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Urban food production on Sydney CBD rooftops.

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1.0 Introduction

This report, dated 4th November 2014, sets out the progress and findings with regards to the City of Sydney Environmental Grant awarded in November 2013 to Associate Professor Dr Sara Wilkinson and Dr Sumita Ghosh of the School of Built Environment, Faculty of Design Architecture and Building at UTS, Sydney. Section two describes the progress to date which has been achieved in respect of setting up the demonstration garden beds on rooftops. The next section discussed the UTS Staff Student Garden Club and is followed by a summary of the food testing. Thereafter the report describes the calculation of the carbon footprint of the food grown and to measure reductions in stormwater run-off. This also informs the work to model the potential for urban food production in the Sydney CBD and also the modeling of the Sydney CBD's potential for reduction in carbon footprint from rooftop food. Finally section two contains the 'how to' guides for the community. Section three sets out the financial accounts with respect to monies spent from the City of Sydney grant on the various parts of the project. In section four a series of photographs are provided to illustrate the report. The additional and unexpected opportunities that are directly connected to the project are discussed in section five with potential for further work identified. The additional and unexpected opportunities are in the form of research collaborations, educational opportunities and media coverage and tours of the gardens by national and international visitors to Sydney.

The UTS staff involved in this project are as follows;
1. Associate Professor Dr Sara Wilkinson DAB.
2. Dr Sumita Ghosh DAB.
3. Mr Lindsay Page DAB.
4. Dr Fraser Torpy Science.
5. Mr Michael Zavattaro Science.

This report was written by Sara Wilkinson and Mr Lindsay Page, with the exception of sections 2.2 which was written by Dr Fraser Torpy and Mr Michael Zavattaro and section 2.3 written by Dr Sumita Ghosh.

2.0 Demonstration Garden Beds

Six beds have been established in total on three UTS roofs as follows;

GARDEN BED SITES AND TYPES

2.0.1 Gumal Student Housing

This roof is located at 9th floor level on Broadway in Sydney. The roof faces southeast. The roof construction is reinforced concrete with an impervious tiled covering. The roof is designed for access, which made it easily adapted to food production. It has a concrete perimeter wall approximately 1200 mm high 600mm wide and 800 mm deep, which is planted out. There is lift access to level 9. It is exposed to full solar radiation and wind gusts.

The garden bed chosen for this site was a UV resistant recycled plastic raised bed supported on a timber frame trestle. The UV resistant recycled plastic was extremely light, easily assembled and its dimensions were 3300 mm long x 1200 mm wide x 300 mm deep. A 3600 x 1200 mm trestle was constructed from 90 x 45 mm treated pine frames, braced with galvanised strapping tied together using a 90 x 45 mm treated pine rail top and bottom. The frames were prefabricated off site to minimise the noise impact during construction, and for easier transportation. Two sheets of ply 1800 x 1200 mm formed the top of the trestle and supported the plastic framework for the bed. See plates 1 and 2.

Plate 1 Gumal under construction.

Plate 2 Gumal bed planted out November 2013.

A layer of food grade rubber waterproofing membrane, ethylene propylene diene monomer (M-class) rubber (or EPDM) was placed over the timber trestle as weather protection. The plastic pod was positioned on the membrane and a bead of food grade silicone sealed the base of the garden bed and held it in place. At one end a floor drain was installed and sealed with silicone, and using a spirit level and some small plastic wedges, the end of the trestle furthest from the floor drain was raised slightly to facilitate drainage. A layer of 20 mm drainage cell sheeting was placed across the floor of the bed with a layer of geo-textile fabric laid over the drainage cells to keep the soil and plant roots from blocking the drain. A layer of fine gravel 20 mm deep was laid onto the geo-textile fabric, followed by another layer of geo-textile fabric. The bed was divided into two sections for different growing media; one was filled with an organic composted cow poo and garden soil mixture and the other a lightweight engineered substrate with a mixture of coir bark, perlite P400, Canadian peat, 0-8mm composted pine bark, all trace elements, Calcium Nitrate, coarse granular Dolomite, Gypsum, Superphosphate, Zeolite 1-3mm and Magrilime. Both beds were top dressed with a compressed pelletised organic seaweed fertilizer (Seamungus).

