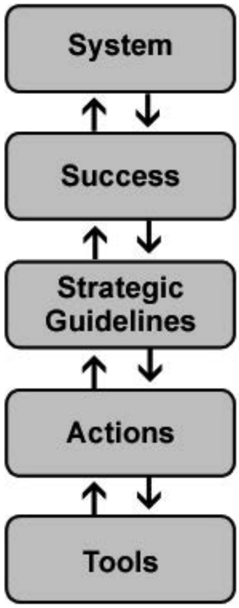


Figure 2.1 Relationship between phases and research questions

2.1 Framework for Strategic Sustainable Development (FSSD)

The FSSD is a scientifically rigorous and peer reviewed model for managing complexity in planning towards sustainability (Robèrt 2000). The FSSD was used to guide our analysis of RA through a systemic sustainability lens. It helped us define our system of study and answer all three of our research questions. The FSSD uses a versatile five level framework (Figure 2.2) to guide strategic planning. The overarching level, *systems*, is used by practitioners to define the entity's place within the biosphere. The *success* level defines conditions that must be met to live sustainably on the planet. The *strategic guidelines* level utilizes backcasting from a vision of success. The *actions* level includes any actions used to move the entity towards success within the system. The *tools* level includes tools, methods, techniques, and instruments used to implement actions towards success within the defined system.



Systems- Society within the biosphere, including the social and ecological rules which govern the system.

Success- Society within the biosphere compliant with conditions for a sustainable society.

Strategic Guidelines- Backcasting from success for socio-ecological sustainability and the associated 3 prioritization questions.

Actions- The actions that help move the global socio-ecological system towards success.

Tools- The tools that support efforts to achieve global sustainability.

Figure 2.2 Framework for Strategic Sustainable Development (Robèrt 2000)

2.1.1 Systems

The *systems level* incorporates the basic outlines and behaviours of a system in reference to socio-ecological sustainability. It can assist any organization or practitioner to understand, describe and analyze the dynamic relationships between ecological and social systems (Waldron et al. 2008). Key elements of this level include understanding basic conditions within the biosphere, such as the laws of conservation of energy and thermodynamics, photosynthesis as the primary producer of life, and the concentration, structure and purity of matter. In addition to those above are the elements of a healthy social fabric, including the incorporation of basic human needs necessary to reach sustainability. Social systems such as organizations, institutions and networks rely on each other to understand their place within society, and ultimately the biosphere (Waldron et al. 2008).

2.1.2 Success

At the *success level* organizations and practitioners define success. Here 'sustainability' is used as a definition of success as defined by a scientifically robust set of principles derived from a consensus-based system-level understanding (Holmberg et al. 1996; Robèrt 2000). These four principles, known as the Sustainability Principles (SPs), represent the minimum conditions that must be met in order to reach sustainability, are identified as:

In a sustainable society, nature is not subject to systematically increasing:
SP1. ...Concentrations of substances extracted from the Earth's crust;
SP2. ...Concentrations of substances produced by society;
SP3. ...Degradation by physical means;
and, in that society,
SP4. ...People are not subject to conditions that systematically undermine their capacity to meet their needs (Robèrt 2000; Ny et al. 2006).

To move towards sustainability, a concrete vision of success must be developed around the compliance with the SPs.

2.1.3 Strategic Guidelines

At the *strategic guidelines* level backcasting[2] from success is used as a central planning method to move a defined system towards sustainability. Backcasting differs from forecasting[3], which often dwells on constraints of historical and present limitations (Dreborg 1996). The Sustainability Principles described in the *success level* define the end goal when backcasting, thus helping to establish an overarching vision of global socio-ecological sustainability. Backcasting is partnered with three minimum prioritization questions (Holmberg and Robèrt 2000) to help determine if a proposed action is in line with short, medium, and long-term visions of success.

2 Backcasting is a planning procedure by which a desired future is imagined, followed by the question: 'What do we need to do today to reach this desired future state?' (Dreborg 1996).

3 Forecasting is a planning procedure which attempts to determine future trends based on current and historical patterns

1. Does the action proceed in the right direction with respect to the Sustainability Principles?
2. Does this action provide a flexible platform for future improvements?
3. Is this action likely to produce a sufficient return on investment to further catalyze the process?

Both backcasting and the prioritization questions are necessary strategies in helping organizations and practitioners achieve success within their defined system.

2.1.4 Actions

At the *actions* level are all of the concrete actions used to strategically move the global socio-ecological system towards compliance with the SPs. It is important that concrete actions be selected using backcasting and the three prioritization questions as the strategic guidelines when moving towards the system conditions of success.

2.1.5 Tools

The *tools* level incorporates any techniques, metrics, monitoring and management systems needed to effectively support actions that lead to strategic sustainability planning. Strategic tools improve the likelihood of achieving success and facilitate the measurement of system performance to ensure actions are moving towards compliance with the SPs (Robèrt et al. 2007).

2.2 Literature Review

For our literature review, we collected information around the subject of rooftop agriculture (RA), which incorporated sources on urban agriculture and green roof technologies, including professional and academic papers, journals, articles, websites, books, and magazine articles.

The literature review was one method we used to answer each of the three research questions, helping to identify the role RA can play in a sustainable society, what challenges exist in implementing RA and how they can be overcome, and what can assist cities in better understanding how to utilize RA strategically.

The literature review was also used to identify stakeholders who would be involved with a rooftop agriculture project and who could contribute to the development of RA. We categorized them into groups as seen in Figure 2.3. The six categories were selected as broad groupings to ensure that all aspects of a RA project were considered in our research. The stakeholders identified were placed in corresponding categories based on our understanding of their relationship to an aspect of a RA project.

1.0 DEVELOPMENT TEAM
Building Owners
Developers
Project Managers
Tenants

2.0 ROOFTOP AGRICULTURE ENTREPRENEURS
Business Owners

3.0 AGRICULTURE & HORTICULTURE SPECIALISTS
Hydroponic Technicians
Agriculture Specialists
Botanists and Horticulturalists
Food Safety Regulators

4.0 INFRASTRUCTURE & LOGISTICS
Structural Engineers
Mechanical Engineers
Electrical Engineers
Architects
Green Roof Specialists

5.0 MUNICIPAL & GOVERNANCE
City Planners
Municipal Drivers
Code Officials & Building Inspectors
Policy Experts

6.0 ADDITIONAL STAKEHOLDERS
Community Members
Resilience Experts
Researchers and Consultants
Universities
Insurance Companies
Financial Institutions
Other

Figure 2.3 Rooftop agriculture stakeholders classified into six broad groups according to the role they may have in a project

2.3 Interviews

To build upon the data collected in the literature review, we identified and reached out to experts from each of our stakeholder categories. To determine who we would interview, we selected stakeholders using the following criteria:
1. first hand RA project experience, or
2. authors of green roof, UA and RA literature, or
3. people directly referred from either 1 or 2 above

We scheduled appointments with 37 experts and conducted interviews via

Skype or phone. During the interviews, we utilized a semi-structured process centered around a set of standardized questions per stakeholder group (see Appendix E). These questions were developed to help us gather data to answer all three of our research questions. To ensure consistency and preserve information from being disregarded, each member of our research team transcribed their own notes of the interviews and we later compiled them into a shared document.

In addition to Skype and phone interviews, we conducted three in-person interviews with stakeholders at the regional center of excellence in the Green Roof Institute of Malmo, Sweden.

2.4 Data Interpretation

We used the five levels of the FSSD to develop a deeper and more structured understanding of RA from a full sustainability perspective. We first defined the city/food nexus as our system of study, and then applied the subsequent levels of the five level model as shown in Figure 2.2. to put the respective aspects of RA into the framework.

2.4.1 Answering Research Question One: The Role of RA in a Sustainable Society

The FSSD outline described in 2.1.6 helped us answer each of our research questions using a clear vision of success as defined by a city/food nexus in compliance with the four Sustainability Principles. Applying this outline as a lens through which we analyzed the collected empirical data, helped us see gaps and strengths of the current RA systems. It also helped us identify gaps in our own theoretical outline and thereby served as a platform for the production of our sustainable rooftop agriculture guide.

To answer RQ 1, we used literature and input from interviews to identify a series of reoccurring and prevalent sustainability problems that cities face. We chose 10 problems to view through an RA lens. These were chosen based on our own expectations and those of our experts that RA may be able to help mitigate each of these problems. To encompass a thorough sustainability analysis, we made sure we had representation of problems from environmental, social and economic categories.

Data from expert interviews was used to determine if any or all of the three types of RA could help mitigate the identified sustainability problems. To help convey these results we assigned a basic low, medium, and high rating based on the potential of each the three RA types to mitigate the identified sustainability problems. These ratings were general as they are dependent on many variables as described under each sub-section.

Next we considered the data using the FSSD outline described in 2.1.6 to determine whether each type would help move the city/food nexus towards sustainability. Finally, we used the vision from the success level to determine how the three types of RA may contribute to violations of the sustainability principles, in order to identify ways in which they must be improved to fit within a successful city/food nexus.

2.4.2 Answering Research Question Two: The Challenges of Implementing RA

We used data obtained during our literature review and interviews with our stakeholders to identify the challenges to implementing RA and what recommendations may allow these challenges to be overcome by city stakeholders. To simplify the diversity of challenges and possible solutions presented, they were organized into environmental, social and economic categories and can be viewed in their entirety in Appendix C.

2.4.3 Answering Research Question Three: Assisting Cities to Better Understand RA

To address the gap in information currently available to help cities to understand what role RA can play in their movement towards sustainability, we used the data obtained from RQ 1 and 2 to answer RQ3. Both RQ 1 and 2 helped us provide a baseline of information on how city stakeholders can better understand how to implement RA and identify its ability to contribute to sustainable development.

2.5 Expert Feedback

To validate our interpretation of the data collected from each expert, we sent a summary of our results back to those experts. The feedback we received provided insight on any gaps that may have been apparent in our findings. Some of these recommendations were taken into consideration and integrated into our paper. Others helped us to identify gaps and limitations of our research.

2.6 SRA Guide

In our final phase, we set out to share the key findings of our research by creating a guide that could directly help city stakeholders better understand how RA may help move a city towards sustainability. Our guide made use of elements of the FSSD, including the funnel paradigm and four Sustainability Principles. These components helped to build an understanding of why RA should be explored by city stakeholders, and how it can be used strategically to move a city/food nexus towards sustainability. We paired those components with the results of our research from answering RQs 1 and 2 (See sections 3.2-3.4). Additional components, such as project and site selection guides, and plant recommendations, were included in the guide as ways to further provide information necessary for city stakeholders to understand RA. These components were chosen based on expressed interest from our interviewed experts to have more information on these specific aspects of RA projects.

2.7 Expected Results

From our preliminary discussions about rooftop agriculture with peers and our literature review we established some expected results for each of our three research questions. Through a review of existing literature, it seemed that RA is essentially the combination of urban agriculture and green roofs, two growing trends that provide sustainability benefits to a city. We expected that the FSSD would provide a lens through which RA could be analyzed from a systems sustainability perspective, helping to define the role RA can have in a successful city/food nexus.

2.7.1 Research Question 1

We expected that our interviews with stakeholders would provide ample evidence that RA could help mitigate various environmental, social and economic problems cities currently face. These benefits to urban areas would incorporate RA's potential to promote water and energy efficiencies while building local food security. We also expected that while RA may be able to address these problems, there may be areas that need improvement on a technical level to truly contribute to a sustainable society.

***Agricultural Green Roofs*.** We expected AGRs would have a high potential to address the sustainability problems focused on in this study. With AGRs closely resembling a combination of green roof and urban agriculture characteristics, we anticipated the experts interviewed would identify many benefits that are similar to what both of those concepts contribute to a city.

Rooftop Container Gardens. We expected that rooftop container gardens would provide many of the same sustainability benefits to a city which an AGR can, but on a different scale. We assumed that container gardens essentially have the same components found on an AGR, but generally cover less surface area on a rooftop so its scale of influence would diminish.

Rooftop Hydroponic Systems. We expected that hydroponic systems would be stronger in addressing food security within a city, and less so on the environmental benefits that AGRs and container gardens could provide. This is due in part that hydroponic systems have been traditionally developed to maximize agricultural yields and have not been specially designed to manage environmental problems.

2.7.2 Research Question 2

We expected to uncover several environmental challenges which RA faces, but that social and economic challenges would prove to be the toughest hurdles to implement RA in cities of the developed world. We believed this to be the case through understanding many of the challenges which green roofs and urban agriculture initiatives have faced to date. We anticipated issues like building codes, zoning and start up capital costs would be the primary barriers to implementing RA.

2.7.3 Research Question 3

Based on our literature review of rooftop agriculture, we expected that our experts would identify a gap in the academic and technical research of RA. Based on this lack of information, we expected that more research and development will be the foundation of what may assist cities to gain an understanding of what type of RA can help them address their sustainability problems.

3 Results

3.1 The City/Food Nexus and the FSSD

As discussed in the methods, the FSSD was used as a guiding framework to consider the city/food nexus and to help identify how RA can strategically move the city/food nexus towards sustainability. This section will consider this nexus through the five levels of the FSSD to help structure our research and organize our results.

3.1.1 System

A city is in itself a promising way of saving resources as materials and wastes can be managed by scale through increased densities. While the potential of greater efficiencies is apparent, the reality is that urban areas require significant inputs of resources to support their inhabitants. This dependence on imported water, energy and natural resources has placed substantial pressure on rural lands, contributing to the systematic degradation of many global ecosystems (Lehmann 2011; Carter and Keeler 2008). Food represents another flow that is predominantly imported into cities. This not only negatively affects the biodiversity of rural areas from un-sustainable methods in agriculture cultivation, but it also creates a level of vulnerability in urban areas as the majority of city dwellers are physically disconnected from the production of their food.

The city/food nexus is our system of study. The current nexus has substantial socio-ecological impacts that are compromising the ability of life to be sustained into the future. The city/food nexus relies on linear flows of substances that are extracted from the Earth's crust and turned into increasing molecular waste in the biosphere after end-of-use. The combustion of fossil fuels resulting in increasing atmospheric $C0_2$ levels has been the primary source of energy for the cultivation, transportation, production and maintenance of operations within the current food system (Audsley et al. 2010; Millennium Ecosystem Assessment 2005). These non-renewable sources of energy are not only expected to expire due to peak-oil before the end of the century, but they have systematically altered the composition of the Earth's atmosphere (IPCC 2007) with a danger of seriously affecting the balance of climate and agricultural zones. Substances produced within society that systemically increase in concentrations within the biosphere are also a product of the existing city/food nexus. Chemical fertilizers, pesticides and preservatives are common in the current agricultural model, and this has caused considerable damage to the health of many global ecosystems. Ecosystems are further degraded and manipulated through various physical means. A vast amount of land has been converted from forests and prairies to monoculture farmlands, livestock facilities and urban landscapes, culminating in the elimination of innumerable species and the exacerbation of global climate change (Millenium Ecosystem Assessment 2005).

In addition to such ecological violations from the existing city/food nexus, there are significant conditions that systematically undermine people's capacity to meet their needs. An unfortunate paradox of the current food system is hunger in the midst of plenty. An unacceptable number of people in the developed world, many of whom live in urban areas, do not get enough to eat on a daily basis (Brown and Carter 2003).

When analyzing the city/food nexus, it is important to understand the broader systems in which it resides. As seen in figure 3.1, the city/food nexus of the developed world is within the technosphere[4], which itself resides in the biosphere. This implies that what happens in the city/food nexus is dependent upon the maintenance of a healthy and stable biosphere.

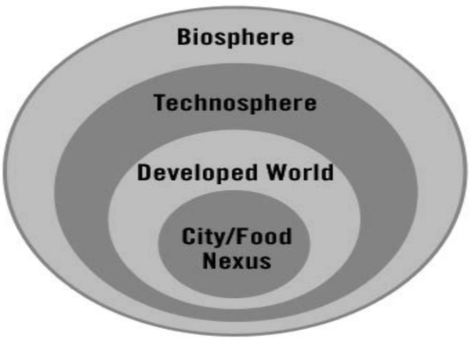


Figure 3.1 Relationship of the city/food nexus within its corresponding systems

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4 Technosphere is a system which is built or modified by humans and is a sub-system within the biosphere

3.1.2 Success

Given the complexity within the existing city/food nexus, a clear and actionable interpretation of success is imperative. To define success from a systemic level, a city must integrate food through a step-wise approach towards compliance with the Sustainability Principles as shown in 2.1.2. A successful city/food nexus does not contribute to violations of the four SPs, implying a pronounced need of using resources more efficiently. Cities have the capacity to produce much of their own food and energy, and manage their water and resources sustainably, thus creating a sufficient level of local resilience and safety.

A successful city/food nexus expands the food-producing areas within a city (SP 3), providing food locally and thus helping to eliminate the dependence on fossil fuels needed for production and transportation (SP 1). In this new nexus, contributions to greenhouse gas emissions are eliminated and great strides are made in mitigating climate change. New forms of urban agricultural production have helped eliminate the reliance on chemical fertilizers and pesticides for growing food as well as abolishing synthetic preservatives needed for transporting it long distances (SP 2). In addition to the elimination of chemical inputs, physical destruction of natural systems is prevented through efficient use of existing developments and brownfields. Spatial planning is an integrated process that considers the needs of local community members and biodiversity within an area (SP 3).

