BUILDING INTEGRATED AGRICULTURE
Utilising Rooftops for Sustainable Food Crop Cultivation in Singapore

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ABSTRACT

Burgeoning population and rapid urbanisation have contributed to two challenges facing cities today: food security and an increasing carbon footprint due to food imports. This paper examines the viability of rooftop farming in urban centres in Asia. A context-specific exploration—sited in Singapore—looks at the challenges of building integrated agriculture. Findings suggest that Singapore's public housing estates are suitable for rooftop farming. Implemented nationwide, such a scheme could result in a 700% increase in domestic vegetable production, satisfying domestic demand by 35.5%. Reducing food imports would also decrease Singapore's carbon footprint by 9,052 tonnes of emissions annually.

KEYWORDS

food security, carbon footprint, rooftop farming, building integrated agriculture, public housing, Singapore

INTRODUCTION
Urbanisation and Agriculture

Worldwide, approximately 800 million hectares of arable land support large-scale agricultural activity (Food and Agriculture Organization, 2004). There are two critical issues with this. First, intensive commercial farming techniques have caused irreversible damage to the land (Hillel, 1991); millions of hectares of grasslands, wetlands and forests have been degraded, ecosystems have been damaged with significant loss of biodiversity (Wilson, 1992). The clearing of land for farming activities also affects long-term carbon sequestration by other permanent wood plants (Williams, 2003).

Second, as the world population increases from the present 6.4 billion to 8 billion by 2025 (Salim, 2004), there will not be enough arable farmland (United States Census Bureau, 2003). This raises the spectre of food crises. The situation is aggravated by rampant urbanisation as more land, previously used for agriculture, is set aside to cope with expanding cities. It is predicted that the proportion of the world's population that lives in cities will increase from 47 percent in 2000 to 60 per cent by 2030 (United Nations, 2001).

Increasingly, people across the world will face the problem of food security, defined as the physical and economic access to food that meets people's dietary needs as well as their food preferences (World Health Organization 2009). When demand increases and production is limited, there will be price inflation as evidenced by the sharp rise in food prices traded on international commodity markets lately (British Broadcast Corporation, 2008). In less than a year, the price of wheat has doubled; rice and coffee have hit ten-year highs.

Urban agriculture—defined as co-locating crop cultivation within city boundaries—is one potential solution to these problems. Integrating food production with buildings offers an avenue that does not impinge on the city's many uses for available land.

There are other benefits to building integrated agriculture. Placing greenery on otherwise hard rooftops, for instance, can alleviate urban heat island effect (Yu, et al., 2008; Chen, et al., 2005). Bringing production closer to consumption can reduce food

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miles, i.e. the distance food travels in getting to the consumer's plate (Severson, 2006), which decreases carbon emissions due to transport. Land outside cities need not be set aside for intensive commercial farming, which of itself has many health-related, social and environmental consequences.

Singapore

Approximately 95% of all vegetables consumed in Singapore are imported (Agri-Food and Veterinary Authority, 2008). This adds to city-state's ecological footprint and leaves Singaporeans vulnerable to rising food costs and food production problems outside in other countries. The city is densely built up; land set aside for agriculture is limited.

To secure food supplies, the Singapore government is setting aside funds to create food zones overseas (The Straits Times, 2009), where food can be produced specifically for consumption in Singapore. Such measures are intended to control price fluctuations in the long term, presumably also to guarantee supply. In the face of growing uncertainty arising from climate change, however, these measures cannot fully deal with the question of food security. Nor do they seek to address Singapore's carbon footprint.

Past studies in Singapore have explored the possibility of rooftop farming. A survey of available residential and commercial rooftops in Singapore suggested that approximately 184,000 tonnes of fresh vegetables could be harvested per year (Wilson G., 2005). That study did not however look at the practicalities of implementation, making this figure optimistic at best.

A demonstration of rooftop farming in 1990s was sited at Singapore's Changi General Hospital. The project was run by a group of hospital staff; the produce generated was used for inhouse consumption by patients. In time, however, the farm was replaced by a garden (Lim, 2009). The question of who manages such a project, on a day-to-day basis, compromised the viability of the undertaking.