These beds were labeled as:

- 1A Full sun with composted cow poo.
- 1B Full sun with engineered substrate.
- 2A Semi shade with composted cow poo.
- 2B Semi shade with engineered substrate.

The beds were planted out with vegetable seedlings and mulched with lucerne hay. Both were fertilised topically fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was applied topically once a month.

2.0.2 Science Roof

This roof is located at 7th floor level on the corner of Harris Street and Thomas Street in Sydney. The roof faces northwest. The roof construction comprises reinforced concrete with an impervious covering. The roof is protected with walled structures approximately three metres high to three sides and a glazed screen to the Thomas Street elevation Two very different beds were constructed at this site, a plastic pond with a reservoir of water in the bottom known as a 'Wicking bed ' and a treated pine timber box elevated to waist height for ease of access.

The Wicking bed derives its name from the fabric that divides the growing medium from the reservoir contained in the bottom of the garden. The geo-textile fabric acts like a wick in an oil lamp and through capillary action allows the soil to obtain moisture at the root zone where it is most needed. The garden is contained in a plastic pond shell obtained from the local hardware store. This bed has a 320 litre capacity and the dimensions are 1500 mm x 750 mm x 300 mm high. The reservoir in the bed is created by laying 100 mm agricultural drainage pipe across the bottom of the pond. A short section of tube is positioned vertically from the bottom of the pond up to the top (in a place where the overflow is visible). This is the filler tube and a section of agricultural pipe is used. A hole, to accommodate a 30 mm threaded tank outlet, is drilled into the pond shell at the height presented by the top of the agricultural pipe, here 100 mm from the base. The outlet has a washer to eliminate leaks. The overflow outlet was located as close as possible to the rooftop drain to minimise the trip hazard created by a hose. A layer of geotextile fabric was placed on top of the agricultural pipe and poked down slightly between random sections of the agricultural pipe to prevent the soil and roots from entering the reservoir and to allow the capillary or wicking action to irrigate the garden bed. Plate 3 shows the bed immediately following planting in December 2013.

Plate 1 Wicking Bed on Science Roof.

The bed was filled with a mixture of soil and compost to a depth of approximately 200 mm. It was top dressed with a compressed pelletised organic seaweed fertiliser (Seamungus). The bed was filled with water through the vertical filler tube until it overflowed from the outlet. It was topped up over two days while the soil conditioned and after this initial phase it was topped up with 30 - 40 litres of water every 6 to eight days. The bed was planted out with vegetable seedlings and then mulched with lucerne hay and fertilised topically fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was applied topically once a month.

Elevated timber garden bed

This garden bed was built from 100 x 100 mm treated pine posts and 150 x 45 mm rails, constructed around a standard size 1200 x 1800 x 19mm form ply sheet. A heavy duty plastic membrane separates the growing medium from the treated pine container which prevents contamination of the soil and plants, retards the decay of the timber, and also enables the excess water to be drained away or recycled via a 30mm threaded tank outlet, thus preventing staining of the roof surface. A layer of 20mm drainage cell sheeting was positioned on the base of the bed with a perforated container covering the drain hole to prevent clogging. A layer of geo textile fabric was placed over the cells. The bed was filled almost to the top with a lightweight substrate composed of crushed brick, scoria, coco fibre and pine bark.

This was topped with a 20mm layer of garden soil to enable the seedlings to take root. The bed was planted out with vegetable seedlings and mulched with lucerne hay and fertilized with a slow release chemical fertilizer (Osmocote). This garden was also fertilised topically fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was applied topically once a month. See plate 4.

Plate 4: Raised timber bed Science roof December 2013.