In a sustainable future, physical encroachment of fertile lands and natural habitats has come to an absolute end (SP 3). The development of infrastructure and mismanagement of land are no longer gradually eroding the potential of natural systems to provide primary energy, food, resources and services within the biosphere.

A successful city/food nexus brings new economic stimulus to cities, providing meaningful and healthy employment opportunities to residents far into the future (SP 4). By integrating agricultural jobs within urban areas, a surge in locally available foods drives demand for venues like farmers markets, community supported agriculture (CSA) programs, and unique entrepreneurial opportunities. Localized agricultural activities help develop healthy populations through access to fresh, nutritious food and increased recreational outlets. Community-based food systems also help build a strong understanding of citizens' interdependence with natural life support systems, foster an appreciation for socio-ecological well-being, and provide valuable input to nurturing sustainable food systems at large. Section 3.2 will show how the various introduced models of RA can fit the overarching description of a successful city/food nexus.

3.1.3 Strategic Guidelines

When determining strategic actions to help move a system towards success both backcasting from a vision compliant with the Sustainability Principles and the three prioritization questions are necessary. These guidelines help to ensure that planners using the framework can understand and ultimately achieve success within the city/food nexus. This is particularly beneficial as this nexus is very complex, encompassing many stakeholders who are driven by varying visions of success. When incorporating strategic actions into future plans, cities can analyze the role they may play by asking the following questions:

1. Does this action help the city/food nexus proceed in a step-wise manner towards compliance with the Sustainability Principles?

2. Does this action provide a flexible platform for future improvements to the city/food nexus?

3. Is this action likely to produce a sufficient return on investment (environmental, social, economic) to support a city's move towards sustainability within the city/food nexus?

The preceding questions can help determine the value the introduced models of rooftop agriculture can bring to a city moving towards sustainability, which will be analyzed in greater depth in section 3.5.

3.1.4 Actions

Underutilized spaces in urban areas can be further developed to support the city/food nexus in its move towards compliance with the Sustainability Principles. Various actions can be incorporated into city infrastructure more effectively, such as rainwater harvesting, energy and agriculture production. Rooftop agriculture is one such action that aims to utilize roof spaces which have traditionally contributed to various sustainability problems in urban areas. RA may be a compelling action that incorporates environmental, social and economic benefits to a community, helping to move the city/food nexus towards sustainability. For a rooftop agriculture project to be strategic, it must appropriately consider the three prioritization questions at the strategic guidelines level.

With regards to a successful city/food nexus as outlined above, it is expected that the three primary types of RA at this level will feature certain advantages and disadvantages. One activity may positively affect the social dimensions of sustainability while at the same time neglecting certain aspects of the ecological dimension. The outlined success level is there to help make the various aspects visible so as to allow appropriate modelling to strategically fit the specific conditions and needs of different regions and municipalities.

3.1.5 Tools

A tool has yet to be created that can help a city determine on what conditions and in what ways the implementation of RA could support their movement towards sustainability. It should be accessible to city planners, business owners and citizens alike as a means to evaluate RA as a potentially compelling action of moving towards a successful city/food nexus.

The framework above will be used to analyze each of the three types of RA from a systems lens in section 3.2. The FSSD will be used to assist in developing a deeper and more structured understanding of RA from a full sustainability perspective. Throughout each subsequent section (3.2-3.5), there will be a linkage made back to this consideration of RA using the FSSD.

3.2 Research Question 1: The Role of RA in a Sustainable Society

With a firm definition of a successful city/food nexus, a thorough analysis of rooftop agriculture's role can take place inside the subsequent levels of the five-level framework. Results in this section will establish the role each of the three types of RA could play in a city's movement towards meeting the above definition of a successful city/food nexus from a strategic point of view.

Through the literature review and dialogues with expert stakeholders, 10 prevalent and reoccurring sustainability problems were identified which RA could potentially help mitigate (section 2.4.1). These problems are classified into environmental, social, and economic categories.

Environmental Problems include Stormwater Runoff, Urban Heat Island Effect, Biodiversity Loss, Greenhouse Gas Emissions**.** *Social Problems* include Community Apathy, Public Health Repercussions, Food Insecurity, and Disconnect from Nature**.** *Economic Problems* include Outsourced Economies and Underutilized Development Opportunities

In the subsequent sections each problem is described and connected to the vision of a sustainable city/food nexus described in section 3.1.2. To better illustrate the potential for RA to mitigate the 10 sustainability problems, a low, medium, and high rating was assigned for each of the three types. This was derived from data collected during the literature review and expert interviews. A summary of these findings can be found in section 3.2.11.

3.2.1 Stormwater Runoff

Stormwater runoff is precipitation water that flows off of impermeable surfaces such as paved roads and conventional rooftops rather than being absorbed into the ground as occurs in natural landscapes (Booth and Jackson 1997; Czemiel 2010). It has become a sustainability problem in urban areas as costly and extensive infrastructure is currently required to carry and treat stormwater. Impermeable surfaces also direct runoff into the sewer systems where it is not uncommon for sewage and stormwater to be funneled through the same pipes. With heavy rainfall, a combined sewage overflow (CSO) can occur when the volume of runoff exceeds the capacity of the wastewater system (Rowe 2010; Baxt 2011). Even when communities have separate systems for stormwater, water can be directed into gutters, sewers and engineered channels where it picks up common contaminants like suspended solids, heavy metals, oils, and other pollutants creating health concerns for local residents (Lawlor et al. 2006; Rowe 2010).

In a successful city/food nexus, stormwater is collected and treated as a valuable resource. It is managed locally and is a source of water for regional industries as well as for consumption by urban residents, it strengthens a city's resilience and minimizes costly and resource intensive infrastructure. Permeable surfaces absorb the majority of rainfall events reducing the need for chemical inputs to treat water, improving the living conditions and health of the general population.

Intensive and extensive green roofs have become increasingly utilized as strategies to mimic natural systems in managing stormwater (Lim et al. 2010; Lawlor et al. 2006; Rowe 2010; Carter and Keeler 2008). Although in a nascent stage, the following section will illustrate how RA has been able to draw from the proven success of green roofs to manage stormwater. Agricultural green roofs, rooftop container gardens, and hydroponic systems have varying potential to address this sustainability problem.

Agricultural Green Roofs

The data collected from our literature review and our expert interviews illustrate that agricultural green roofs have a *high potential* to mitigate stormwater runoff when several factors are taken into consideration. First, the depth of the soil directly influences the volume of water which a surface can retain, with deeper soils holding more moisture (Nasr 2011; Mentens et al. 2003; Coffman 2007; Rowe et al. 2006). Second, the types of plants grown will also play a role in the amount of water retained (VanWoert et al. 2005). A surface which features plants with a high leaf area index (LAI), or plant surface area, will improve interception of rain by the vegetation (Wees 2011; Bass 2011). Since food crops are seasonal, runoff mitigation will be reduced at times of the year when plants are absent or in the development stage as there is a reduced LAI. The root mass of a plant factors into the ability to absorb moisture since a greater mass can increase absorption and mitigation of runoff (Wees 2011). Third, the surface area of an AGR will directly influence the amount of runoff which is mitigated. A greater surface area corresponds to an increased ability to mitigate runoff (Doshi 2011; Nasr 2011; Bass 2011).

Rooftop Container Gardens

Container gardens have *medium potential* to mitigate stormwater runoff. This potential is dependent on the same factors discussed in the agricultural green roofs section above, including soil depth and types of plants selected, but generally imply less impact as the surface coverage of growing media in container gardens is less than AGRs. Self-watering containers have the capacity to capture and store water in a reservoir during rainfall events (Janvier 2011). This can help when addressing nutrient runoff, which is discussed in more detail in section 3.3.

Rooftop Hydroponic Systems
Hydroponic systems have *low potential* to mitigate stormwater. Greenhouses are particularly ineffective at addressing this problem as a result of being constructed with impervious materials like plastic and glass (Bass 2011). It is however possible for hydroponic greenhouses to manage stormwater if a capture system is integrated into its design (Lufa Farms 2011). Without a capture system, a hydroponic greenhouse would in itself be unable to actively mitigate stormwater (Bass 2011). An open/exposed hydroponic system also has little ability to mitigate stormwater runoff based on the design of current systems lacking any rain catchment system.

3.2.2 Urban Heat Island Effect

An urban heat island (UHI) refers to a metropolitan area that is significantly warmer than its surrounding rural areas (Santamouris et al. 2011). The UHI effect occurs when cities replace vegetated areas with dark surfaces such as rooftops and pavements which absorb solar radiation and re-radiate it as longwave radiation or heat (Bass and Baskaran 2003; Rizwan et al. 2008). This phenomenon has led to urban air temperatures being up to 5.6 degrees Celsius warmer than the surrounding countryside (US EPA 2003).

This anthropogenic increase in ambient air temperature is a cause for concern for a number of reasons. UHIs create an increased demand for electricity, which is predominantly generated from the combustion of fossil fuels (International Energy Agency 2010). Bass and Baskaran (2003) found that for every one degree Celsius increase in the air temperature past a variable threshold, air conditioning demands led to a 5% increase in electricity consumption. The increased temperatures associated with the UHI effect also intensifies pollution, causing human discomfort and health problems (Hassid et al. 2000; Santamouris et al. 2007; Bass and Baskaran 2003; Changnon et al. 1996).

A successful city/food nexus will make use of strategies to reduce the adverse effects of heat islands. It will take advantage of the natural cooling capabilities provided by vegetation and better integrate it into the urban landscape, thus cooling ambient air temperatures and mitigating the UHI effect. By reducing the UHI effect, a city will minimize consumption of fossil fuels through decreased energy demands. Reduced urban temperatures will also maintain the health and comfort of urban residents through pollution abatements.

Intensive and extensive green roofs have been shown to cool the air through moisture retention and subsequent evaporation and transpiration. With this in consideration, the area of vegetated roofs within an urban area needed to make a significant temperature difference is estimated to be about 50% coverage (Bass 2011). Considering that several types of RA feature vegetation and growing media, the concept could be used to mitigate the UHI effect.

Agricultural Green Roofs (AGR)

Agricultural green roofs have a *high potential* to reduce the UHI effect when several factors are taken into consideration. The types of crops selected will have a significant impact on the amount of solar reflection and evapotranspiration which takes place. There is a strong link between plants with a high leaf area index (LAI) and their ability to lower ambient air temperatures (Wees 2011; Anonymous C 2011). Total plant mass has also been shown to influence the ability of vegetation to lower air temperatures (Wees 2011). As a result of this, perennial crops and self-seeding plants are desired, or fast growing plants can be continuously introduced to match each season in an effort to maintain consistent coverage (Nakano 2011; Wees 2011). A deeper soil substrate has been shown to influence the amount of water retained (VanWoert et al. 2005; Monterusso et al. 2004; Mentens et al. 2003), which will influence the type of plants a surface can support (Rowe 2010; Dvorak and Volder 2010) and subsequently effect the ability of the surface to mitigate the UHI effect.

Rooftop Container Gardens

Container gardens have a *medium potential* to mitigate the UHI effect. The potential is lower than agricultural green roofs for several reasons. Since the coverage and LAI of plants play a direct role in lowering air temperatures (Wees 2011; Anonymous C 2011; Bass 2011), the relative lack of continuity and surface coverage of container gardens reduces its potential impact. This however is variable with each project, and it appears that some projects are still able to cover approximately 70% of a roof surface (Boucher-Colbert 2011). It was identified that the ease of implementation of a container system allows for the potential widespread addition of vegetation to existing structures (Doshi 2011; Nasr 2011). This presents an opportunity to grow vine-based vegetables, which maximize the LAI per growing area (Doshi 2011). Even if these systems are only temporary during the summer months, they could provide a cooling effect during the time of year when the UHI effect is most pronounced (Nasr 2011).

Rooftop Hydroponic Systems

Hydroponic systems have *low potential* to mitigate the UHI effect. By having a soil-less design, they lack the ability to make use of evapotranspiration to achieve a cooling effect (Bass 2011). If there is extensive surface coverage, an exposed hydroponic system could utilize some transpiration from plants until harvest time to achieve minimal cooling (Bass 2011). This study lacks sufficient data to determine the potential for hydroponic greenhouses to mitigate the UHI effect.

3.2.3 Biodiversity Loss

Biodiversity is the variety of life and its processes. It includes the diversity of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur (California Environmental Resource Evaluation System 1991). Distinct types of plants, animals and micro-organisms are vital for the production and stability of the food and medicinal systems in which society relies (Vernooy and Song 2004). The loss of biodiversity threatens ecosystem services which provide clean water and air for the biosphere (Pretty 2002; Wilson 2010; Millennium Ecosystem Assessment 2005).

The expansion of urban spaces has led to significant habitat loss (Lawlor et al. 2006; Schrader and Boning 2006), with ecosystem health being further threatened as rural lands have been developed for agricultural means. This degradation and elimination of habitats has contributed to current species extinction rates that are estimated at 100 to 1000 times the average rates in the evolutionary time scale of the planet (Lawton and May 1995). Biologist E. O. Wilson (2002) estimates that if current rates of human destruction of the biosphere continue, one-half of all species of life on earth will be extinct within 100 years.

In an ideal city/food nexus biodiversity is preserved and reintroduced into urban landscapes through strategic land-use planning. Natural ecosystems are better integrated into city centers as the services they provide will be valued on social and economic levels

RA can help integrate biodiversity into existing infrastructure. Because rooftops make up a significant portion of an urban footprint, they offer a great platform to bolster and support biodiversity within an urban landscape (Currie 2011; Lawlor et al. 2006; Peck et al. 1999; Dunnett and Kingsbury 2004). Vegetated rooftops, including several types of RA can be designed to play two key roles: they can be a "stepping stone habitat," connecting natural isolated habitats in cities with each other, or an "island habitat" that is separate from habitats at ground level for less mobile species (Lawlor et al. 2006, 13; Kim 2004). While a roofspace may not be accessible to all species native to a given region, they can provide food, habitat, shelter, nesting opportunities and a safe resting place for spiders, beetles, butterflies, migratory birds and other invertebrates (Currie 2011; Brenneisen 2003; Gedge 2004).

Agricultural Green Roofs

Agricultural green roofs have a *high potential* to increase biodiversity within a city, when designed with several factors taken into account. The depth and composition of the growing medium will directly influence the diversity and quantity of plant and animal species which can be supported. Deeper substrates such as those found on intensive rooftop systems will be ideal for supporting a diverse range of edible and ornamental plants which subsequently attract a wide variety of organisms (Hann 2011; Nakano 2011; Wees 2011; Brenneisen 2006; Schrader and Boning 2006). An irregular irrigation schedule will also maximize how well a system can mimic natural ecosystems which experience variable moisture cycles (Brenneisen 2006). The properties of a rooftop such as height and orientation will influence the micro-climates created (Jones 2002; Brenneisen 2003; Brenneisen 2006).

To increase biodiversity in both intensive and extensive AGRs, the regular input of organic matter is needed to maintain a healthy soil for resident plants and animals (Hann 2011; Joaquin 2011; Schrader and Boning 2006). One consideration worth noting is that while AGRs can support biodiversity, there is potential conflict between birds, bugs and humans who may compete for the edible food crops, unless planned for in an appropriate way (Nakano 2011).

Rooftop Container Gardens

Container gardens have *medium potential* to address biodiversity loss. Containers are subject to the same variables as discussed under agricultural green roofs, but may not offer as much surface area to support organisms in comparison to AGRs. Container gardens can be highly variable in their configurations and offer a unique opportunity to create several variable ecosystems in different containers all within a single rooftop (Jones 2002;

Brenneisen 2003; Brenneisen 2006; Joaquin 2011; Wees 2011). Being able to place containers in line with the load bearing sections of a rooftop enables containers to benefit biodiversity through the use of more natural soils instead of lighter semi-synthetic blends as common in AGRs (Hann 2011; Schrader and Boning 2006; Brenneisen 2006).

Rooftop Hydroponic Systems
Hydroponic systems offer *low potential* to address biodiversity loss. Much of RA's biodiversity supporting potential is dependent on the presence of natural substrates, which are not featured in hydroponic system designs (Hann 2011; Brenneisen 2003; Brenneisen 2006; Schrader and Boning 2006). Exposed systems could still provide habitat for some species due to the presence of living vegetation. Hydroponic greenhouses are closed off from the natural environment and are subject to strict management of environmental conditions, minimizing their ability to host biodiversity on site (Lufa Farms 2011; Hann 2011; Williams 2011).