APPROACH

Over 80% of Singapore's population lives in public housing in Housing and Development Board apartments, known as HDB (Housing and Development Board Annual Report, 2007/2008). The extensive scale of housing estates and amount of roof space available represents a significant opportunity for the implementation of large-scale building integrated agriculture. HDB estates are supported with well-tuned management infrastructure—from waste collection to block maintenance—offering implementation possibilities that are not easily replicable in other building types, say, commercial buildings and condominiums.

Tampines New Town (Figure 1), a HDB estate located in the northeast corner of Singapore, was selected for this study. Tampines was completed in the early 1990s; at the time it was conferred the United Nations World Habitat Award (Housing and Development Board, 1992), suggesting that its design offers lessons that are replicable in public housing elsewhere.

The density and layout of the Tampines plan is used to extrapolate total rooftop area of all HDB flats in Singapore. This figure is adjusted following a closer look at two block types found in HDB design.

The projected annual yield of vegetables resulting from combined roof space of all HDB slab blocks is calculated. This is cross-referenced with earlier studies on rooftop farming and local production know-how. Figures on existing demand and projected production are compared. Reduction in food imports, resulting from increased local production, is estimated along with implications on food miles and carbon footprint.

This study also examines opportunities for rainwater harvesting. Within the context of a precinct in Tampines it reviews logistical infrastructure and strategies for access to/between cultivated roofs.

FINDINGS

HDB Block Typology

There are two types of HDB blocks; slab and point blocks (Lim, 2009). Point blocks are taller—25 floors, including roof—with smaller roof area. Slab blocks have a larger roof area, and are typically 10 to 13 floors high. Much of the roof area of point blocks is occupied by essential equipment such as water tanks, lift motor room, TV antennae and water distribution pipes. This study limits itself to slab blocks due to constraints posed by point blocks. The ratio of slab blocks to point blocks in Tampines and most other HDB estates is 7:3, and that in newer HDB

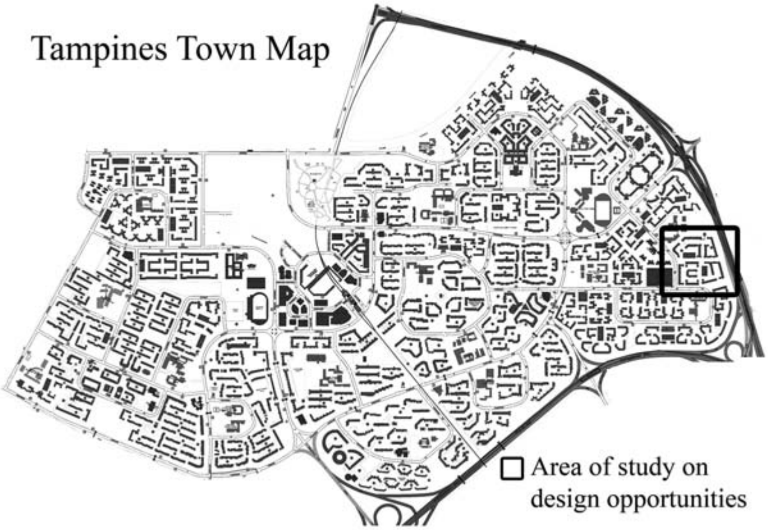


FIGURE 1. Overview of Tampines New Town on plan.
Source: Streetdirectory Pte Ltd, 2009. Available online at: www.streetdirectory.com.sg.

estates such as Punggol and Sengkang is 1:1. As a conservative measure, the available roof space of HDB blocks is taken as 50% of the total area.

Tampines has a total building footprint of 88.9 hectares; the total land area of the estate is 500 hectares. Using this footprint, the total roof area of all HDB flats in Singapore—spread over a land mass of 7,435 hectares—is estimated to be 1322 hectares. Eliminating 50% for unusable point blocks leaves 661 hectares of available roof space.