2.0.3 DAB Vertical Gardens.

This roof is located at 5th floor level on Harris Street in Sydney. The roof faces North West. The roof construction comprises reinforced concrete with an impervious tiled covering. The roof is designed for access and has a concrete parapet wall approximately 1200 mm high and 200 mm deep to one side. Two sides are flanked by buildings which rise to a height of 7 floors and 20 floors. The remaining edge has a metal framed glazed fence and over looks an internal courtyard at fourth floor level. The roof is enclosed on all sides by tall buildings. In summer months, when the sun is high there are around six hours of direct sunlight on the roof, however in winter months there is minimal direct sun. Furthermore the buildings do encourage very high wind levels at times. There is lift access to level 5 however there are steps out onto the roof terrace area which made transportation less easy. The garden beds used on this site were supplied by V Gardens in Sydney. The beds have a timber frame and a large base bed with a series of metal framed horizontal trays to a height of 1600 mm. The horizontal trays are approximately 150 mm deep. One bed has a self-watering system on a 12 volt timer which utilises a submersible 12 volt pump and drippers. It is powered by a battery which is recharged by photovoltaic cells and the sun. The reservoir at the base of the garden houses the submersible pump and acts as a wicking bed for the lowest garden. The second bed is identical in design apart from the irrigation system and wicking bed. See plates 5. These beds were planted with a variety of herbs including basil, mint, chillies, oregano and vegetables such as lettuce, eggplants, silverbeet, and capsicums.

Plate 5: V Gardens on DAB Level 5 roof planted out December 2013.

2.1 Garden Bed Performance

2.1.1 Gumal student housing building

As noted above in section 2.0.1 these beds were labelled:

- 1A Full sun with composted cow poo.
- 1B Full sun with engineered substrate.
- 2A Semi shade with composted cow poo.
- 2B Semi shade with engineered substrate.

The 2 beds on level 9 of the Gumal housing building displayed different characteristics seasonally and also required different watering regimes.

Bed 1A (compost/cowpoo) which was predominantly in full sun throughout the day performed much better overall in the winter months. It also required the most watering. The broccoli formed flowering heads quite early and after the main flowering heads, which averaged 300 grams, were cut, a steady supply of offshoot flowering clusters. The cabbages in this bed were also robust and the largest weighed in at 1.5 kgs. There was a slug problem which had to be attended to by hand on a regular basis. The cauliflowers suffered from an aphid infestation which was treated with a spray made from garlic and hot chilli. The spray dispersed the predators, however the cauliflower's were very small and disappointing. The celery was robust but at harvest time it was discovered that slugs had made snacking trails up and down the inner stalks which gave it an unsightly appearance. Overall the other vegetables produced a reasonable return except for the beetroots, which may have been stressed from being root bound at the transplant stage.

Bed 1B was also in full sun. In this bed and bed 2B we tested an engineered lightweight substrate which was predominantly coco peat, coir and perlite. This growing medium had no inherent nutrients as such and so the plants were very reliant on the organic fertilisers. These vegetables were much less impressive in general except the rocket and marigolds both of which thrived. Also, all of the Brassicas in this bed suffered from insect attack. They were also randomly assaulted by Cockatoos, although the damage was never significant. It is worth noting that the engineered substrate on Bed 1B required substantially less watering and this is possibly due to the water retention of the coco fibre component.

The vegetables grown in semi shade in Beds 2A and B were quite healthy although they grew to a smaller scale, presumably a sunlight factor. Slugs were more active on this shaded bed as were the aphids. The lettuce and rocket went to seed extremely quickly on these beds which may also be attributable to the availability of sunlight. Once again, the food grown in composted cow poo produced more.

The Gumal beds on level 9 from July to November 2013 contained broccoli, cabbage, cauliflower, rocket, lettuce, onions, silverbeet, beetroot, mizuna, basil and marigolds. During the summer months (and it was another record breaking summer heat wise) there was a very different result. Several weeks after planting out these gardens in early November 2013 we experienced a number of days of substantial deluge and the drains in our garden beds had become blocked. This was causing the soil to remain waterlogged and anaerobic which was having an adverse affect on growth in the young plants (except the lettuce). After this was discovered and rectified, everything sped up remarkably and we harvested the first lettuce and the first tomatoes after only 4 weeks. We harvested some picture perfect Cos lettuce at week 6. Then, as summer progressed we suffered a couple of record breaking heat waves and we recorded temperatures of up to 38 degrees, and some days of very extreme wind. Between the 22nd and 30th December, all the leafy vegetables were very stressed and the lettuce and silverbeet grown in full sun (Beds 1A and B) were badly sunburnt and wind damaged. It could easily be described as a very hostile growing environment. Overall the vegetables grown in semi-shade and composted cow poo (Bed 2A) produced the best results. The shallots did very well, but the Zuchini did not grow well at all. They suffered from a powdery mildew and the fruit kept falling off before maturing. The eggplants were prolific but were a poor choice for a small garden project, because of their substantial girth. The beans, the whole plant in fact, proved to be popular with the cockatoos; as were the tomatoes and marigold flowers. The gardens in full sun required substantially more watering.