3.2.4 Greenhouse Gas Emissions

Greenhouse gases (GHGs) are atmospheric gases that absorb infrared radiation produced by solar warming of the Earth's surface (IPCC 2007). They are responsible for warming the Earth's surface and atmosphere, significantly impacting rainfall and maintenance of glaciers and sea ice levels (IPCC 2007). Carbon dioxide ($C0_2$) is the principal anthropogenic GHG (IPCC 2007). Since the beginning of the industrial revolution, the burning of fossil fuels has contributed to the increase of $C0_2$ in the atmosphere from 280ppm to 392ppm (National Oceanic and Atmospheric Administration Earth System Research Laboratory 2011), which in turn has contributed to the warming of the Earth's surface. 85% of the energy used throughout the world is currently derived from the combustion of fossil fuels like coal, oil and natural gas (IEA 2010). Urban areas have been responsible for significant contributions of fossil fuel use as they require 67% of the global energy demand (IEA 2008). In addition to the GHG impacts of cities, a significant portion of anthropogenic gases can be attributed to agricultural activity which feeds urban residents (IPCC 2007). A recent study by Audsley et al. (2010) found that when taking into account the entire value chain of agriculture, transportation and associated land-use changes, food can account for 66% of a developed country's GHG emissions.

An ideal city/food nexus will eliminate its GHG contributions through diverse and strategic methods. Buildings are designed to make use of natural insulative techniques and be self-sufficient, durable and healthy for its inhabitants. Natural carbon sequestering will be used to help stabilize atmospheric warming. Regional agriculture will minimize the GHG impacts associated with land-use changes and transportation.

RA can help contribute to reducing GHGs associated with food transportation (Currie 2011; Nasr 2011). Several types of RA can also be considered a vegetated roof, a measure which can help to reduce GHG's as they extend the life of the roofing membranes (Nasr 2011; Liu and Baskaran 2003; Lawlor et al. 2006; Kosareo and Ries 2007), minimizing the mining, construction and disposal of roofing materials, which rely on carbon-intensive processes.

Agricultural Green Roofs

Agricultural green roofs have *medium potential* to mitigate GHG's. This potential will be variable upon the design goals of the project. The vegetation grown on a rooftop can sequester carbon in its tissues (Rowe 2010; Nasr 2011), helping to offset many of the impacts resulting from food being transported from outside the city (Bass 2011; Currie 2011; Nasr 2011). The presence of growing media will increase the insulation of a building roof and can help extend the life of the roofing membranes (Nasr 2011; Williams 2011).

Rooftop Container Gardens

Container gardens have *low potential* to mitigate GHGs as their growing surface is less than an AGRs. Rooftop containers are still capable of contributing to GHG emission reductions from transporttion as they are able to provide a place to grow food within a city (Murphy 2011; Snyder 2011). There is insufficient data to determine if container gardens would provide significant durability or insulating capacities to a building membrane (Nasr 2011; Boucher-Colbert 2011), which is another proven way RA can mitigate GHGs.

Rooftop Hydroponic Systems

Hydroponic systems have *high potential* to reduce overall greenhouse gas emissions within a city because of their strong yield capabilities. Increasing food production in urban areas can provide the opportunity to significantly reduce emissions related to food transportation (Bass 2011; Donnelly 2011; Lufa Farms 2011). In addition, based on a study by

Vanthof and Arvizu (2010), the high yields available from hydroponic systems enable it to be the best solution for paying back the embodied carbon and energy of any RA system (Bass 2011).

3.2.5 Community Apathy

Many urban initiatives and infrastructure decisions inhibit community interaction and lead to a sense of apathy among residents. Substantial expanses of concrete structures, roads, and paved over parking lots create a landscape that dispels not only biodiversity but also community engagement. Growing food and developing green spaces in urban and semi-urban areas has proven to be an effective way of getting people out of their homes and offices and into spaces where they can interact with each other (Koby 2011; Baxt 2011).

There have been many cases where the introduction of food production into a cityscape has helped bridge generational and race gaps (Lundberg 2011). A prime example of this is the Montreal-based organization *Santropol Roulant* which uses young volunteers to grow and deliver healthy local food to elderly people within the community (Murphy 2011; Janvier 2011; Currie 2011).

In an ideal city/food nexus community development is valued as an integral component of socio-ecological sustainability. Urban infrastructure is designed around engaging human interaction through appropriate and humane scales. Streets are walkable and integrated with natural vegetation and biotopes, improving both physical and social health of city residents. Projects and programs that harvest stronger community ensure that all citizens have an opportunity to meet their social needs. Agricultural projects in cities are platforms for residents to meet their needs for subsistence and recreation, bolstering a sense of local pride and urban resilience.

As described below, RA can contribute to this vision of success by creating space where new conversations and new actions for business can take place (Koby 2011). It can also serve as an educational tool, bringing youth together around leadership and local initiatives (Koby 2011).

Agricultural Green Roofs
AGRs have *high potential* in mitigating community apathy through various means. The *Eagle Street* AGR farm in New York City relies on a network

of volunteers to manage and maintain operations (Anonymous A 2011). There are also great opportunities for AGRs to bring venues such as farmers markets to engage the local community, accompanying a high social value associated with RA development (Eagle Street 2011; Levenston 2011; Bass 2011).

Rooftop Container Gardens

Container gardens also contribute *high potential* in mitigating community apathy when considering the ease of application and customization of usage (Janvier 2011; Levenston 2011; Boucher-Colbert 2011; Snyder 2011). A container garden installed on the roof of *Wolff Olins* brand agency in London has brought together company employees, local youth groups and regional non-profits around its development and operations (Koby 2011). In addition, the rooftop container garden at the *Uncommon Ground* restaurant in Chicago uses the space for entertainment purposes, hosting events and receptions on site (Snyder 2011).

Rooftop Hydroponic Systems

Hydroponic systems offer *medium potential* to address community apathy. Their success is somewhat dependant on the configuration of the system. The technical nature of hydroponic systems, while intriguing, may also intimidate some community members (Hann 2011). This being said, there are also opportunities to use traditional education subjects in the context of local food production which has been illustrated at the *New York Sun Works* floating science barge (NY Sun Works 2011). Hydroponics also have the potential to be valuable assets in strengthening UA initiatives, which can be partnered with farmer's markets and CSA's just as with AGR's and container gardens.

3.2.6 Public Health Repercussions

The development of urban areas has compromised the health of its inhabitants in a number of ways, including poor air quality and inadequate access to healthy food. The industrialized agriculture system of the current city/food nexus has improved efficiencies in food production, but this improvement has not translated into healthier food options for many living in the developed world (Horrigan et al. 2002). With existing foodstuffs traveling from the hinterlands to get from farm to fork, agricultural producers have become increasingly reliant on the use of chemical preservatives to stay profitable. Most fruit and vegetable varieties sold in supermarkets today are chosen for their ability to withstand industrial

harvesting equipment and extended travel, not for their taste or nutritional quality (Brown and Carter 2003).
The lack of healthy options is most noticeable in urban areas that struggle socio-economically. A study of all food stores in three low-income zip codes in Detroit, Michigan found that only 19% carried a minimal number of products based on the food pyramid (Brown and Carter 2003). Many living in urban areas have limited time for shopping and cooking, which can be translated into an increased reliance on processed and convenience foods. This malnourishment can be visualized in the obesity and diet-related illnesses found in most cities of the developed world (Horrigan et al. 2002).

Beyond a lack of access to healthy food, an additional repercussion of the current city/food nexus is poor air quality (Mayer 1999). The most common health related symptoms of air pollution are increased occurrences of respiratory illnesses such as asthma and a greater incidence of cardiovascular disease (Pope et al. 1995).

In an ideal city/food nexus residents have access to fresh, nutritious food that is grown locally. Food is produced, stored and distributed in a sustainable manner. Programs promoting healthy eating habits are available to all citizens. Air quality is managed through the increased inclusion of vegetation into the urban landscape.

Rooftop agriculture can help by improving access to local and healthy food, as well as through noise and air pollution abatements. As noted in section 3.2.5, growing edible plants on a rooftop in the city can help reduce the import of food from outlying areas, thus reducing air pollutants from transportation. Furthermore, vegetation has been proven to mitigate noise pollution. Tests have shown that a 12 cm layer of substrate can reduce sound by 40 dB (Peck and Callaghan 1999, 30).

Agricultural Green Roofs
AGRs can offer *medium potential* in mitigating public health repercussions. They are an effective leisure activity and provide the potential to improve air quality if plants are selected with high LAIs (Anonymous C 2011; Wees 2011) and high biomass (Wees 2011). The production of healthy and locally accessible food is another opportunity that AGRs can fill, although their effectiveness to feed the masses is uncertain (Currie 2011; Cohen 2011).

Rooftop Container Gardens
Rooftop container gardens also have *medium potential* in mitigating public health repercussions. Their primary advantage over AGRs is the accessibility of implementing the systems, suggesting an opportunity to bring fresh food to more people who might not be able to afford the alternative options (Boucher-Colbert 2011). A disadvantage from AGRs is their smaller surface area, thus minimizing their impact to clean air and produce food to the same extent.

Rooftop Hydroponic Systems
As with AGRs and rooftop container gardens, hydroponic systems also provide *medium potential* when addressing public health repercussions. Hydroponics have been identified as a space efficient way to maximize the amount of fresh food grown close to urban populations (Anonymous C 2011; Anonymous A 2011; Krist 2011), thus providing the strongest ability of the three RA types to bring nutritious food to the most people. Also, by producing relatively more food locally, air pollution from the import of food can be minimized relative to the other types of RA. Hydroponic systems are less likely than AGRs and container gardens to improve physical activity within an urban area as they are subject to tightly controlled environmental conditions which deter human interaction.

3.2.7 Food Insecurity

Food insecurity generally refers to the availability of food and an individual's ability to access it (Brown and Carter 2003). This issue affects the quality of life for urban residents in many ways, be it through actual food insufficiency, nutritional quality, or anxiety about a future lack of food (Brown and Carter 2003). Heavy commoditization of the food industry has become the norm, placing increasing reliance on national and multi-national contracts to feed growing populations.

By 2015, over 25 cities in the world are expected to have a population of 10 million inhabitants or more (Drescher et al. 2000). To feed a city of this size, at least 6,000 tons of food must be imported daily (Drescher et al. 2000). Perishables like fruits and vegetables can spend as many as seven to 14 days in transit before arriving to their destinations. This has contributed to almost half of all food that is transported being lost to spoilage (Brown and Carter 2003). In addition, the distance food travels ties agriculture prices directly to volatile energy and fuel prices. The repercussions of this financial volatility was exposed in 2008 when sharp food price increases led to the malnourishment of 130 million additional people throughout the world, much of which occurred within urban populations (Cohen and Garrett 2009).

In today's society in which many city residents are physically disconnected from food production, vulnerabilities to disruptions in the global food system are high. The majority of city dwellers have little more than a few days food supply at home and limited or no access to the essentials they need to survive (Hall 2000).

In an ideal city/food nexus all residents have access to healthy, locally produced foods. Various forms of urban agriculture create a resilient and secure food portfolio.

RA can contribute to strengthening a region's food security. While it has been noted that the volume of food grown through RA may be somewhat limited relative to consumption rates of the population (Snyder 2011; Currie 2011; Boucher-Colbert 2011) its potential to influence food security is disproportionate as it offers spaces where people can learn and be inspired to grow their own food and build support for the local food-shed (Baxt 2011).

Agricultural Green Roofs
AGRs can provide *medium potential* when building food security. Intensive AGRs were identified as being superior to extensive systems in terms of output potential of food yield (Bass 2011; Nakano 2011; Tillapaugh 2011). The increased depth of soil presents the opportunity to grow a greater variety of plants (Bass 2011; Nakano 2011; Baxt 2011), which can allow the choice of crops to meet specific dietary needs. While AGRs are shown to play an important part in addressing food insecurities, it is important to respect the limitations of the volume of food which can be produced for an urban population versus consumption rates, particularly in colder climates where growing seasons are limited (Levenston 2011; Currie 2011).

Rooftop Container Gardens
Container gardens also have *medium potential* in addressing food security. The versatility of a container system allows them to be easily designed, constructed or improvised with minimal capital costs (Wees 2011;

Boucher-Colbert 2011). The simplicity and ease of implementing container gardens enables them to contribute positively to the accessibility of fresh food. Some technologically advanced systems have the opportunities to focus more on attaining higher yields (Joaquin 2011).

Rooftop Hydroponic Systems

Rooftop hydroponic systems have a *high potential* to strengthen a city's food security. Hydroponics have the ability to produce higher yields than soil-based growing techniques and be reliable in doing so (Nasr 2011; Donnelly 2011). This high yield has been noted as the main reason for bringing food producing hydroponic systems into a city (Krist 2011; Nasr 2011; Anonymous C 2011). A report commissioned by the City of Vancouver found that a hydroponic greenhouse can average 13 times a conventional output based on data from the British Columbia Ministry of Agriculture (Holland Barrs Planning Group et al. 2002). It is worth noting that hydroponic systems, particularly greenhouses, take planning and development to bring to fruition, so their effectiveness to respond to regional emergencies is somewhat limited.

3.2.8 Disconnect from Nature

Urban areas are often developed with little regard to the integration of natural elements. Concrete, glass, asphalt, steel and plastics comprise the majority of views seen out of urban windows. This development has come at the expense of not only the biodiversity that is replaced by these artificial environments, but also many aspects of social health. Researchers are beginning to uncover that the need for meaningful contact with nature may be as important as people's need for interpersonal relationships (Kaplan 1993). Furthermore, impediments to meaningful contact with nature have been shown to be a 'contributing factor to rising levels of stress and general dissatisfaction within our modern society' (Zubevich 2004).

Harvard biologist E.O. Wilson coined the term 'biophilia' to describe humanity's inherent affinity for life and lifelike processes (Wilson 1984). His work has pioneered a number of studies supporting the benefits nature provides societal health. One such report by Taylor et al. (2001) determined that children with Attention Deficit Disorder (ADD) were noticeably more relaxed and better behaved after playtime in green settings compared with children who did not have access to green space (Banting et al. 2005). Similarly, the implementation of gardens by hospitals has shown

to improve patient recovery rates, which has also translated into cost savings in health care (Peck and Callaghan 1999).
In a successful city/food nexus biophililic measures are fully acknowledged and promoted within its system. Natural vegetation, urban forests and biotopes that harbour diverse species are integrated throughout the urban landscape. Residents living in urban areas draw a greater appreciation for natural systems and are more inclined to live harmoniously with the greater environment.

The ways in which RA can increase a connection to nature for inhabitants within the city/food nexus are described below.

Agricultural Green Roofs
AGRs provide *high potential* for connecting people with nature. Considering its use of natural elements like organic substrates and potential for flora and fauna diversity, AGRs can be used as an effective tool to introduce natural ecosystems into urban areas. It is worth noting that the deeper substrates of intensive rooftop systems are better suited for supporting a diverse range of organisms than extensive green roof substrates (Hann 2011; Nakano 2011; Wees 2011; Brenneisen 2006; Schrader and Boning 2006), thus suggesting that their impact for replicating natural systems is highest. AGRs also provide a strong visual impact within an artificial urban area, offering aesthetic benefits to city residents.

Rooftop Container Gardens
Rooftop container gardens also provide a *high potential* for introducing nature into artificial city environments due to their accessibility and ease of customization. This allows containers the ability to be utilized by many people, offering a higher quantity of opportunity to connect individuals with nature. Also, because of the versatility as containers, any number of crops can be planted to nurture biological integration.

Rooftop Hydroponic Systems
Hydroponic systems have a *low potential* for connecting people with nature. As hydroponics require technical and soil-less maintenance, they lose significant impact in connecting citizens with natural ecosystems (Murphy 2011; Hann 2011). Greenhouse hydroponic systems are particularly ineffective in this area as all other types of RA offer the benefit of surrounding buildings with a view of natural vegetation. Furthermore, hydroponic systems don’t support the biodiversity found within substrates

seen in AGRs and containers, further limiting their ability to connect people to natural systems.

3.2.9 Outsourced Economies

Cities are dependent on outsourcing food production to heavily mechanized farms which rely on substantial amounts of fossil fuel energy for production and transport of goods to consumers. This has commoditized the food industry and placed much of the economic leverage around agricultural production into multinational corporations and away from local communities. Development of local economies can be promoted in urban regions when inner-city residents gain the ability to grow and market their own food, and when urban farmers markets provide new opportunities for commercial farmers and entrepreneurs (Brown and Carter 2003; Cohen 2011).

An ideal city/food nexus offers local, healthy food not as a niche product but as a norm. It ensures that all residents within a community are able to access and afford nutritious foodstuffs that keeps money in the local economy, strengthening regional resilience. Mechanization common with industrial agriculture is replaced by human labour, creating local jobs.

Keeping food dollars local has been a strategy of many communities to create economic sustainability (Brown and Carter 2003). When it comes to food, it has been shown that some consumers are even willing to spend more money to support local growers for novelty or niche produce which is of exceptional freshness and nutritional quality (Wilson 2010; Janvier 2011; Joaquin 2011; Boucher-Colbert 2011; Donnelly 2011; Currie 2011). The Maine Organic Farmers and Gardeners Association estimates that if every family in Maine spent $10 dollars a week on local food, it would put $104 million into the local economy (Brown and Carter 2003). Rooftop agriculture presents an opportunity to stimulate local economies, creating a new sector within an urban area and offering unique enterprise prospects that can cater to a growing market of city dwellers.

Agricultural Green Roofs

AGRs have a *medium potential* for developing local economies. Opportunities to promote economic development within urban areas can occur through site planning, development, operation, maintenance and production (Peck and Callaghan 1999). Yields can be sold to local markets, CSAs and directly to consumers, further building awareness and economic value around local food initiatives.