Method of Crop Cultivation

Inorganic hydroponics is a technique in which plant roots are suspended in either a static, continuously aerated nutrient solution for a continuous flow or mist of nutrient solution (Benton, 2005). Inorganic hydroponics is considered the more appropriate farming option in the HDB context. Compared with conventional soil culture, it has higher yield, lower labour requirement and, importantly, needs only lightweight systems, which can be easily assembled over an existing roof.

Crop Yield

In an earlier study on the feasibility of inorganic hydroponics, it was estimated that some 39,000 tonnes of vegetables could be grown on an area of 212 hectares (Wilson G., 2005). Using this as an index for this technique, 661 hectares of roof-space should yield some 121,599 tonnes of vegetables. Adding to this the current domestic yield of about 18,967 tonnes from local farms (Agri-Food and Veterinary Authority, 2008), the projected total annual yield—with building integrated agriculture in place—could reach 140,566 tonnes of vegetables.

A Singaporean consumes on average 82.6kg of vegetables annually (Agri-Food and Veterinary Authority, 2008). With the present population of 4.8 million individuals (Singapore Statistics, 2008), Singapore needs 396,480 tonnes of vegetables annually. Roof top farming, in combination of traditional farms, can therefore satisfy some 35.5% of Singapore's vegetable needs, a significant increase from the 5% currently met.

Rainwater Availability

Crop cultivation requires a substantial amount of water. To produce a kilogram of tomatoes using traditional land cultivation methods, 200 to 400 litres of water is required; hydroponics however requires about 4 times less water for the same yield (Ziegler, 2005). As an approximation, the amount of water required for each kilogram of vegetables harvested by soil culture is estimated to be 200 litres (Hoekstra et. al, 2002). This translates to 50 litres of water required in the case of hydroponics. To meet this demand, strategies for rainwater harvesting are considered.

The local annual rainfall in Singapore is 2360mm (National Environment Agency of Singapore, 2009).

Taking into account the total HDB residential land area in Singapore new towns, a total catchment area of 7435 hectares (Housing and Development Board Annual report, 2007/2008) can contribute to a collection of approximately 175 million cubic meters of rainwater annually. This figure is about 25 times more than the water needed for rooftop farming in HDB estates, suggesting that rainwater harvesting can be a sustainable strategy.

Carbon Emission

In 2007, 46% of the all imported vegetables came from Malaysia, 28% from China (The Straits Times, 2008), and 26% was from other neighbouring countries, mainly Indonesia, Thailand, Vietnam and Australia (Asian Productivity Organization, 2006).

A rough estimation on the distance between these countries and Singapore forms an indication of the carbon emissions due to transportation of imported vegetables. Due to limited information available on the exact locations of imported vegetables, the distance is measured from a central location of each country (Figure 2).

Table 1 shows an estimation of CO_2 emissions due to vegetable imports in the year 2007. A total weight of 381,532 tonnes of imported vegetables in 2007 contributed to 28,401 tonnes of carbon emissions. Based on this calculation, if 121,599 tonnes of vegetables are produced annually in HDB estates, there will be a reduction of 9,052 tonnes of CO_2 emissions[3] per year.

DISCUSSIONS

Environment and Health

Commercial farming requires large amounts of agrochemicals, especially fertilizers, to replace the nutrients that are taken up at a rate faster than the substrate could provide (Fertilizer Advisory, Development and Information Network for Asia and the

[3]Carbon emission due to maintenance, equipment manufacture and construction of the farm are not factored in this study, as figures supporting this tabulation are hard to access. It could be argued however that these are required regardless of where the crops are cultivated and so, moving production to Singapore will not substantially alter this total.