The Gumal beds on level 9 from November 2013 till March 2014 contained: lettuce, rocket, silverbeet, beetroot, shallots, eggplant, zucchini, beans, chilli, capsicum, carrots, tomatoes, mizuna, basil and marigolds.

In March 2014 all beds were dug up re-fertilised and replanted with: broccoli, cabbage, pak choy, celery, radicchio and silverbeet. The beds had now begun to germinate their own seedlings from prior plantings let go to seed heads. We had self-germinating tomatoes producing fruit in the middle of June 2013, which seemed incongruous for Sydney. In August 2013 the beds were dug up re-fertilised and replanted with lettuce, radish, silverbeet, kale, tomatoes, pak choy and mizuna. The pak choy and mizuna went to seed extremely quickly and the radishes were table ready within 3 weeks of transplanting. The addition of pelletised organic manures and the digging through of the lucerne mulch each time the gardens were replanted had the effect of enriching the engineered substrate in 1B and 2B and so subsequent plantings became more successful. It was observed that these beds didn't suffer from compaction or hydrophobia, whereas the soil (composted cow poo) in the other beds, over the 12 month period diminished in height/volume by more than a third. Bed 1A which was in the full sun 9 stories up during summer became hard and compacted and when occasionally left too long between watering, the soil became water repellant. We anticipate that this will result in additional garden soil being required within 18 months owing to the fact that there was only 200 mm depth of growing medium at the start of this project.

The water consumption of these gardens was measured by means of a flow meter which connected between the tap and the hose. After prolonged pluvial events, the 90 litre tubs placed under the beds (see stormwater mitigation section) were emptied back onto the garden beds, or recycled, which had a significant impact on the amount of reticulated water consumed.

Water consumption recorded:

- Gumal bed 1 A = 966 litres over 389 days = 3.4 Litres/day
- Gumal bed 1 B = 802 litres over 389 days = 2 Litres/day
- Gumal bed 2 A = 925 litres over 389 days = 2.3 Litres/day
- Gumal bed 2 B = 767 litres over 389 days = 1.9 Litres/day

2.1.2 Science Building

The two beds on the science building Level 7 had a similar story through the summer months although they suffered less stress because their water supply was constant. The 'wicking' bed with compost and soil performed extremely well. The lettuce matured early and was quite sweet in taste and I suspect it may have something to do with never becoming water stressed. The zucchini was a failure again due to powdery mildew. The eggplant took up too much room and overcrowded the lettuce and beets. The rocket, basil and chillies all thrived. During the heatwave the leafy greens were all burnt but there was less wind damage due to the relatively sheltered site.

The raised timber bed utilized a lightweight green roof substrate with a large crushed brick and scoria component. It was fertilized with a pelletised organic seaweed product (Seamungus) and a slow release chemical fertilizer (Osmocote). The bed was watered 3 minutes daily with a sprinkler system on a timer. Given the paucity of anything nutritious in the substrate, it was surprising as to how well the vegetables grew. Obviously none of the root vegetables flourished due to the inhospitable substrate but the eggplants, chillies and rocket did extremely well and the zucchini outperformed all the other gardens.

Science building beds on level 7 from December 2013 till February 2014 contained eggplant, zucchini, rocket, basil, carrots, lettuce, chilli, silverbeet, beetroot and marigolds. In March 2014 both beds were dug up re-fertilised and replanted with broccoli, cabbage, pak choy, celery, radicchio and silverbeet. The beds were replenished with the same vegetables in late May 2014 after the majority were taken for testing. In early August 2014 all beds were dug up, fertilized and replanted with: kale, mizuna, pak choy, lettuce, silverbeet, beans, radishes and tomatoes. The water consumption of these two beds was recorded over a 6 week period in peak summer as follws;

- Wicking bed = 285 or 6 litres daily.
- Raised timber bed = 399 or approx. 9.5 litres daily.

The timber raised data is approximated because the bed was irrigated by a sprinkler on a timer and there was obviously an amount of water loss by errant spray not landing in the catchment and the sprinkler was still in use during periods of rainfall.