Rooftop Container Gardens
Container gardens have a *medium potential* for developing a local economy. The Uncommon Ground restaurant in Chicago and Noble Rot in Portland both utilize container gardens to support their businesses, drawing economic benefits from yield productivity and marketing opportunities (Snyder 2011; Boucher-Colbert 2011).

Rooftop Hydroponic Systems
Hydroponics can offer a *high potential* in stimulating local economies if the production and retail of food is a primary motivator. *Lufa Farms* in Montreal is able to support 10 employees from a 2,880 sq m hydroponic greenhouse system (Lufa 2011). Since hydroponic systems are able to produce more food relative to the other types of RA, they can maximize the food available for local markets, CSAs and directly to consumers, further building awareness and economic value around local food initiatives.

3.2.10 Underutilized Development Opportunities

In many cities of the developed world, decisions that shape how buildings are constructed and used are often driven by isolated and profit-driven motives. This has left many urban landscapes with an abundance of underutilized spaces that could be used much more productively. As discussed in the introduction, rooftops make up a significant percentage of an urban area's footprint. While there have been examples of rooftops being used to generate electricity, capture rainwater and act as amenity space, the vast majority of them have not been utilized in environmentally, socially, or economically productive manners.

In an ideal city/food nexus, roofspaces will be used productively. Zoning and policy measures mandate and incentivize measures that develop new properties, and use existing properties in ways that comply with the Sustainability Principles. Building technologies are ecologically restorative and designed for durability. Local economies are strengthened as the built environment will be productive and resilient.

Introducing vegetation onto a roof surface of a building has been shown to be a beneficial way to make buildings contribute to a successful city/food nexus. Not only do they provide substantial environmental benefits, but they also can be seen as prudent financial investments. Without greening, flat roofs are 50% more susceptible to damage after 5 years (Peck and Callaghan 1999, 17), minimizing the need for ongoing and costly maintenance and repairs. Additional benefits include reduced utility costs (Rowe 2010; Bass and Baskaran 2003; Lawlor et al. 2006), reduced costs from stormwater runoff (Clark et al. 2008), and increased amenity value (Peck and Callaghan 1999). Other financial motivations lie in improved property values and increased worker productivity when presented with views of green spaces (Osmundson 1999; Peck et al. 1999).

The opportunity to lease out rooftops has been cited as a way to add value to existing developments and create potential for inclusion into future projects (Westeinde 2011; Lynn 2011; Peck and Callaghan 1999; McConkey 2011). Leasing is one potential working arrangement for rooftop enterprises, while other agreements may see the building owner benefit from shifting roof maintenance costs and responsibilities to the RA tenant in exchange for tenure (Baxt 2011). Regardless of the tenure model, some building owners and tenants have gained significant marketing value for their businesses as a result of rooftop agricultural projects (Baxt 2011; Boucher-Colbert 2011; Snyder 2011).

Agricultural Green Roofs

AGRs provide a *high potential* in addressing underutilized development opportunities. They have been shown to improve building efficiencies through energy reductions (Mayer 2011; Nasr 2011), offer employment opportunities (Nasr 2011), improve a company's image (Bass 2011), and create market value for building tenants (Bass 2011; Kaufmann 2011). Mayer (2011) estimates that 50-70% of 3-8 story midrise buildings built prior to 1950 in the United States can accommodate extensive green roof or semi-intensive herb gardens, opening up a substantial market for potential AGR developments into the future.

Rooftop Container Gardens

Rooftop container gardens have a *high potential* in addressing underutilized development opportunities. In addition to their versatility of application, they have proven to offer significant economic value in PR opportunities for building owners. Snyder (2011) highlighted $50,000 worth of television spots in a year from the interest in the *Uncommon Ground* rooftop container garden in Chicago.

Rooftop Hydroponic Systems

Rooftop hydroponic systems have a *high potential* to contribute to development opportunities. With lighter system weights than AGRs and container gardens, hydroponics have tremendous potential to add value to many buildings throughout cities of the developed world. *Lufa Farms* in Montreal is a pioneering concept, incorporating a 2,880 sq m hydroponic greenhouse system on an office building, providing a new revenue stream for the building owner while keeping ground level sites available for future development (Lufa 2011).

3.2.11 Summary of Results

For a breakdown of the potential for addressing impacts AGRs, rooftop container gardens, and hydroponics systems have in relation to the 10 identified sustainability problems, see Figure 3.2 below.

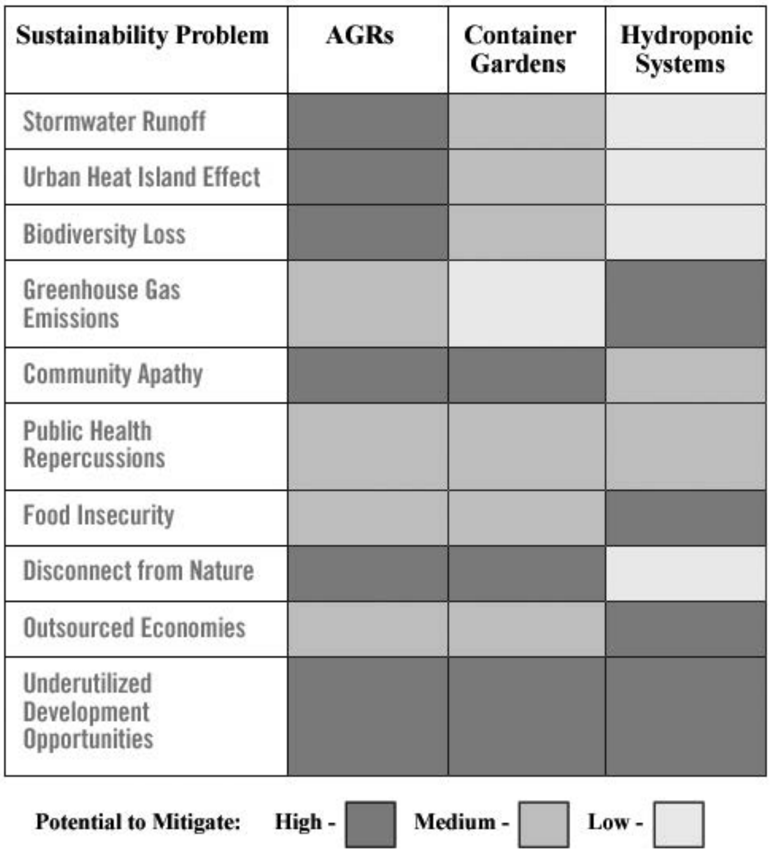

Figure 3.2 Relationship of identified sustainability problems to RA types

3.3 RA's Sustainability Problems

Sections 3.2-3.2.10 show how RA can mitigate several sustainability challenges. While each of the three primary types of RA can be effective at mitigating various sustainability problems, it is worth noting that each one also may have negative sustainability impacts. Improvements must be made to each of the three types of RA in this study to make them fully compliant with the Sustainability Principles. The following sections will identify how each of the types may contribute to unsustainability. A more extensive list of problems and corresponding recommended solutions from our literature research and expert interviews can be found in Appendix D.

3.3.1 Sustainability Problems Common to all Three Types of RA

Agricultural green roofs, rooftop container gardens and hydroponic systems contribute to violations of the four Sustainability Principles. Materials which are used in each RA system may contain elements that are drawn from the lithosphere. Petroleum-based plastics are frequently used to construct drainage layers, decking, containers and greenhouse components, all of which contribute to violations of SP 1. Reliance on fossil fuels for manufacturing and transportation of various materials further contributes to violations of SP 1.

Regarding contributions to violations of SP 2, each type of RA uses artificial and synthetic inputs during operations and maintenance. Producing potable water is another chemically intensive process, and rooftop agriculture systems have often required this resource for crop irrigation.

Ecosystem degradations by physical means also occur when developing RA projects, thus contributing to violations of SP 3. Land can be destroyed in the production of the materials required for RA infrastructure, and substrates, even if organic in nature, are frequently taken from offsite locations. In addition, RA developments can contribute to violations of SP 4, with the primary social needs not being met due to a of lack of access to rooftops and a potential lack of affordability of locally-produced foods for all residents within a community.

3.3.2 Sustainability Problems Common to AGRs and Rooftop Container Gardens

Both agricultural green roofs and container gardens have a handful of their own sustainability problems that need to be addressed when striving towards compliance with the four SPs. Many AGRs and container gardens utilize growing media that are heat treated to reach certain performance characteristics, requiring significant amounts of energy to produce. This energy is primarily drawn from fossil fuels, which contributes to violations of SP 1. The accumulations of nutrient runoff in growing media during rainfall events, and continual inputs of artificial fertilizers both compromise SP 2 from being met. Furthermore, growing food on roof spaces where wind and sun are generally stronger than at ground level demands the use of more potable water for irrigation, adding stress to many cities' shortages of water. This places further demand on urban areas to produce and treat water that is often derived from chemical-intensive processes.

3.3.3 Sustainability Problems Common to Rooftop Hydroponic Systems

Hydroponic systems offer a unique set of sustainability problems from AGRs and container gardens. With the need for continued energy inputs, such as lights, fans, heating and pumps, hydroponics can have high carbon and energy footprints which contribute to violations of SP 1. Contributions to SP 2 violations are made through the use of artificial nutrient accumulation in processes that discharge chemicals into the water system, compromising public health and adding stress to water treatment facilities. The general lack of biodiversity integration in hydroponic systems also fails to replace the habitat in which the project is developed, thus contributing to violations of SP 3.

3.4 Research Question 2: The Challenges of Implementing RA

The previous sections describe the role RA can play in a sustainable society and some potential sustainability problems that need to be considered in order for each type of RA to be used strategically. In application however, many environmental, social and economic challenges currently exist that are preventing RA from being implemented on any scale of significance.

These challenges need to be better understood to help cities determine the role RA might play in their future plans.

The following sections will identify key challenges identified through literature and expert interviews and how they might be overcome. For further details, please see Appendix C.

3.4.1 Environmental Challenges of Implementing RA and How They Might be Overcome

RA developments face several environmental challenges. Harsher growing conditions in the form of elevated winds or a lack of shade on rooftops may require the careful selection of plants which are able to adapt to these conditions while still accomplishing the goals of each project (Nakano 2011; Wees 2011; Currie 2011; Mayer 2011; Whittinghill 2011). While techniques such as the introduction of windbreaks, irrigation systems (Osmundson 1999) or biodynamic farming practices (Kortright 2001; Hann 2011) may help address some of these concerns, there needs to be more research conducted into the viability of integrating different edible crops into roofspaces (Nakano 2011; Bass et al. 2011).

Growing food on a rooftop requires careful attention to the growing media. Soils that are ideal for plant growth may be prone to increased nutrient loss, compaction increased maintenance requirements when placed on a rooftop (Nakano 2011; Hann 2011). To counter this, it is important to build healthy soils rich in nutrients, while maintaining control over nutrient runoff as discussed in section 3.2. Other challenges include conflicts between local fauna and edible crops (Nakano 2011), and potential contamination from urban air pollution (Bass 2011; Wees 2011; Carter 2011).

3.4.2 Social Challenges of Implementing RA and How They Might be Overcome

Rooftop agriculture is a relatively unknown concept amongst the general public and policy makers (Tillapaugh 2011; Joaquin 2011). RA has also received relatively little attention by academic and technical researchers thus far (Whittinghill 2011; Nakano 2011; Doshi 2011). While the concept appears to have untapped potential as identified through sections 3.2-3.2.10, there is a need to increase support for technical research at education institutions, in non-profits and at government research centers in order to better understand the opportunities and challenges (Brown and Carter 2003; Whittinghill 2011; Doshi 2011; Mendes 2011).

The introduction of new concepts and innovative technologies such as RA can often be suppressed or lack support due to fears that it has yet to be proven effective and safe in the field (Anonymous C 2011; Kaufmann 2011; Snyder 2011; McConkey 2011; Anonymous B 2011; Nasr 2011). Dvorak and Volder (2010) suggest that introducing reputable industry guidelines to North America such as the FLL standards established for green roofs in Europe could help open up new opportunities for establishing vegetation on rooftops. Peck and Callaghan (1999) feel that government co-sponsored design competitions could help move new technologies into the mainstream, while some cities such as Chicago already provide grants for innovative projects as a different approach (Snyder 2011).

Concerns over insurance costs and increased liability (Nasr et al. 2010; McConkey 2011; Krist 2011; Kent 2011; Lynn 2011; Nowak 2004) is another challenge which could benefit from the establishment of more research projects and vegetated rooftop standards.

If approached only in terms of food production and not from a systems perspective, many stakeholders identified that cities may favour underutilized land in the peri-urban or nearby rural areas which may be easier and cheaper to convert for food production (Cohen 2011; Currie 2011; Anonymous B 2011; Tillapaugh 2011; Bass 2011; Nasr 2011). Carter (2011) identified urban density as a predominant factor in the development of RA projects, suggesting that the concept will primarily be utilized in areas like New York City where property values are high and land availabilities low.

Another implementation challenge RA developments currently face in implementation surrounds various policy measures. Multiple socially constructed policies which may prove challenging for developing rooftop agriculture projects were cited, including building codes (Lynn 2011; Nasr 2011; Mayer 2011; Mendes 2011) and zoning regulations (Mendes 2011; Cohen 2011; Lynn 2011; Nasr et al. 2010). A number of options to overcome zoning challenges have proven successful including temporary permits, rezoning (Nasr et al. 2010) and overlay zones (Carter 2011). In response to code issues holding back the green roof industry, Peck and

Callaghan (1999) suggested a streamlined process to assess new technologies and approve amendments could prove beneficial.
Regional policies which do not include urban agriculture provisions (Janvier 2011; Nasr et al. 2010) or restrictions of on-site processing and sale of food (Anonymous B 2011; Mendes 2011; Levenston 2011; Brown and Carter 2003) were identified as some potential obstacles to some cities developing RA projects. San Francisco is an example of a city which reviewed barriers to urban food production and recently released ground breaking policies to encourage local agriculture activities and enterprises (Cohen 2011; Levenston 2011).

When it comes to developing productive spaces within existing landscapes, a few possible hurdles were identified by stakeholders. Land tenure and roof access are significant considerations to a developer or entrepreneur when considering an investment in an RA project (Nasr et al. 2010, 2011; Kent 2011; Levenston 2011; Kortright 2001; Nowak 2004). Nasr et al. 2010 suggests that one possible avenue to address the tenure issue is to explore the use of a third-party organization to manage lease arrangements.

3.4.3 Economic Challenges of Implementing RA and How They Might be Overcome

The financial investment and economic return on investment will vary greatly from project to project and will be influenced by the type of RA chosen, building type, project goals and additional variables. To date there have been very few projects constructed, and the industry will be viewed with some uncertainty until it can be shown that there are economically viable success stories (Nasr 2011; Anonymous B 2011; Westeinde 2011; Kent 2011; Doshi 2011; Brown and Carter 2003).

RA often has higher upfront capital costs than a standard roofing membrane which several stakeholders identified as a great hurdle to overcome (Cohen 2011; Anonymous A 2011; Nakano 2011; Anonymous B 2011; Tillapaugh 2011; Doshi 2011; Westeinde 2011; Nasr 2011; Nowak 2004). While this investment may add value to the building and community for the long-term, these benefits may not be recognized by financing organizations, making it more difficult to attract investors willing to pay premiums (McConkey 2011).

To help address the issue of higher upfront capital costs, Peck and Callaghan (1999) suggest that the implementation of full cost accounting would help projects like green roofs become more economically viable. Government supported incentive programs, tax breaks and innovation grants could also help drive the growth of RA projects (Murphy 2011; Kaufmann 2011; Snyder 2011). Rooftop agriculture and other types of local food production face an uphill battle when attempting to compete with the heavily subsidized industrial food system (Levenston 2011; Kent 2011; Williams 2011; Boucher-Colbert 2011). While this battle may be significant, RA may be able to demand a premium price in niche markets or as a result of the superior quality of fresh, nutritious locally grown produce (Janvier 2011; Joaquin 2011; Boucher-Colbert 2011; Currie 2011; Donnelly 2011).

3.5 Research Question 3: Assisting Cities to Better Understand RA

A city looking to utilize RA requires a comprehensive and systems understanding of how it can relate to their city/food nexus. A robust framework such as the FSSD will be helpful in aligning a project's goals with a clear definition of success as defined in sections 3.1.2 and 3.1.3. Without this vision of success, RA may be implemented in a way that does not move city towards sustainability. If a project is reducing a city's contributions to the violations of one of the Sustainability Principles, but is increasing contributions to another, then it may not be leading the city in the right direction. Due to the complexity of the city/food nexus, a strategic approach to developing RA projects is imperative.

For city stakeholders to understand the benefits RA can provide in moving a city towards sustainability, it is important to first build a clear understanding of the sustainability challenge society currently faces. Sections 3.2.1 - 3.2.10 have addressed many of the sustainability problems the existing city/food nexus faces and how RA effectively can help move it towards success as defined in 3.1.2. It is also beneficial for city stakeholders to recognize the current challenges RA faces in implementation and how they might be able to overcome them. Sections 3.4.1-3.4.3 identified various environmental, social and economic challenges that relate to RA's ability to be developed into the future. Answers to research questions one and two provide a platform to understand the role RA can play in assisting cities of the developed world to move towards sustainability.