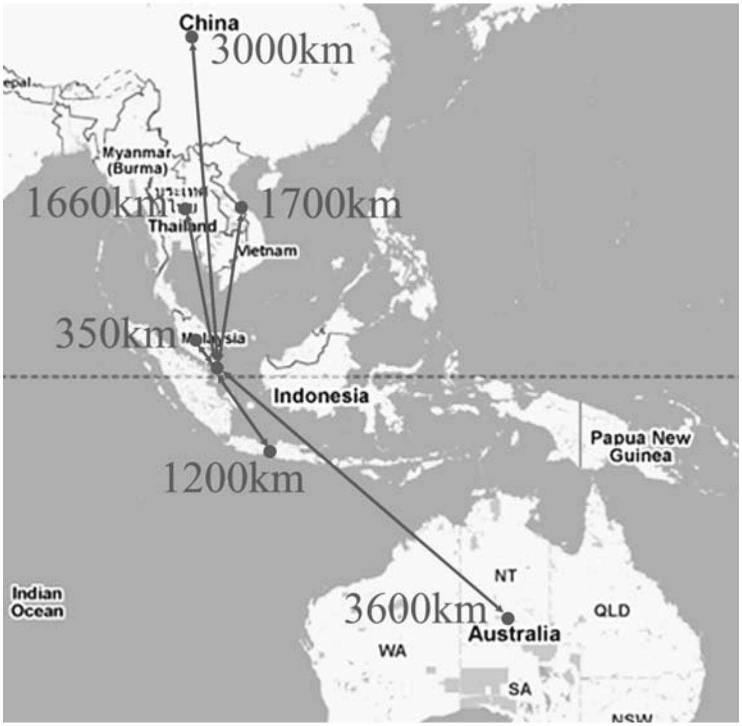


FIGURE 2. Average travel distance between Singapore and other countries. *Source:* Google Map, 2009. Available online at: http://maps.google.com/maps.

TABLE 1. Estimated CO_2 emissions due to vegetable imports in year 2007.

Total weight of vegetables imported *(*Agri-Food and Veterinary Authority, 2008*)*			381,532 tonnes
Country	Malaysia	China	Other countries, mainly Indonesia, Thailand, Australia, Vietnam
Percentage imported	46%	28%	26%
Weight	175,505 tonnes	106,829 tonnes	99,198 tonnes
Average distance travelled	350 Km	3000 Km	2040 Km (Averaged amongst the 4 main countries)
General mode of transport	Truck (Asian Productivity Organization, 2006)	Ship (Asian Productivity Organization, 2006)	Ship (Asian Productivity Organization, 2006)
General rate of CO_2 emission	207 g/ Tonne-km (Whitlegg, 1993)	30 g/ Tonne-km (Whitlegg, 1993)	30 g/ Tonne-km (Whitlegg, 1993)
Estimated CO_2 emissions	12,715 tonnes	9,615 tonnes	6,071 tonnes
Total CO_2 emissions	28,401 tonnes (Taking into account transportation only)		

Pacific, 2002). Pesticides and herbicides are also used to combat insect pests and microbial diseases agents. As a result, agricultural runoff contains large quantities of chemicals, which cause water pollution. The use of agrochemicals negatively impact human health (Nguyen et. al., 1997); farming is associated with many health risks such as infectious diseases like schistosomes, malaria and geohelminths. In building integrated agriculture, this reliance on pesticides, resulting in toxic runoff, is eliminated. An annual reduction of at least 30,400 tonnes of pesticides use can be achieved. The average pesticide use varies between different countries (Table 2). As a conservative measure, the calculation is based on an average figure of 0.25 pesticide consumption to crop harvested ratio in Malaysia. In addition, hydroponics systems take up one-fifth of the space required for soil farming systems (Turner, 2009). If 661 hectares of roofspace is utilized for food crop cultivation in Singapore, 3305 hectares of land from neighbouring countries can be freed from agricultural use.

TABLE 2. Average pesticide use in different countries (Abhilash, 2008).