2.1.3 DAB Vertical Gardens

The vertical gardens on Level 5 of the DAB faculty were planted and replanted at similar intervals as the other vegetable gardens typically with basil, silverbeet, eggplant, marigolds, celery and assorted edible flowers. The vegetables that weren't taken for testing were picked by staff regularly as the gardens were located near the staff kitchen. Except during the record breaking heatwaves in December 2013 and January 2014, when all gardens suffered heat stress and casualties, these gardens were a lot more successful in the summer months when there was more sunlight available. During the winter months the shadowing of surrounding buildings curtailed growth. No water consumption data was recorded as these beds were maintained in an ad hoc manner by the DAB staff.

All the garden beds, when planted with fresh seedlings, were mulched with Lucerne straw and fertilized with pelletised seaweed (Seamungus). A tonic of Seasol was also applied at this stage. Every several weeks a topical application of fish emulsion and or worm tea was applied. The gardens were weeded by hand and no chemical herbicides or pesticides were used.

Of all the rooftop garden beds, the wicking bed on building 4 level 7 was consistently the most successful, easily maintained and bountiful.

2.2 Testing food grown for pollutants and contaminants.

Substantial changes to both urban and metropolitan areas in most developed countries have resulted from an exponential growth in population density; with urban sprawl as a byproduct. This has produced developing concerns over long-term sustainability and food security, with urban agriculture increasing in popularity as an alternate means of food production. This rise of Australia's population has led to an expansion of urbanisation onto critically important agricultural land, with urban sprawl deemed as a primary cause of farmland deprivation (Brown et al. 2005; del Mar Lopez et al. 2004; Hart 2004). Government bodies such as the City of Sydney Council have garnered interest into researching and developing urban farms within metropolitan and urban areas. Given the densely populated and often industrial nature of urban areas, the threat of heavy metal contamination from anthropogenic processes within these city areas is largely unknown.

Environmental contaminates are often highly hazardous materials that can be found within any environment (Feleafel and Mirdad, 2013). Many of the more common contaminates are derived from anthropogenic processes brought on by industrialization. Different pollutants can have their own characteristic effects on plants, animals and humans, and heavy metals are one such common contaminate that is consistently at the fore front of eco-toxicological and phytoremediation studies. One such example is lead (Pb), a well-known and documented heavy metal that is commonly found deposited within soil and water sources, and is a health concern due to its persistence within the environment. Heavy metals have been found to bio-accumulate at the cellular level within susceptible organisms (Feleafel and Mirdad, 2013).

Heavy metals pose a risk for the future development and acceptance of urban farms if crops bio-accumulate heavy metals to a concentration greater than the Australia New Zealand Food Standards Code (ANZFSC). Therefore, the current preliminary study screened several urban food crops grown within the Sydney CBD for the bioaccumulation of lead. It should be noted that this was a preliminary study and further research is required to obtain results that can be generalized with greater confidence.

2.2.1 Experimental design and methodology

This experiment was designed as a pilot manipulative field experiment. The first sample site was situated on an outdoor rooftop of a residential apartment (Gumal student housing, University of Technology, Sydney). The second sample site was on top of the UTS faculty of Science building, and the final sample site was located in the faculty of Design, Architecture and Building (DAB) courtyard. Each sample site was exposed to outdoor climatic conditions during the entirety of the experiment. Both growing substrate and crops varied between sample sites.

Crops, substrate and lucerne mulch were collected and tested for lead after an initial crop in July 2013, and a second crop in June 2014. Seasol and fish emulsions were used on the 2013 and 2014 crops at both Gumal and the Science Faculty building bed locations in an attempt to increase crop growth rate. As a result, the Seasol and fish emulsions used were also analysed for the presence of lead along with the residential housing rooftop tap water, rain water and the drained bed water.

For further detail into the setup of the UTS faculty of Science roof sample site beds, residential housing Gumal sample site beds and the DAB faculty sample site beds, see 2.1.1, 2.1.2 and 2.1.3 respectively of this report.

Each vegetable that was collected from the sample site was finely sliced and weighed accurately into 1 g samples. The samples were then washed with 20 mL of ultra-pure water and shaken for 30 seconds with a Griffen Flask Shaker on a medium setting. This water was then poured into 50 mL Falcon tubes and were analysed as 'washing' samples. The washed vegetable samples were then processed with a non-metallic kitchen grater and extracted with 10 mL of 2% nitric acid for 20 minutes on a flask shaker before dilution to 20 mL with ultra-pure water.