Tillapaugh (2011) and Joaquin (2011) identified that RA is a relatively unknown concept amongst the general public and policy makers. It is clear that information is lacking around the concept which could help city stakeholders understand and ultimately implement RA projects.
A guide that can help stakeholders understand how RA might help move a city towards sustainability should be comprehensive. It should build context for rooftop agriculture by highlighting the sustainability challenge and how urban development and the industrial agriculture system have contributed to unsustainability. It should present rooftop agriculture as one of many potential solutions in mitigating various environmental, social and economic problems. It should also highlight the areas in which RA must improve to comply with the system conditions required to achieve sustainability. These elements will provide a clear identification of the role RA might play in moving society towards socio-ecological stability.

A strategic guide promoting RA's role within society should also utilize a framework that can analyze the concept from a systemic lens. The FSSD can provide a comprehensive approach to analyzing various systems. Ideally, a guide would assist a project by placing it within an appropriate system in the biosphere and help direct a project towards success by defining project goals that move towards compliance of system conditions needed to reach socio-ecological sustainability. In addition, a guide should highlight the key differences each type of RA provides and how they fit within sustainability. The three prioritization questions identified in 3.1.3 should be used to help a city stakeholder select the appropriate type of RA that will be most strategic in moving society towards sustainability.

In an attempt to fill the gap in information, we created a prototype of a Sustainable Rooftop Agriculture (SRA) Guide, a summary of the research collected from answering RQs 1 and 2 and formatted to be accessible to city stakeholders and the general public. The SRA Guide includes many of the preceding components, and can be found in Appendix A.

-An introduction to the sustainability challenge, including the funnel metaphor and the four Sustainability Principles
-A brief description of urbanization trends and why creative solutions to address the sustainability challenge are imperative
-A brief description of the current industrial agriculture system and why it is not sustainable

-An overview of key sustainability problems society faces in which rooftop agriculture can help to mitigate
-A description of the three primary types of RA and how they can uniquely address key sustainability challenges
-Project case studies for each of the three primary types of RA
-An identification of the sustainability problems which each of the three types of RA may contribute to in construction and operations
-A basic project selection guide, helping city stakeholders identify intentions, scope and expectations of an RA project
-A basic guide helping city stakeholders select a site for RA project development
-A plant recommendations list, suggesting which varieties may be successfully grown for each of the three types of RA

4 Discussion

The city/food nexus is a complex system with many stakeholders hosting fragmented and differing visions of success. When problems are addressed without consideration of the system in which they reside, a selected solution may produce unforeseen consequences that may prevent it from moving towards sustainability. To avoid this, a strategic sustainability lens must be applied to ensure that developments within a sub-system, e.g. RA in cities, are moving in the right direction also in the context of the full system – civilization in the biosphere. The FSSD provided our research with such a lens, helping to guide our analysis of RA and provide us with a clear definition of success within the city/food nexus. This defnition provided a vantage point from which to backcast. It highlighted the opportunities in which the current nexus can be improved upon to strive towards compliance with the Sustainability Principles.

4.1 Key Findings from Research Question 1

RQ1: What can be the role of agricultural green roofs, rooftop container gardens, and rooftop hydroponic systems when moving towards a sustainable society?

The three primary types of rooftop agriculture have been found to have potential in mitigating a variety of environmental, social and economic sustainability problems which cities currently face. Our research identified that each of the three types had their own strengths and limitations, and that a successful city/food nexus would likely make use of all three in helping to move it towards sustainability.

4.1.1 Agricultural Green Roofs Best Applied

As we had initially expected, agricultural green roof strengths lie primarily in contributing to the mitigation of environmental and social problems in an effort to move towards a successful city/food nexus. The recent growth of the green roof industry throughout the developed world is a promising sign for AGRs, as its success can be related to the advancement of any soil-based vegetated roofing system.

A particular strength AGRs provide is an effective educational and community building platform. The *Eagle Street* rooftop farm in New York City currently relies on a network of volunteers to develop and maintain seasonal harvests. This shows an eagerness for city dwellers to reconnect with the soil, but does little to address the financial viability of AGRs over time.

As discussed in section 3.1, local economic development is an integral part of reaching socio-ecological sustainability. AGRs have yet to prove if they have a strong enough financial return on investment to garner additional support from city stakeholders. The *Brooklyn Grange* project in New York City was recently developed to be the first commercial scale AGR operation in the developed world, so it will be influential in determining the role this RA type can play into the future.

4.1.2 Rooftop Container Gardens Best Applied

As identified throughout much of section 3.2 and as expected, rooftop container gardens have the potential to mitigate a variety of environmental, social and economic sustainability problems which are common to urban areas. The primary factor which has driven this potential is the versatility and customization of configurations in which they can be implemented.

With the accessibility and simplicity of container gardens comes the potential of widespread utilization. As the volatility of food prices is projected to press many regions of the developed world, container gardens appear to be the best suited type of RA to react quickly to improving local resilience and food security. Building owners and tenants alike have the opportunity to rapidly implement container gardens on their property with relative ease. As discussed in the introduction, roofspaces make up a substantial portion of an urban footprint and have great potential for becoming productive.

We had expected rooftop container gardens to have a lesser ability to mitigate environmental problems such as stormwater runoff and the UHI effect when compared to AGR. This was confirmed for each specific project but we discovered that the simplicity and versatility of the container systems makes it a more likely candidate for widespread implementation on existing buildings in the urban landscape without the need for additional structural infrastructure. This brings forth the possibility that containers could rival the potential of AGR's when being used strategically to mitigate environmental problems within the city/food nexus.

4.1.3 Rooftop Hydroponic Systems Best Applied

Rooftop hydroponic systems offer unique attributes to a city/food nexus moving towards sustainability. As expected, and as identified throughout section 3.2, hydroponics are capable of producing higher agricultural yields when compared to traditional food cultivation methods. For a city concerned with food security, hydroponics was found to be the strongest solution. *Lufa Farms* has just finished their first harvest in a 2,880 square meter rooftop hydroponic system in Montreal (Lufa 2011) which is designed to supply 1,000 families in their local community with fresh produce on a weekly basis. This project, in addition to several others currently being developed, are setting the stage for this type of RA to be recognized as a valuable component of a successful city/food nexus into the future.

In addition to impressive yields, our findings show that hydroponic systems can be influential in stimulating local economies through the creation of jobs. The *Lufa Farms* project currently employs 10 individuals to help operate and maintain their hydroponic system. If this case study can prove its financial viability, hydroponic farming on roofs could soon become a staple in urban centers throughout the developed world.

4.2 Key Findings from Research Question 2

RQ2: What are the challenges of implementing rooftop agriculture in cities of the developed world and how might they be overcome?

Our research identified several environmental, social and economic challenges exist which can inhibit the concept from being implemented. As expected, social and economic challenges proved to be the toughest hurdles for the implementation RA in cities of the developed world

4.2.1 Environmental Challenges

As identified in our research, several unique environmental challenges presented themselves, but proved not to be predominant enough to inhibit RA projects from being developed. More extreme growing conditions on rooftops, like increased sun and wind exposure and nutrient runoff were all identified as challenges that ground level agriculture cultivation doesn't face to the same levels. It was uncovered that these unique conditions can be addressed by using wind breaks, shading methods and efficient irrigation systems. Furthermore, microclimates can be utilized on rooftops to take advantage of building ventilation systems that produce heat, extending growing seasons and providing conditions for differing plant varieties.

4.2.2 Social Challenges

As expected, social challenges proved to be the toughest hurdles for the implementing RA in cities of the developed world. The overriding barrier uncovered was a lack of information surrounding the concept. As discussed in 3.4.2, RA is a relatively unknown amongst the general public and has received minimal attention from academics and researchers thus far (Tillapaugh 2011; Joaquin 2011). To understand its true value within the city/food nexus, RA requires a significant amount of exploration to take place from both the public and private sectors. Government incentives, policies and industry guidelines supporting RA development would greatly accelerate innovation within the field. The formation of such policies could leverage the recent successes of the green roof and urban agriculture industries, which have both garnered a considerable amount of attention throughout cities of the developed world.

As a nascent concept, our research identified a need for role models as many city stakeholders are hesitant in developing RA as to avoid unknown consequences. This could soon change however as there have been a handful of entrepreneurial individuals and organizations who have recently developed RA projects throughout cities of the developed world. The *Eagle Street Rooftop Farm* and *Brooklyn Grange* in New York City, *Lufa Farms* in Montreal, and *Uncommon Ground* in Chicago are key projects aiming to prove that the benefits of growing food on a roof can be higher than its liabilities. This suggests that the next few years will be crucial for the concept as these projects will be exposing many potential successes and failures. It is important that transparent information and dialogues be shared throughout the development of RA projects as to allow alternative practitioners and stakeholders the opportunities to evolve the concept.

Another element that should not be overlooked in garnering interest for RA is its ability to get people to think about city living in unique ways.

Rooftop agriculture possesses the quality of garnering authentic curiosity and enthusiasm in minds of those that are familiar seeing concrete, steel and glass in urban areas. This helps to create a strong visual relationship between urban residents and their food, build awareness around sustainable living and ultimately strengthen a city/food nexus.

4.2.3 Economic Challenges

In addition to the social challenges of implementing RA, various economic barriers were identified when answering our second research question. It was uncovered that start up costs of developing the infrastructure required for cultivating food on rooftops proved to be a significant challenge. Public policies, incentives and full cost accounting were identified as methods that could help to accelerate implementation of RA projects in the developed world. A part of this full cost accounting is a stronger valuation of the social and environmental benefits identified throughout section 3.2.

An additional economic barrier RA developments face was a higher cost of production compared to traditional agricultural practices. The property values of urban areas and limited economies of scale in which food can be grown in cities contribute to a challenging economic climate for growing food on rooftops. Corresponding to this was the identification that food costs associated with industrial agriculture practices are artificially low. This is due in part to unnecessary government subsidies and a lack of accounting for externalities. These artificially low prices make it difficult for sustainable food production to compete with the economics of the industrial agriculture system which society has become dependant on.

Our research identified various ways in which the economic challenges RA projects face can be addressed. As a nascent industry, rooftop agriculture can take advantage of a growing demand in urban centers for local, healthy and organic food. Recent development of CSAs, farmers markets, and food co-ops being integrated into communities throughout the developed world has shown promise in strengthening urban agriculture production. Janvier (2011), Joaquin (2011), Boucher-Colbert (2011) and Currie (2011) all identified RA as an exciting concept right now that may be able to charge a premium for novelty or niche produce which is of exceptional freshness and nutritional quality. Several restaurants in North America have leveraged this growing interest in local food as a way to maintain economic viability.

4.3 Key Findings from Research Question 3

RQ 3: What can assist cities of the developed world to better understand how rooftop agriculture can address their sustainability problems?
As identified in section 3.4.2, cities of the developed world lack information on understanding how RA can assist them in moving towards sustainability. For city stakeholders to best utilize RA strategically, the concept must be approached from a systems perspective. Research questions one and two provided our project with a comprehensive understanding of the role RA fits within a sustainable society and a current reality of the challenges the concept faces in implementation and how they might be overcome. Recognizing that this information would be valuable for city stakeholders, we created the Sustainable Rooftop Agriculture Guide.

We hope the SRA Guide will be a beneficial resource for those looking to access basic information on rooftop agriculture. It communicates the context in which RA resides by exploring the sustainability challenge and the need for creative solutions within the city/food nexus. It also highlights key sustainability benefits of agricultural green roofs, rooftop container gardens and hydroponic systems and how each type can be best applied.

The FSSD helped shape the creation of the content found in the guide but was not incorporated directly into its body. A stepwise recommendation process to help readers define their goals of an RA project as well as a site selection guide and plant recommendation guide were additional elements included in the resource.

4.4 Research Strengths, Weaknesses and Limitations

4.4.1 Research Strengths

This research has several strengths. Through interviews we gathered and interpreted data and insights from many leading researchers in the green roof, urban agriculture and rooftop agriculture fields. The information drawn from these sources was analyzed through the scientifically rigorous and peer reviewed Framework for Strategic Sustainable Development. An analysis of RA from a systems sustainability perspective had not been done before and can help create a baseline on which future research and development can be based.

The culmination of this research was the identification of information which cities could use to help them better understand RA and how it could address some of their sustainability problems. This information was then used to create a prototype Sustainable Rooftop Agriculture Guide, a visual and user friendly resource aimed to make the information collected from this project more accessible to the general public. This guide attempts to present the compiled information to city stakeholders throughout the developed world. We hope it will help address the identified gap of RA information currently being difficult to access.

4.4.2 Research Weaknesses

While our research contributed valuable ideas to academia surrounding RA, it did have some weaknesses. Our rating of low, medium and high used to communicate the potential of each of the three RA types to mitigate sustainability problems lacks a clear structure to standardize and explain the designation of each rating. Rating each type in relation to mitigation ability proved to be an extremely difficult endeavour as the number of moving parts in every project was substantial. Compounding this complexity was the reality that each RA development may be designed to accomplish different goals and operate under varying environmental conditions. An additional weakness of our research was that the SRA Guide has not yet been sent out to city stakeholders to be tested and reviewed for comprehensiveness and applicability.

4.4.3 Limitations

This study performed a broad sector analysis on RA to build a foundation for future research into the concept. While the findings should help build a general understanding and awareness of rooftop agriculture, this paper does not provide hard, proven numbers which is often sought by people attempting to gain an understanding of new concepts and ideas.

As a result of very few researchers studying rooftop agriculture directly, we relied on green roof and urban agriculture experts to provide information on rooftop agriculture. This required experts to perform some extrapolation of RA specific information based on their knowledge and expertise in their respected fields. In addition, while we identified an extensive list of six stakeholder categories with numerous sub-categories, our completion of 37 interviews were not enough to receive input from every sub-category.

The availability of specific data on hydroponic systems was somewhat limited. More information on potential yields from hydroponic systems, as well as environmental implications of urban greenhouses would have helped add depth to the information presented in this paper.

4.5 Recommendations for Future Studies

We are optimistic that this paper can help provide a foundation for future rooftop agriculture research and development. We hope that our analysis of RA with the scientifically robust Framework for Strategic Sustainable Development will highlight the need for future research to approach RA with the city/food nexus in mind.

From our findings, it appears that interdisciplinary collaboration and consolidation of research efforts within the fields of green roofs, urban agriculture and rooftop agriculture would be the most strategic way to investigate RA due to the complexity of variables involved in a project's development. This would help to ensure comprehensive and diverse inputs would be involved in developing RA into the future.

Another study that would be of value for the nascent RA industry would be a food systems analysis. While some studies have investigated the potential for urban agriculture to contribute to a regional food system (Nasr et al. 2010), similar studies for rooftop agriculture could garner public interest and support for the concept.

Other technologies and concepts which would benefit from more research, but were not included in this study are aquaponics, aeroponics and other forms of building integrated agriculture such as living walls. These subjects have the potential to help evolve urban agriculture initiatives throughout cities of the developed world.

5 Conclusion

This study used the Framework for Strategic Sustainable Development (FSSD) to understand the relationship between rooftop agriculture and a successful city/food nexus. The research determined that while currently in a nascent stage, rooftop agriculture has the potential to be a strategic action to move a city of the developed world towards sustainability.

Our findings determined the importance of RA being approached from a strategic sustainability perspective to fully value its potential. While RA can contribute key benefits to the city/food nexus in isolation, its strengths lie in its ability to address environmental, social and economic sustainability problems simultaneously. The FSSD played a critical role for this research, and acted as the backbone for collecting and interpreting our results.

RA has shown to be a strategic method in bridging the gap between the current city/food nexus and an ideal one when viewed from a systems perspective. A lack of information and subsequent awareness of RA amongst the general public and policy makers reoccurred as the most significant challenges which the industry currently faces. To accelerate innovation within the field, government policies, incentives and industry guidelines supporting RA development should be created. RA as an industry will also benefit from future collaboration and coordination between RA practitioners, green roof technologists and urban agriculture stakeholders to effectively share and make use of research findings and best practices.

We hope that this research will help shed light onto the environmental, social and economic benefits that can be achieved by using creativity and innovation to explore new ways of using existing spaces within the built environment. RA is just one of countless ways which society can redesign the spaces in which we live work and play in an effort to become more healthy, happy and sustainable.