Country	**Weight of pesticides used to weight of crop harvested ratio**
Bangladesh	0.164
Cambodia	0.212
China	0.258
DPR Korea	0.250
India	0.250
Rep. of Korea	0.266
Lao PDR	0.250
Malaysia	0.250
Myanmar	0.250
Nepal	0.250
Pakistan	0.251
Philippines	0.250
Sri Lanka	0.268
Thailand	0.371
Vietnam	0.489

Renewable Energy

Urban farming will offer Singapore a source of biofuel, generated from vegetable crop waste. Biomethanisation[4] facilitates the generation of electri-

[4]Bio methanisation is already practised in Singapore: the waste treatment plant facility has a capacity of processing up to 800 tons of organic waste per day and estimated to generate 6MW of electrical energy per hour, providing enough power for itself and over 10,000 households or equivalent industrial facilities. (Mulchand, 2007; Wong, 2007). The challenges faced by this fledgling industry is the availability of biowaste, which a large scale urban food crop farming can address.

cal power and heat from organic waste. This energy would be a carbon-neutral source for Singapore, which at present relies on the burning of fossil fuels. Waste heat recovered can be directed to industry, contributing to further reduction of green house gas emissions. In addition to power and heat, the process can yield high quality compost that can be as fertilizers for horticulture, enabling a closed nutrient loop in urban farming.

Landscape Opportunities

The collection of rainwater presents landscape opportunities. Ponds can be created within the housing estate as aesthetically pleasing landscape elements. These ponds can serve as central rainwater storage to which surface runoff from the nearby buildings and pavements can be directed, before being channelled to rooftop farms (Figure 3). This offers an opportunity for aquaponics (Diver, 2006), also known as the integration of hydroponics with aquaculture, as the fertile fish-pond water may serve as a valuable resource for vegetable crop cultivation (Fernando, 2000). Organic waste from the vegetable farm can in turn be used as fish feed, whilst water discharge from the hydroponic system can be returned to the ponds.

FIGURE 3. Tampines town precinct study on plan—rainwater harvest and landscape opportunities.

Community Engagement

Crop production within a community can become a potent symbol of the connection between production and consumption, between people and land. It is noteworthy that in Singapore today, this is largely absent. The few existing farms are situated in remote areas on the fringes of community life.

Localised food production could also reinforce bonds within the community. In a recent report on ideas for Singapore, 2009, local practitioners suggested inclusion of ponds and vegetable plots within the public housing estate to spark a community spirit amongst the young and the old (Tay, 2009).

Examples of this already exist, albeit on a small scale. At a community garden in Taman Jurong (Bridge, 2009), several elderly residents have committed to maintaining a small vegetable garden, saying that it offers them an opportunity to be with friends. In another example, residents living near a hydroponics farm come together to cultivate vegetables, herbs and flowers for their own consumption (Hydroponics and Plant Care, 2009).

Roofscapes and Identity

Rooftop farms offer an opportunity for an aesthetically pleasing roofscape to emerge. HDB makes up a very large proportion of the built environment in Singapore; it therefore has a significant impact on the country's skyline. At present, roofs of many HDB blocks are retrofitted with add-on decorative structures (Figure 4). This suggests, firstly, that there is perceived need to define and communicate identity, and secondly, that existing roofs have some built-in capacity to cope with add-on structures. It could be argued here that rooftop farming is one means of identity making, partly due to the presence of new hydroponic structures and greenery, and partly from the type of vegetable they produce (block clusters could for instance be dedicated to tomato cultivation, and be known as such).

Movement and Access

To facilitate an efficient farming, the flow of materials and people must be considered. Farming staff will need dedicated circulation corridors and vertical access for the movement of equipment and produce, to minimise disruption to everyday living. The construction of additional lift cores at each block clus-

FIGURE 4. Example of additional ornamental structures on existing HDB slab blocks.

ter, coupled with block-to-block linkways for movement across the cluster, is one possibility (Figure 5). Past retrofits of HDB estates have shown that new lift cores can be added easily and that it is possible to reconfigure circulation in these estates.

Distribution Hubs

For large-scale crop production, distribution hubs are needed to accommodate storage, packaging, and processing. A review of HDB design guidelines suggests that the multi-storey car park (MSCP) is a possible site for these new hubs.