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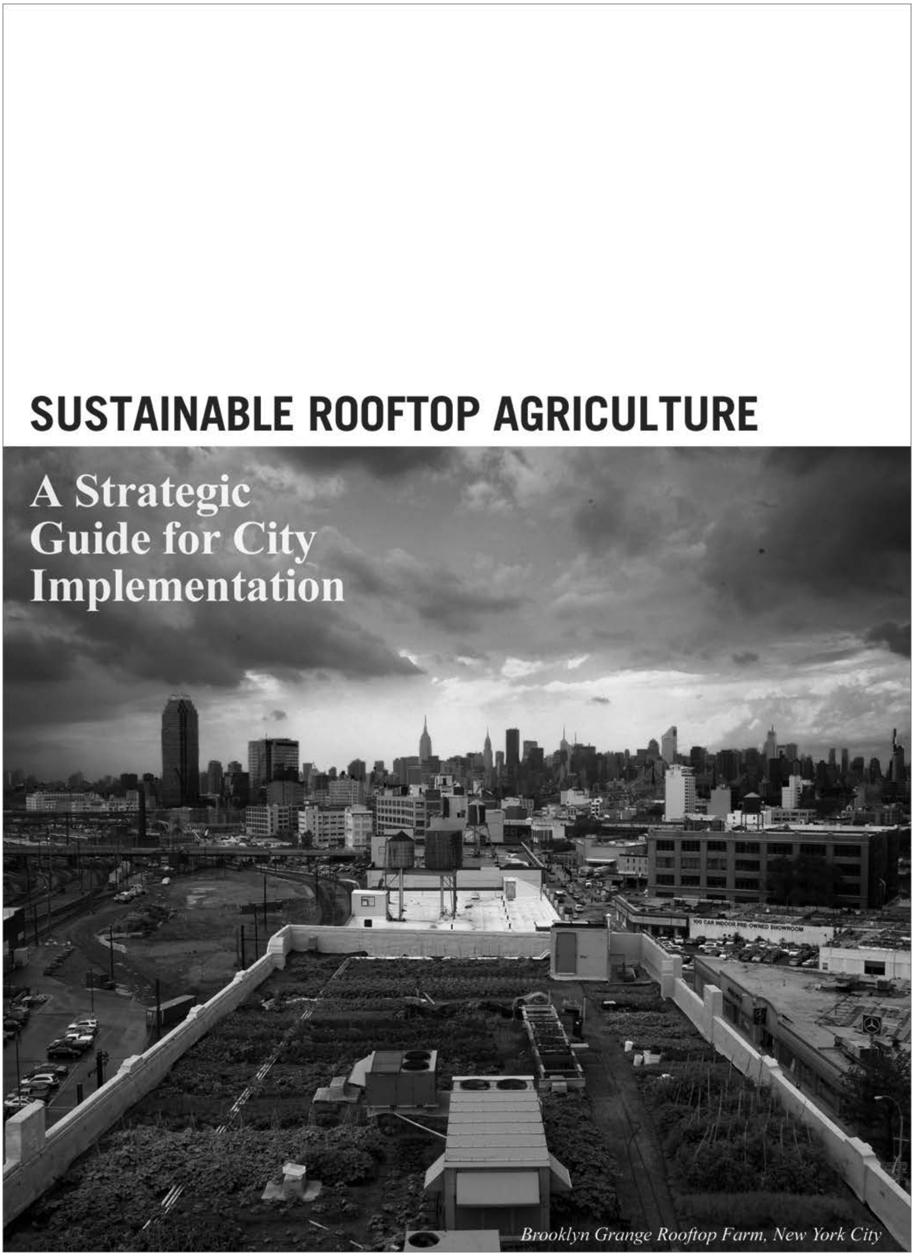
6 Appendices

Appendix A: SRA Guide

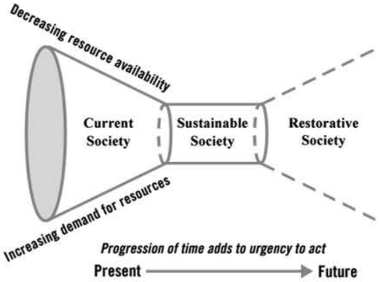


CONTENTS

The Sustainability Challenge

Human development in its current form is unsustainable and the evidence is everywhere- climate change, species extinction, pollution and social inequality are deteriorating the capacity to sustain our ways of life. It is estimated that about two-thirds of the ecosystem services upon which human society depends are being degraded or used in ways that cannot be sustained (1). This degradation is occurring at an alarming rate from a global time scale, yet the majority of society has not comprehended the socio-ecological impacts for which it has been predominantly responsible. It is increasingly clear that the current mindset of a linear and reductionist understanding of the planet and our role within it is insufficient in dealing with today's myraid of environmental and social challenges. A new "whole-systems" way of thinking, planning, and living requires breakthrough solutions that step outside of the limitations of the current mental model. The image to the right is representative of the socio-ecological system in which society exists and is referred to as the 'funnel paradigm' (2).

It is a visual metaphor which represents a decreasing capacity of the Earth's systems to support society in relation to time. Increasing human populations which demand ecosystem services have led to increasing resource



consumption, while access to these resources and the health of ecosystems upon which society relies have been in decline. This path of development which humans have chosen will inevitably lead to the breakdown of the socio-ecological system. From a scientifically robust perspective, the following four Sustainability Principles define system condision that must be met to reach sustainability (3).

In a sustainable society, nature is not subject to systematically increasing:

1_ Concentrations of substances extracted from the Earth's crust;
2_ Concentrations of substances produced by society;
3_ Degradation by physical means;

And in that society,

4_ People are not subject to conditions that systematically undermine their capacity to meet their needs.

Urbanization & Agriculture

Society has continually become more urbanized since the industrial revolution, coming at the cost of massive consumption of materials and energy. In 1900, 15% of the global population lived in an urban setting, and in 2010 that figure had risen to 51%. This trend is expected to continue with projections suggesting that number will rise to 66% by 2025 (4). The rapid population surge has placed tremendous pressure on global resource demands, with urban areas requiring a significant portion of this. At present, modern cities are responsible for the consumption of 75% of the world's resources on less than two percent of the global land area (5).

As cities have expanded, the surrounding areas which have generally been agriculturally productive have been developed into food consuming areas. This imbalance of input and output for food distribution has led many cities down an unsustainable path and has created a level of food insecurity, which refers to the availability of food and ones access to it. There is evidence indicating that global climate change and ozone depletion is affecting the productivity of the already uncertain global food production and has illustrated that the sustainability of the world's major cities is more fragile than previously thought.

The fact that in North America the average food item on a store shelf has traveled approximately 2,000 km from its point of harvest has created an agriculture system heavily dependant on transportation (6). With transportation being such an integral part of our current food system, the industry has become interconnected with that of the petroleum industry. With oil prices being notoriously volatile and subject to heavy fluctuations our food system is now at the mercy of this volatile market.

Experts suggest that to prepare for emergencies (either natural or human induced), every community should be able to produce or supply at least a third of the food required by its residents. At present, less than five percent is produced on average (6). It is increasingly apparent that a resilient city would have a local food system that connects producers, processors, distributors and consumers.

Rooftop Agriculture

Two of the most effective actions to help build resilience into a city include increasing local food production within urban and peri-urban areas and rethinking how existing spaces such as rooftops can be used in productive ways. Rooftop agriculture (RA) is an exciting concept that aims to combine these two strategies. RA is the production of fresh vegetables, herbs and flowers on rooftops for local consumption. They have been shown to create green jobs, increase local food production, and provide the ecological benefits of green roofs while leaving vacant urban land available for alternative development.

Rooftop agriculture has the potential to be a significant asset in moving cities towards sustainability. The following benefits can be utilized by RA projects:

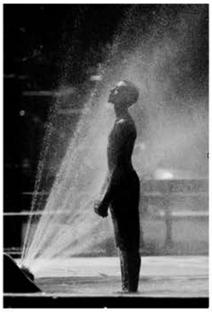
Stormwater Management

Many regions have now mandated stormwater management plans, increasing their rationale for controlling water through capturing techniques on rooftops. Green roofs have become increasingly popular as stormwater management strategies, with a basic 10cm green roof absorbing nearly two thirds of rainfall from a storm event, releasing the remainder over an extended period of time.

Certain types of RA share similar capturing capabilities as green roofs, providing municipalities with an effective platform for minimizing infrastructure demands and associated costs. Furthermore, localizing water management has social benefits as well, reducing the potential for combined sewage overflows that compromise public health in many urban areas.

Urban Heat Island Mitigation

Incorporating vegetation into urban areas is a proven way to combat the UHI effect. Vegetated roofs have been recorded 3-4 degrees C cooler than surrounding roofs on an annual average, and up to 16 degrees C cooler during the summer time (6).



RA can be a strategic part of a development plan to help regulate urban temperatures as they can contribute high leaf area indexes (LAI) which are key in helping to lower ambient air temperatures. It is worth noting that the area of vegetated roofs needed to make a significant difference on a regional scale is estimated to be about 50% coverage city wide.

Biodiversity Habitats

The expansion of urban spaces and artificial environments across the globe has led to significant habitat loss and fragmentation for many animal species. While a roofspace may not be accessible to all species native to a given region, they can provide food, habitat, shelter, nesting opportunities and a safe resting place for spiders, beetles, butterflies, birds and other invertebrates.

RA can play an integral role in promoting biodiversity within urban areas. When partnered with strategies such as biodynamic farming, RA can be agriculturally productive while maintaining the presence of diverse species.

Greenhouse Gas Reductions

While many of these greenhouses gases (GHGs) from cities can be associated with electricity generation, construction, manufacturing and service industries, a significant portion can be attributed to agricultural activity which feeds the urban residents. A recent study found that when taking into account the entire value chain of agriculture, transportation and associated land-use changes, food can account for 66% of a country's GHG emissions (8).

Given that in North America the average food item has traveled approximately 2,000 km from farm to fork (6), RA has the potential to reduce GHG's from the transportation of food. In addition, RA can also sequester carbon in plant life, improve insulating properties of a building envelope, and extend the lifespan of a rooftop, all of which can further reduce a city's GHG emissions.

Educational Platform

Integrating agriculture into urban and artificial environments can help to build a stronger understanding of the natural cycles within the biosphere. It supports the development of 'systems thinking,' a philosophy for seeing interrelationships rather than isolated parts.

RA can help citizens better understand systems thinking by improving the access to highlight water, energy, and waste impacts within a city. In addition, RA can serve a strong role for building 'food literacy,' which strengthens awareness around the production, distribution, and consumption of food.

Community Development
Many municipality initiatives and infrastructure decisions inhibit community interaction. Substantial expanses of concrete structures, roads, and paved parking lots create a landscape that dispels not only biodiversity but often times community engagement.

RA has been shown to encourage community development through several ways. First, people from various socio-economic backgrounds can come together and work with their hands on an actual agricultural project. Second, local food movements can be nurtured through rooftop farming, supporting growing local initiatives like CSAs and farmer's markets.

Food Security
With food products traveling such long distances, agricultural costs are tied directly to volatile energy and fuel prices. Urban dwellers are particularly disconnected from food production, making cities vulnerable to disruptions in the global food system. Most people have little more than a few days food supply at home and limited or no access to the essentials they need to survive. RA can contribute to urban agriculture development, increasing the food security and resilience within a region.

The US Department of Agriculture recently released a fantastic resource that highlights areas in America that are 'food deserts'. To find an area that is food insecure near you, follow this link: *http://www.ers.usda.gov/data/fooddesert/index.htm*

Public Health Improvements
Agricultural producers have increasingly become reliant on the use of preservatives and other processing methods to stay profitable. Most fruit and vegetable varieties sold in supermarkets today are chosen for their ability to withstand industrial harvesting equipment and extended travel, not for their taste or nutritional quality.

RA can contribute to an urban agriculture portfolio by localizing the production of healthy and nutritious food. It can also promote improved public health by cleaning polluted air in urban areas through the utilization of high LAI plants and appropriate growing substrates. Physical benefits can also be drawn through the promotion of RA as a recreational activity.

Connection to Nature

Many cities have been developed with little regard to the integration of natural elements. Concrete, glass, asphalt, steel and vinyl billboards comprise the majority of views seen out of urban windows. This elimination of nature has come at the expense of not only the biodiversity that is replaced by these artificial environments, but also many aspects of social health. Biophilia is concept that describes humanity's inherent affinity for life and lifelike processes. RA can be an effective strategy to increase biophilia in cities, which have been shown to reduce personal stress, improve productivity, and develop a stronger appreciation for biodiversity and ecosystem preservation.

Local Economies

Food production is currently reliant on heavily mechanized farms which rely on substantial amounts of fossil fuel energy for production and transport of goods to consumers. By encouraging local food production, GHG emissions can be drastically reduced and local jobs can be created.

RA can contribute to localizing economies by creating a new sector of urban development that employs product suppliers, manufacturers and installers, garden nurseries specializing in plant selections, design and engineering professionals, maintenance people and local food delivery services. The Maine Organic Farmers and Gardeners Association estimated that if every family in Maine spent $10 dollars a week on local food, it would put $104 million into the local economy (6).

Underutilized Development Opportunities

Rooftops make up approximately 15 to 35% of an urban footprint (9). While there are some examples of these roofs being used to generate electricity, capture rainwater or act as amenity space there are still significant opportunities for developers and building owners to better utilize this commonly unoccupied space. Vegetated roofs have been proven to protect the roofing membrane against ultra-violet (UV) radiation, extreme temperature fluctuations and puncture or physical damage from recreation or maintenance

Additional benefits include reduced utility costs, reduced costs from stormwater runoff, and ammenity value. Furthermore, the opportunity to lease out rooftops has been acknowledged as a way to add value to existing developments and potential for inclusion into future projects. And as somewhat of a bonus, building tenants have been able to gain marketing value for their business as a result of rooftop agricultural projects.

And last but not least:

The Cool Factor!

Rooftops are unique urban spaces, sitting high above the bustling and chaotic streets yet are very much grounded in the city. They offer fantastic views, structural isolation, and uncontested access to water, wind, and sun, making them valuable real estate in an urban market that is in desperate need of creative solutions for its existing building stock. Agriculture on rooftops is beginning to capture people's imaginations throughout the developed world, highlighting the under-utilization of cities' ample resource. RA possesses the unique quality of garnering authentic curiosity in minds of those that are used to seeing nothing but concrete, steel and glass in urban areas. This wow factor helps draws attention to people's relationships with not only their food, but ultimately their relationship with the planet. Cities that encourage the development of RA have been seen as forward thinking and innovative, drawing progressive citizens to support its collaborative progression.

Agricultural Green Roofs

Agricultural green roofs (AGRs) integrate edible crops into a soil based growing medium on top of a waterproofing membrane. They often include additional layers such as a root barrier, drainage layer and an irrigation system.

AGRs can be divided into two sub categories, extensive and intensive roofs. Extensive AGRs incorporate lightweight substrates with depths ranging between five and 15cm. They have traditionally been used to grow herbs and vegetables with low root systems like leafy greens and weigh between 50-200 kg/m2. Intensive AGRs rely on substrates deeper than 15cm, allowing them to grow a much wider variety of edible crops and expand upon the benefits that extensive roofs provide. These types of systems are much heavier than extensives, weighing between 200-1000kg/m2.

AGRs can provide tremendous value to municipalities aiming to lighten their socio-ecological footprints. Their strengths lie primarily in the environmental and social aspects of urban development, and have yet to be proven from an economic perspective. Environmentally speaking, AGRs are very effective at managing stormwater, mitigating the urban heat island effect and creating ecosystems for various biodiversity, all which have tremendous value for improving city sustainability. They are also strong educational platforms when approached appropriately, introducing a systems thinking perspective which can build awareness around local food production, distribution, and consumption. In addition, AGRs can offer various public health benefits, from recreation and access to healthy food to improved air quality and food security.

AGRs have the opportunity to be healthy investments when viewed from a systems level, but have to this point lacked financial viability when developed independently. They can contribute to closing water, waste, energy, and food loops within a city, all of which take their toll on municipal budgets and have considerable environmental impacts. They can also build upon the success of green roofs by acting as thermal insulators for the structures they sit upon, effectively minimizing utility costs and energy demands. In addition, vegetated roofs have been shown to improve property values as access and views of green spaces are economically valuable. Infrastructure costs can vary substantially to support AGRs, which can inhibit feasibility for many locations.

photo via Adam Gol

Eagle Street Rooftop Farm

The Eagle Street Rooftop Farm is a 6,000-square-foot agricultural green roof atop a warehouse in Greenpoint, New York City. The farm produces vegetables for a CSA program, running June-November, and a Sunday Market Day which is open to the public to purchase from the harvest. In addition, rooftop honey is harvested from two beehives. One can also taste Eagle Street's produce at various area restaurants, including Anella, Eat, Marlow & Sons, Manducati Rustica, Pauli Gee's, Vesta, and at the monthly Greenpoint Food Market. Besides providing local produce, Eagle Street's main mission is to spread urban agricultural knowledge and provide opportunities for community members to be directly involved in growing the produce they buy. Volunteers are welcome to contribute to harvestting and each Sunday at 2pm the farm hosts a workshop on a varying agricultural topic.

Rooftop Container Gardens

Container gardens involve planting vegetables, herbs, and wildflowers in pots or raised beds which contain soil-based growing media. They can range from simple pots to more elaborate systems and are capable of covering a large portion of a rooftop. The depth, yield, and installation costs of container gardens vary significantly and are dependant on the goals and budget of a project.

The environmental benefits of container gardens are very similar to AGRs when coverage of a roofspace is substantial. Stormwater management, urban heat island mitigation, and biodiversity integration are each dependent on the quantity of soil, leaf area index, and diversity of plants which containers are capable of providing. The advantage container gardens have over AGRs is their ease of customization and implementation. Examples have ranged from rooftop kiddie pools to expansive raised bed gardens with built in irrigation. The accessibility of containers allow them the opportunity to be utilized much more frequently than the alternative RA options, and ultimately gain an opportunity to promote the social benefits through education, community development, improved public health and food security. Considering the wide range of container applications, it is worth noting that environmental, social and economic benefits can be minimal if systems of scale are not developed.

Uncommon Ground

Uncommon Ground is a restaurant in Chicago that features a 2,500 square foot rooftop deck, 650 sq/ft of which consists of soil in container gardens.

The restaurant is North America's first certified organic rooftop farm, hosting events and environmental efforts on their roofspace. Organic vegetables are rotated through raised bed containers and include: peppers, eggplants, lettuce, heirloom tomatoes, radishes, beets, spinach, fennel, and shallots. These vegetables, in addition to various herbs and honey from four rooftop beehives, are used in the restaurant below.

The containers are watered via a drip irrigation system and are supplemented by water collected from rooftop rain barrels. Furthermore, food scraps from the restaurant are composted and reintroduced as fertilizer on the rooftop and elsewhere.



Hydroponic Systems

Hydroponics is a method of growing plants using mineral nutrient solutions, in water, without soil. The technology offers several significant advantages over AGRs and container gardens. The first being the lighter weight of the hydroponic system as it doesn't require the use of soil, which allows it the possibility of being implemented on top of many buildings that have structural limitations. Another advantage is the productivity of hydroponic systems, which have been shown to produce the same yield as soil gardens in about 1/5 of the space. Contributing to this is the extension of seasons that can result from establishing hydroponics within greenhouses, further increasing a system's yield productivity. Control over the nutrients used within the growing process can also be seen as an advantage of hydroponic systems, effectively containing many of the contaminants that effect soil-based agriculture. And finally, hydroponics can be very efficient with water, using as little as 90% less than traditional growing methods.

There are also disadvantages of hydroponic systems that are worth noting. Developing greenhouses and the specific equipment needed for growing can be expensive, so high upfront capital is generally required. Hydroponics also rely on consistent energy inputs to keep a system in operation which adds to operational costs and environmental impacts. Furthermore, technical expertise is often necessary to manage hydroponic systems, which can be seen as a clinical process that inhibits connections to bio-diversity and ecosystem restoration. This corresponds with hydroponics not being as strong an educational tool or community builder as AGR and container gardens could be as they are intended more for production and profit than social development.

Finally, hydroponic greenhouses are not inherently designed to mitigate stormwater, the UHI effect, or solid waste streams like the other two RA types can, so their value for a municipality may be limited in regards to these specific problems. Stormwater capture and renewable energy systems can however be integrated into a hydroponic system's design, minimizing or eliminating the negative attributes this concept may produce.

Rooftop hydroponic systems make the most sense for municipalities looking to improve food security within their region. They can also serve as great platforms that provide local green jobs to a community as construction, operations, and maintenance require manpower and expertise.

Lufa Farms

Lufa Farms is a Montreal-based enterprise that develops innovative urban agriculture facilities to grow high-quality produce for discerning urban consumers and chefs. The company's first facility is a 31,000 sq. ft. greenhouse on top of a 2-story office building in downtown Montreal. The facility grows more than 25 different crops sufficient to provide the annual fresh produce requirements for more than 2000 individuals. Future facilities of greater than 150,000 sq. ft. of growing area are planned for Montreal, Toronto, and selected sites in the Northeastern U.S.

The Lufa Farms greenhouse employs controlled-environment agriculture, which enables the operation to yield as much produce as a conventional farm 10 times its size. In addition to using controlled-environment farming methods, the facility collects rainwater and will filter and re-circulate water used in crop irrigation.



Summary of RA's Sustainability Benefits

Agricultural green roofs, rooftop container gardens, and hydroponic systems all provide unique beneftits to the sustainability problems many cities currently face. The identified benefits discussed earlier are show here in relationship to each of the three primary types of RA. It is worth noting that this is a general overview of the concepts and not based off of technical data.

Key: High Impact- (dark shading)

Medium Impact- (medium shading)

Low Impact- (light shading)

Sustainability Benefits	AGRs	Container Gardens	Hydroponic Systems
Stormwater Management	High	Medium	Low
UHI Mitigation	High	Medium	Low
Biodiversity Habitats	High	Medium	Low
Greenhouse Gas Reductions	Medium	Low	High
Educational Platform	High	High	Medium
Community Development	High	High	Medium
Public Health Improvements	Medium	Medium	Medium
Food Security	Medium	Medium	High
Connection to Nature	High	High	Low
Local Economies	Medium	Medium	High
Underutilized Development Opportunities	High	High	High
The Cool Factor!	High	High	High

RA's Sustainability Problems

RA has been shown to provide many benefits to cities moving towards sustainability. As productive as the three primary types of RA may be at mitigating environmental, social and economic problems, it is worth noting that they may not in and of themselves be sustainable. Improvements must be made to existing RA technologies to make them fully compliant with the Sustainability Principles that were presented earlier.

Sustainability Problems Common to all Three Types of RA

Agricultural green roofs, rooftop container gardens and hydroponic systems are all responsible for unique violations of the four Sustainability Principles. Materials which comprise each RA system may contain elements that are sourced unsustainably from the lithosphere. Petroleum-based plastics are frequently used to construct drainage layers, decking, containers and greenhouse components, all of which violate SP 1. The first Sustainability Principle is further compromised through the reliance on non-renewable energy for manufacturing and transportation of various materials.

Regarding violations of SP 2, each type of RA has been shown to be responsible for using artificial and synthetic inputs during operations and maintenance. Producing potable water is another chemically intensive process, and rooftop agriculture systems have often required this resource for crop irrigation. Ecosystem degradations by physical means are also apparent when developing RA projects, thus violating SP 3. Land can be destructed in the production of materials required for RA infrastructure and substrates. Even if organic in nature, substrates are generally taken from offsite locations. In addition, violations of SP 4 can be produced by RA developments, with a lack of access to roofspaces and affordability of food grown in cities as the primary barriers to social sustainability.

Sustainability Problems Common to AGRs and Container Gardens

Many AGRs and container gardens utilize growing media that are heat treated to reach certain performance characteristics, requiring significant amounts of energy to produce. This energy is primarily drawn from fossil fuels, which violates SP 1. Accumulations of nutrients in stormwater, and continual inputs of artificial fertilizers both compromise SP 2 from being met. Furthermore, growing food on roofspaces where wind and sun are generally stronger than ground level demands the use of more water for irrigation, adding stress to many city's shortages of potable water.

Sustainability Problems Common to Rooftop Hydroponic Systems

Hydroponic systems offer a unique set of sustainability problems from AGRs and container gardens. With the need for continued energy inputs, such as lights, fans, heating and pumps, hydroponics have high carbon and energy impact which violate SP 1. SP 2 is violated through artificial nutrient accumulation in discharge processes. The general lack of biodiversity integration in hydroponic systems fails to replace the habitat in which the project is developed, thus violating the third Sustainability Principle.

Defining Your Project

This section is a modification of **Alternatives and the Rooftop Garden Projects: Guide to Setting up Your own Edible Rooftop Garden**

The first thing one should do when considering a RA project is to determine the intentions, scope, and expectations of a concept. The following five steps should provide an adequate guide to defining, and ultimately developing your project.

1. Describe the Roles and Goals of your RA Project

Make an outline of your project for this initial step. Consider its goals and what factors will motivate the project. There are many possibilities. For example, you can create a garden with aims that are:

Social and Community-Based

Growing food and developing greenspaces in urban and semi-urban areas has proven to be an effective way of getting people out of their homes and offices and into spaces where they can interact with each other. For seniors, gardens stimulate social encounters and physical activity. It can mean getting back to the earth for some and participating in a lively project that comes with various therapeutic benefits. The community in contact with the garden will benefit from the feeling that comes from helping others, commitment to a project and socializing with one another;

Educational

Integrating agriculture into urban and often artificial environments helps to build a stronger understanding of the natural cycles within the biosphere.

RA can be a great place for people of all ages to experiment and connect with nature and provides a space for pedagogical and recreational activities that can reinforce classroom learnings such as ecology, botany, health, cooking, gardening, biology, etc.

Food Security

RA projects can provide fresh and nutritious fruits and vegetables to local residents and communities. Its potential to influence food security is disproportionate to the food produced in an individual project as it offers spaces where people can learn and be inspired to grow their own food and build support for the local food-shed. Ra can also help get nutrition to vulnerable demographics as illustrated by the Montreal-based organization Santropol Roulant which uses young volunteers to grow and deliver healthy local food to elderly people within the community

Economic

A rooftop farm can be designed to maximize the development of local economic opportunities. Whether you are creating a for profit business like Lufa farms, or strengthening existing enterprises as the Uncommon Ground and Noble Rot restaurants did, RA has tremendous potential. RA projects can even be designed to have the maximum influence on improving a building's energy efficiency.

Recreation
A rooftop project which is aiming to support recreational activities for building occupants or community members may be designed quite differently than a for profit business. You may want to design more amenities into the rooftop if you are aiming to draw people to the space for recreational purposes.

Environmental Health
An RA project has the potential to mitigate several environmental problems cities are facing as discussed in detail in the masters thesis; Solutions from Above: Using Rooftop Agriculture to Move Cities Towards Sustainability. Some RA developments have been specifically designed to maximize energy efficiencies of a structure, mitigate the UHI effect and stormwater runoff.

Whatever the goals of your project may be, it will be much more efficient and effective to have a firm grasp on these priorities during the design stage. The goals of your project will also have an influence on the technologies or type of RA which may be ideal.

Groups should clearly mark out their project goals when planning begins to ensure that all the concerned participants have the same expectations. Planning charrettes and workshops are highly recommended. They will enable you to work efficiently at building the project. It is also recommended that you involve the team that will use and look after the garden as early as possible to get their ideas, know their needs and stimulate their interest!

2. Define the scale and scope of your RA project

Determining the scale of the project to be developed is a critical step in the planning process. You may be interested in your RA project being only temporary, a project that will evolve over a few years or a project that will be established permanently. Your site choice may influence the scale of the project, or vice versa.

3. Select the type of RA

For more detailed information on agricultural green roofs, container gardens and hydroponic systems please refer to pages 14 -21 of this guide.

4. Make a List of People Involved in the Project

The inclusion of all stakeholders into the design stage of the project is highly desirable to minimize any unexpected complications. Some of the potential stakeholder groups may include:

Development Team
Stakeholders who will be critical to the development of your RA project may include real estate developers, project managers and the owner and tenants of the building which will host your project

Rooftop Agriculture Entrepreneurs
Depending on the scope and goals of your project, you should define who will be in charge of the daily operations of the farm, and possibly who will me managing the business if it is a commercial operation.

Agriculture and Horticulture Experts
Depending on the type of RA you choose, you may want to consult with farmers, botanists, hydroponic or green roof technicians to better understand which plants are best suited to your project to help you reach your goals.

Infrastructure and Logistics
Each project will have different requirements, but some of the stakeholders who may need to be consulted in this category include engineers (mechanical, structural and electrical), architects and green roof specialists.

Local government
You will undoubtedly want to consult with local building inspectors, city planners and health regulators who will all have an interest in ensuring your RA project meets all of their standards. Given that rooftop agriculture projects are a new concept to many municipalities, you may even garner more attention than you had originally anticipated. Because of this it is beneficial to keep a dialog open with these regulators throughout all phases of your project.

Additional Stakeholders
The experts that you may want to consult will be highly variable for your project but may include: insurance companies, financial institutions, community members and local resilience experts. There may even be opportunities to partner with local universities and researchers who may use your project as a means to better understand and document the benefits and challenges of RA.

Selecting a Site

Modified from **Alternatives and the Rooftop Garden Projects: Guide to Setting up Your own Edible Rooftop Garden**

If you are working with a specific rooftop, you may be constrained by the type of RA project which is feasible. Conversely, if you have defined the goals and objectives of your project, you must choose the appropriate site. There are several considerations which should be taken into account when choosing a site for your RA project.

1. Loading Capacity

The first step is to evaluate the roof's loading capacity, the load that the roof can support. This is important as the weight of soil based growing media, crops and equipment must be considered. To undertake this structural analysis, you must call on a structural engineer. You should inform the engineer of the type (agricultural green roof, container garden or hydroponic system) and surface area of the garden you would like to create. This will greatly influence the structural needs. Not to be over looked is the number of people which may be present on a roof at any given time as this 'live load' needs to be addressed by the engineer.

After studying the situation, the engineer can either mark out certain parts of the roof where the garden can be set up or propose a frame-work for reinforcement. The latter solution will undoubtedly mean costs that may lead you to turn to another site or modify the type of project you are looking to construct. Therefore, proceeding with a structural analysis at the very beginning of the project is recommended.

2. Municipal Regulations

Before starting construction of a rooftop garden, you must get information on regulations from your city. Regulations vary from city to city and sometimes from borough to borough. In addition to building codes that regulate materials and ensure conformity to the building code norms, you must also check the zoning regulations for setbacks, use of space and maximum height of the building. Certain buildings may also be classified as historical monuments or as being part of a historical sector, which also limits some types of possible actions. Get information concerning railing, access and security limits. These are important points you should pay attention.

Access is often regulated by fire codes (emergency exits). You should make sure regulations do not require two exits for this particular project, in which case you may need to add a staircase. There may also be restrictions on flammable materials and on the height of structures like pergolas and pavilions. In certain cases, you may be able to request an exemption from local authorities that would allow you to carry out the project even if it is not exactly up to municipal codes. This will, however, add extra delays and costs, and there is no guarantee you will obtain the exemption. Architects and architectural technicians are professionals who are qualified to do this research and verify project conformity to norms and regulations.

3. Sunlight and Wind Exposure

Sunlight

Light is a fundamental need for plants. A study of sunlight hours on the roof must be carried out. As roofs are elevated, they generally offer superior light conditions to most ground level sites in urban areas. Food cultivation necessitates long hours of daily sunlight. As a general guideline, leafy plants need at least six hours of sunshine while eight hours are recommended for fruiting plants. Depending on the chosen plants and features you would like to incorporate in your garden (reading corner, composting area, etc.), you should plan the garden in the area(s) (full sun, part shade) that correspond to your needs.

Wind

Wind is often stronger at rooftop heights than at ground level. The higher a rooftop is from the ground, the higher the wind speeds. A light breeze may be pleasant for gardeners, but strong winds can seriously damage plants. Creating a wind breaker (vegetal walls, structures, canvases, etc.) is recommended if there are strong winds. The wind break must be sturdy and must not change the roof's water resistance or structural integrity.

4. Access and Security

Several elements related to gardener's access and safety must be analyzed before choosing the site.

Practical Access and Roof Safety

There should be an official access point to the roof (stairway or elevator) to make the garden accessible. This access should be functional for transporting material to and from the garden.

Access to Water for Plants

Like sun, water is a fundamental need for plants. As rain does not always come on time, access to water for irrigation is essential.

The need for irrigation can be minimized by incorporating water retention technologies (drainage layers, moisture retention mats) into the design of the RA project if loading capacity permits. Some low rise buildings may be ideal candidates for storing rainwater in cisterns at ground level and utilize solar powered pumps to supply the rooftop irrigation system. As a last resort, the project should be able to access municipal water to ensure that the crops can be watered when needed.

Access to Electricity

An electrical source is very practical for construction work and development or for the simple pleasure of listening to music in the garden.

Access to a Storage Area

Plan an access to an area sheltered from inclement weather to store equipment, material and gardening tools.

Tenure Security

Land tenure is a very important part of an RA project, especially if you are not the building owner. It is recommended that a multi-year arrangement be worked out to ensure that everyone involved in the project is onboard for the long-term to avoid any unpleasant surprises a few years in.

5. Specific Needs

If the garden's clientele has specific needs, you must account for them from the beginning. Easy access will be an important issue if the garden is destined for elderly people or physically challenged individuals. Installing shady areas is recommended if seniors or young children use the garden.

Plant Recommendations

The plants selected will be highly variable on the goals and objectives of your project. Some projects may seek to produce large volumes of vegetables, while others may seek high value niche crops, or plants which can provide higher environmental benefits such as mitigating the heat island effect or stormwater runoff.

Below are some plant types which are categorized by growing media depth and were suggested by experts in the field. Other variables such as space availability (bush crops vs vines), sun/wind exposure and water availability must also be taken into account. Overall, culinary herbs, gourmet greens, and heirloom vegetables have been successfully grown in rooftop agricultural systems.

AGRs and Container Gardens

Less than 15cm of growing media

In a system with less 15cm of growing media the success of most plants will depend heavily on the watering regime with drought tolerant herbs and strawberries being likely candidates for doing well. Some leafy greens may be able to also succeed during some seasons.

15-30cm of growing media

Some of the plants which have been successfully grown in this depth of media include; chives lavender, sage, cilantro, time, lemongrass, sunflowers, and tomatoes.

30cm + of growing media

This depth of growing media provides a great platform to experiment with a wide variety of plants, bushes and even shrubs. In addition to the plants mentioned to perform well in shallower substrates, the deeper growing media can support: kale, carrots, potatoes, blueberry bushes, raspberries, gooseberries, boysenberry

Hydroponics

A rooftop hydroponic greenhouse offers very different conditions then a container garden or AGR. Plants which are commonly grown in hydroponic systems whether it be a ground based or rooftop system include cucumbers, tomatoes, eggplants, peppers and leafy greens.