A MSCP can be found in each existing block cluster, situated less than 30m from blocks it serves (Figure 6). The roofs of the existing MSCPs are reserved for future additional car parking lots (Housing and Development Board, 2006), meaning that structurally, they can be built upon. A lift shaft has provided in the existing MSCPs to cater for future installation of the lift car.

FIGURE 5. Tampines town precinct study on plan—Design strategy of roof linkage between farms.

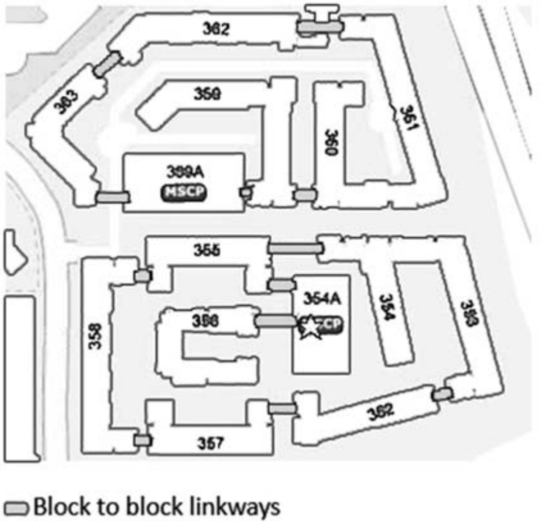
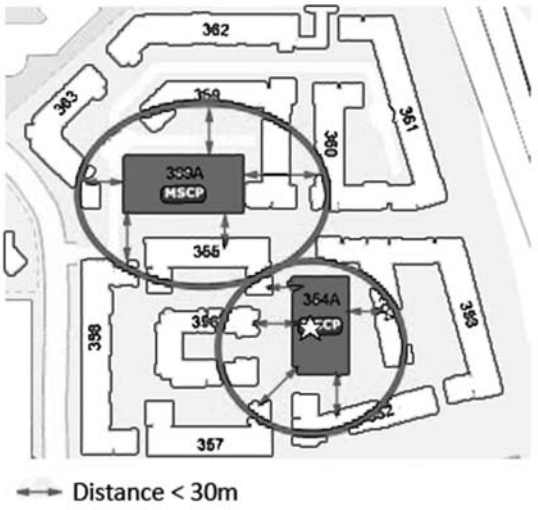


FIGURE 6. Tampines town precinct study on plan—Integration of MSCP as distribution hub.



Policy and Incentives

Any new large-scale infrastructure requires policy support. There is evidence that in Singapore such policies are coming into place. The Urban Redevelopment Authority (URA) and National Parks Board (NParks) for instance have launched a scheme, "Landscaping for Urban Spaces and High-Rises" (LUSH), that seeks to encourage developers to provide greenery on upper floors of high-rise buildings (Chong, 2009). This initiative overlaps with Singapore's Sustainable Development Blueprint target of 50 hectares of sky-rise greenery by 2030. Meanwhile HDB has initiated a pilot project to introduce green roofs on existing multi-storey carparks in some of its estates, such as Sengkang and Punggol (Housing and Development Board, 2007/2008).

CONCLUSION

With current local vegetable production meeting only 5% of Singapore's present-day needs, the prospect of rooftop farming merits serious consideration. This study suggests that such an initiative, if implemented across public housing estates, would increase local production to 35.5%. This would begin to address the issue of food security and reduce the carbon footprint associated with food imports. Other benefits include increased availability of biofuels, health and environmental dividends due to safer farming techniques, the opportunity to remake local identity and encourage community engagement. This study has identified several design constraints and opportunities within the HDB context, for instance the limitation posed by existing block typologies, the potential for rainwater harvesting and modification of existing blocks for new infrastructure.

Singapore has in place policy instruments that recognise the value of building integrated greenery. The prospect of large-scale building integrated agriculture however is the next step to this process, one that requires a quantum leap, beyond quality-of-life drivers, towards a more holistic view of sustainability and ecological footprint.

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