Plants that develop large roots, like carrots and radishes, cannot be grown hydroponically because the soil-less growing medium cannot expand in the same way that soil does. Included in this list are plants like potatoes.

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Appendix B: Expert Interview Categorization

1.0 Development Team *-Building Owners* *-Developers* *-Project Managers* *-Tenants*	2.0 Rooftop Agriculture Entrepreneurs *-Business owners*	3.0 Agriculture and Horticulture Specialists *-Hydroponic Technicians* *-Agriculture Specialists* *-Botanists and Horticulturalists* *-Food Safety Regulators*	4.0 Infrastructure and Logistics *-Structural Engineers* *-Mechanical Engineers* *-Electrical Engineers* *-Architects* *-Green Roof Specialists*	5.0 Municipal Stakeholders and Governance *-City Planners* *-Municipal Drivers* *-Code Officials*	6.0 Additional Stakeholders *-Resilience Experts* *-Researchers and Consultants* *-Universities* *-Insurance Companies* *-Financial Institutions* *-Community Members* *-Other*
Gaëlle Janvier Alternatives International	**Kurt D. Lynn** Lufa Farms	**Karl Hann** Biota Farm	**Zach Williams** Carlisle Roof Garden	**Anonymous B** City of Victoria	**Brad Bass** Environment Canada/ University of Toronto
Jonathen Westeinde Windmill Development Group	**Anonymous** Sky Vegetables	**Michael Levenston** CityFarmer.org	**Anthony Mayer** Pioneer Roofing	**Wendy Mendes** City of Vancouver	**David Wees** Mcgill University
Bethany Koby Wolff Olins	**Alan Joaquin** Farm Roof	**Michelle Nakano** Kwantlen Polytechnic University	**Louise Lundberg** Scandinavian Green Roof Institute	**Aley Kent** Heifer International	**Joseph Nasr** Ryerson University
Juli Kaufmann Milwaukee Fix	**Alec Baxt** Farming Up	**Shane Tillapaugh** Eco Island GardenScapes	**Curt Hallberg** Watreco	**Susan Smith** British Columbia Ministry of Agriculture	**Terry McConkey** Citizens Bank Of Canada
	Marc Boucher-Colbert Urban Agriculture Solutions	**David Snyder** Uncommon Ground	**Anders Lindskog** Watreco		**Nevin Cohen** Five Borough Farm Project
	Matthew Krist Feed Your City	**Tim Murphy** Santropol Roulant			**Anonymous C** Environmental Health Clinic
		James Godsil			**Danielle**

		Sweet Water Organics			**Donnelly** Mcgill University
					Hitesh Doshi Ryerson University
					Beth Anne Currie Environment and Public Health Consultant
					Leigh Wittinghill Michigan State University
					Tim Carter Butler University

Appendix C: RA Implementation Challenges and Solutions

Environmental Challenges of Implementing RA and How They Might be Overcome

Challenge	**Overcoming challenge**
Rooftops present harsher growing conditions such as elevated winds, no shade, lower pollination levels and winter freezing conditions due to full exposure (Nakano 2011; Wees 2011; Currie 2011; Mayer 2011; Whittinghill 2011)	-Use windbreaks, mulches, interplanting and irrigation systems to help moderate conditions (Osmundson 1999; Kuhn 1995). -Introduction of bee hives could help address pollination concerns (Whittinghill 2011)
Choosing plant types which can handle rooftop conditions and accomplish project goals (Rowe 2010; Nakano 2011)	-Support research to study edible crops and their viability on rooftops (Nakano 2011; Bass et al. 2011). -Ensure to work with horticulture experts to create biodynamic systems which improve performance and the longevity of a rooftop agriculture system (Kortright 2001; Hann 2011)
Rooftop soils can be subject to increased nutrient loss, compaction and maintenance requirements to provide adequate growing conditions. (Nakano 2011; Hann 2011)	-Build healthy soils with organic material and biodynamic principles and design nutrient capture systems into the project (Hann 2011)
Conflicts between flora and fauna, such as edible crops and birds (Nakano 2011)	-Design systems to work in harmony with nature, and possibly use biodynamic principles as guidelines (Hann 2011)
Some concern has been raised in regards to the effect of air pollution on crop health and productivity (Bass 2011; Wees 2011; Carter 2011)	-Choose veggies which will be washed before consumption and avoid leafy greens which are most prone to contaminants found in urban areas (Wees 2011). -The restriction of synthetic fertilizers and pesticides can help reduce chemical accumulation in soils and plants (Brown and Carter 2003).

	-Growing in a controlled environment such as a greenhouse maximizes the effectiveness of using biological controls for pest management and removes the need to avoid certain crops for fear of contamination (Donnelly 2011)

Social Challenges of Implementing RA and how they might be overcome

Challenge	**Overcoming challenge**
RA is a relatively unknown concept amongst the general public and policy makers (Tillapaugh 2011; Joaquin 2011)	-Encouraging involvement and research by non-profits and educational institutions at all levels can help build awareness of new concepts (Brown and Carter 2003). -Government sponsored pilot projects could help policy makers become more informed of new technologies (Peck and Callaghan 1999; Holland Barrs Planning Group, Lees + Associates, Sustainability Ventures Group 2002)
There is limited research published on RA projects which establish the opportunities, challenges and viability of the concept (Whittinghill 2011; Nakano 2011; Doshi 2011)	-There needs to be increased support for the research to fill our technical and economic knowledge gaps, while ensuring findings are accessible to all (Whittinghill 2011; Doshi 2011; Mendes 2011). -Peck and Callaghan (1999) suggested that an online repository of all international data accrued could help support the growth of a new industry
-Innovative technologies and projects are often not encouraged or supported (c 2011; Kaufmann 2011; Snyder 2011). -Failures of past projects can instill fear and hesitation to experiment with new technologies (McConkey 2011; Anonymous B 2011; Nasr 2011)	-Some cities like Chicago provide grants for innovative projects which can include rooftop agriculture initiatives (Snyder 2011). -Peck and Callaghan (1999) suggest that government co-sponsored design competitions could help move new technologies into the mainstream. -Government procurement support can also act as a tool to encourage technology diffusion (Peck and Callaghan 1999). -Reputable industry guidelines such as the

	FLL for Green Roofs in Europe can be developed in Canada or the USA for rooftop agriculture or green roofs (Dvorak and Volder 2010)
-Concerns over insurance costs and increased liability is acting to deter rooftop projects (Nasr et al. 2010; McConkey 2011; Krist 2011; Kent 2011; Lynn 2011; Nowak 2004) -Need to have realistic expectations of food quantity (Snyder 2011; Currie 2011; Boucher-Colbert)	-There needs to be increased support for the research to fill our technical and economic knowledge gaps, while ensuring findings are accessible to all (Whittinghill 2011; Doshi 2011; Mendes 2011)
Many cities have undeveloped land outside of the urban center which could potentially be a more favourable location for agriculture (Cohen 2011; Currie 2011; Anonymous B 2011; Tillapaugh 2011; Bass 2011a; Nasr 2011; Carter 2011)	-Need to look beyond only food production and take a systems perspective of the concept of rooftop agriculture to appreciate environmental, social and economic benefits
Current building codes often hinder or prevent the construction of rooftop developments (Lynn 2011; Nasr 2011; Mayer 2011; Mendes 2011)	-Streamline a process to assess new technologies and approve amendments to building codes (Peck and Callaghan 1999). -There may be opportunities to partner with local organizations who have already successfully established rooftop projects (Koby 2011). -Density bonuses can be used to promote urban RA projects (Anonymous B 2011; Westeinde 2011; Holland Barrs Planning Group, Lees + Associates, Sustainability Ventures Group 2002). -The Living Building Challenge can also be seen as a model program, which mandates urban agriculture within the built environment (Kaufmann 2011)
Many policies and incentives are designed to address a problem in isolation, often without	-Use a systems lens when attempting to form new policies and incentives (Carter 2011)

consideration of the larger system (Carter 2011)	
City zoning regulations can restrict or prevent agriculture activites in many areas (Lynn 2011; Nasr et al. 2010; Mendes 2011; Cohen 2011)	-Nasr et al. (2010) identified several temporary solutions for permitting agriculture in areas of Toronto, including a minor variance obtained from the municipality and the use of temporary bylaws. -More permanent solutions may include changes to official development plans to include urban agriculture and garden zoning designations as has been seen in several U.S. cities (Nasr et al. 2010). -Carter (2011) suggested zoning overlays could be an effective tool to help include RA into existing land designations
Some governments may be lacking the inclusion of sustainable development into their plans or have regional policies which prohibit certain activities within the urban landscape (Janvier 2011; Nasr et al. 2010)	-A city may benefit from a review of policies and potential barriers to the expansion of urban agriculture (Nasr 2011; Veenhuizen and Danso 2007). -A city may also benefit from urban agriculture assessment plans, inclusion of urban agriculture into site planning and the formation of a food policy council (Holland Barrs Planning Group, Lees + Associates, Sustainability Ventures Group 2002)
Urban agriculture activities often are restricted by access to customers through point of sale regulations (Anonymous B 2011; Mendes 2011; Levenston 2011; Brown and Carter 2003)	-San Francisco has recently released ground breaking policies to encourage the development of urban agriculture activities and enterprises (Cohen 2011; Levenston 2011). -Seattle and Vancouver have been successfully bringing together various planning departments to help address food system planning issues (Cohen 2011; Mendes 2011)
Land tenure and access to growing spaces for citizens can prove to be a challenge for rooftop agriculture	-Establishing local guidelines for tenure and taxation of urban agriculture could help promote expansion to underutilized

(Nasr et al. 2010, 2011; Kent 2011; Levenston 2011; Kortright 2001; Nowak 2004)	spaces (Nasr et al. 2010). -There are also opportunities to explore the use of a third-party organization to manage lease arrangements (Nasr et al. 2010)
Rooftop agriculture requires the establishment of a continual and stable management plan to ensure proper maintenance (Westeinde 2011; Hann 2011; Murphy 2011)	-Base your management strategy based on the goals and set-up of the project (Janvier 2011; Holland Barrs Planning Group 2007)
Many buildings are under private ownership and could present a unique challenge for RA (Mendes 2011)	-Use a systems lens when attempting to form new policies and incentives (Carter 2011).Government grants can be more inclusive to include RA in green roof incentives (Murphy 2011)
Health and safety of food in urban areas (Mendes 2011)	-Public health authority should review of good agriculture practices (Smith 2011)
Light emissions from greenhouses/ neighbour concerns (Mendes 2011; Lynn 2011	-Choose systems which do not have artificial lights or are designed to limit emissions. -Public outreach and community consultation are critical components to successful neighbourhood integration (Nasr et al. 2010)
Many policies created around incentives are designed around one problem, not a systemic lens (Carter 2011)	-Use a systems lens when attempting to form new policies and incentives (Carter 2011).

Economic Challenges of Implementing RA and how they might be overcome

Challenge	**Overcoming challenge**
Upfront costs are higher than traditional rooftop options as substantial infrastructure is often needed for project development (Cohen 2011; Anonymous A;	-The implementation of full cost accounting (Peck and Callaghan 1999) can help identify benefits which new rooftop technologies can offer over traditional rooftop options.

Nakano 2011; Anonymous B 2011; Tillapaugh 2011; Doshi 2011; Westeinde 2011; Nasr 2011; Nowak 2004	-New buildings can be designed for one extra floor of load bearing potential (Wees 2011). -Ultra light weight RA systems can be used to minimize infrastructure modifications (Joaquin 2011; Whittinghill 2011)

Appendix D: Sustainability Challenges of RA

Sustainability Challenges Common to all Types

Potential Sustainability Problems	**Possible Solutions**
RA materials may be comprised of elements that are sourced unsustainably from the lithosphere	-Use biodegradeable materials for construction, or materials that maintain chemical integrity when recycled (McDonaugh and Braungart 2002)
RA materials reliant on non-renewable energy for manufacturing and transportation	-Source materials locally and transported through sustainable means (Nasr 2011; Coffman 2007), utilizing renewable energies for material production
Artificial inputs during operations of RA systems	-Use natural fertilizers and pest control means aided by principles of organic and biodynamic farming (Hann 2011; Kaufmann 2011)
Using potable water to grow food	-Implement and use graywater/rainwater capture systems (Bass 2011; Coffman 2007; Koby 2011; Lufa Farms 2011)
Land can be destructed in the production of materials required for RA infrastructure. Substrates and soils, even if organic in nature, are frequently taken from offsite locations	-Promoting a habitat exchange, as mandated by the Living Building Challenge (Kaufmann 2011) is a way to offset ecosystem and land impacts from development
Accessibility to space and food may be publicly compromised	-Ensure that members of the community are able to access RA farms and afford the food it produces (Cohen 2011; Nowak 2004)

Sustainability Challenges Common to Agricultural Green Roofs

Potential Sustainability Problems	**Recommended Solutions**
High embodied energy in manufactured growing media	-Incorporate more naturally derived or recycled components to growing media which do not rely on heat treatments (Rowe 2010; Nakano 2011; Hann 2011) -Use locally available growing media

	(Coffman 2007; Hann 2011)
Nutrient accumulation in stormwater with the potential for eutrophication	-Choose plants, substrate composition, and substrate depth which can minimize volume and contamination of effluent (Rowe 2010) -Use rain gardens, bioswales (Rowe 2010) or filters to recover any excess nutrients (Williams 2011; Baker and Brooks, 1989)
Continual input of organics needed	-Build healthy soils which are able to minimize artificial inputs (Hann 2011; Joaquin 2011; Snyder 2011)
Increased water consumption due to rooftop location	-Use water efficiently by making use of technologies such as drip irrigation (Williams 2011; Snyder 2011)

Sustainability Challenges Common to Rooftop Container Gardens

Potential Sustainability Problems	**Recommended Solutions**
High embodied energy and carbon in growing media	-Incorporate more naturally derived or recycled components to growing media which do not rely on heat treatments (Rowe 2010; Nakano 2011; Hann 2011) -Use locally available growing media (Coffman 2007; Hann 2011)
Continual input of organics needed	-Build healthy soils which are able to minimize artificial inputs (Hann 2011; Joaquin 2011; Snyder 2011)
Nutrient accumulation in stormwater with the potential for eutrophication	-Choose plants, substrate composition, and substrate depth which can minimize volume and contamination of effluent (Rowe 2010. -Construct containers with water retention and control systems (Doshi 2011; Snyder 2011). -Use rain gardens, bioswales (Rowe 2010) or filters to recover any excess nutrients (Williams 2011; Baker and Brooks 1989)

Increased water consumption due to rooftop location	Use water efficiently by making use of technologies such as drip irrigation (Williams 2011; Snyder 2011)

Sustainability Challenges Common to Rooftop Hydroponic Systems

Potential Sustainability Problems	**Recommended Solutions**
High embodied energy and carbon in materials	-Make use of recycled materials (Rowe 2010)
Greenhouses may use non-renewable energy for operations (lights, fans, heating, pumps)	-Design systems which do not require artificial lighting and heating. -Use renewable energies to meet energy input requirements (Holland Barrs Planning Group, Lees + Associates, Sustainability Ventures Group 2002)
Nutrient accumulation in discharge	-Use rain gardens, bioswales (Rowe 2010) or filters to recover any excess nutrients (Williams 2011; Baker and Brooks 1989) -Eliminate all discharge from the system (Lufa Farms 2011)
Lack of biodiversity integration	-Make an effort to introduce aspects of natural systems into the roof top, for example bees hives (Lufa Farms 2011)

Appendix E: Interview Questions

1.0 Development Team
What are the primary benefits you see rooftop agriculture providing for your development?

What are some of the key challenges you have confronted when dealing with the implementation of rooftop agriculture and how have you approached overcoming them?

What recommendations do you have that could help accelerate the implementation of rooftops being used for agriculture production?

2.0 Rooftop Agriculture Entrepreneurs
Which type of rooftop agriculture system is most appealing to you and why?

What are the primary challenges you have identified when trying to build an enterprise around rooftop agriculture and how have you addressed them?

What recommendations do you have that could help accelerate the implementation of rooftops being used for agriculture production?

3.0 Agriculture and Horticulture Specialists
What factors should be considered when growing food on rooftops?

Which species of plants are best suited for rooftop harvesting and why?

What recommendations do you have that could help accelerate the implementation of rooftops being used for agriculture production?

4.0 Infrastructure and Logistics
Which types of agriculture production are best suited for rooftops and why?

What infrastructure requirements need to be addressed when considering the cultivation of food on rooftops?

What recommendations do you have that could help accelerate the implementation of rooftops being used for agriculture production?

5.0 Municipal Stakeholders and Governance

What role can rooftop agriculture play in a municipality's social, environmental and economic development?

What's holding rooftop agriculture back from being promoted at municipal levels?

What recommendations do you have that could help accelerate the implementation of rooftops being used for agriculture production?

6.0 Additional Stakeholders

What relationship do you or your organization have with rooftop agriculture?

What are the opportunities and challenges you see in further developing rooftop agriculture?

What recommendations do you have that could help accelerate the implementation of rooftops being used for agriculture production?