The samples were then centrifuged with a Scanspeed 1580R Refrigerated Centrifuge at 20°C and 4000 RPM for 5 minutes. Following centrifugation, the samples were filtered into new tubes through MicroScience MS 4HA Quantitative Hardened Ashless Filter Paper as preparation for Microwave-Plasma Atomic Emission Spectrometric (MP-AES) analysis.

The soil substrates from each of the sample site beds were sampled via a composite means, where 10–15 small samples were collected from each bed, mixed thoroughly and analytical samples taken from the combined sample.. Each substrate was suspended in 10 mL of 2% nitric acid then diluted to 20 mL with ultra-pure water and shaken for 20 minutes with a Griffen Flask Shaker on a medium setting. The substrate samples were then centrifuged and filtered as previously described.

The Seasol and a fish emulsion fertilizers were used on the 2014 crops at both the Gumal and Science Faculty building bed locations. 1 mL of Seasol and fish emulsion were sampled and diluted with ultra pure water by 1:1000. The fertilizer samples were then mixed with 10 mL of 2 % nitric acid and diluted to 20 mL with ultra-pure water. The fertilizer samples were then centrifuged and filtered as described previously.

The Gumal rooftop tap water, rain water and plant bed drainage water were also analysed for lead. 1 mL of each water sample type was extracted with 10 mL of 2 % nitric acid diluted to 20 mL with ultra pure water and centrifuged and filtered as above.

Samples were analysed for lead using an Agilent 4100 Microwave-Plasma Atomic Emission Spectrometer (MP-AES). A rational calibration fit was used for lead at an analyte wavelength of 217 nm with a 20% calibration error for lead.

Software used for data management and analysis were the propriety Agilent 4100 MP-AES analysis program and Microsoft Excel 2010 for Windows 7 (Microsoft Corporation, US).

2.2.2 Heavy metal analysis results

The results shown in Table 1 indicate that there were significant lead levels found within the initial samples collected in 2013. Of particular significance are the lucerne mulch, compost soil mix and the engineered substrate within the Gumal sample beds. These substrates tested positive for trace amounts of lead with lucerne mulch bed 1 having 0.12 mg/kg, bed 2; 0.10 mg/kg, compost soil mix bed 1; 0.09 mg/kg, bed 2; 0.36 mg/kg, engineered substrate bed 1 to have 0.21 mg/kg and bed 2; 0.21 mg/kg. Whereas the brick mixture and the vegetable and herb mix used on the Science rooftop, along with the soil vegetable and herb mix at DAB were all found to have no trace lead levels within the tested samples in any of the beds.

Table 1: The initial average lead concentration collected from samples in 2013 and analysed via MP-AES in the 5 different substrate types, tap and rain water, and the Seasol and fish emulsion fertilisers at each site.
+Mixture contains coir bark, perlite P400, Canadian peat, 0-8 mm composted pine bark, all trace elements, calcium nitrate, coarse granular dolomite, gypsum, superphosphate, zeolite 1-3 mm and magrilime.

The average lead concentration of the different water sources were analysed between the Gumal and Science rooftop sites as seen in Table 2. The rain water collected at either site was not found to have any lead, however the tap water at Gumal had 0.02 mg/kg of lead in the sample. It should be noted that the tap water used to water the Science beds derived from the rain water tank, therefore one can ascertain the lack of lead within the rain tank water will also be present within the tap water. The Seasol fertiliser had an average lead concentration of 0.01 mg/kg of lead whereas the fish emulsion had no detectable lead levels. Whilst these results suggest the

Initial 2013 Substrate Heavy Metal Analysis

	Type	Site	Bed	Average Lead Concentration (mg/kg)
Substrate	Lucerne mulch	Gumal	1	0.12
			2	0.10
	Compost soil mix	Gumal	1	0.09
			2	0.36
	Engineered substrate	Gumal	1	0.21
			2	0.21
	Brick mix^{+}	Science	1	0.00
	Vegetable herb mix		2	0.00
	Vegetable herb mix	DAB	1	0.00
			2	0.00
Water	Tap water	Gumal		0.02
	Rain water			0.00
	Tap water	Science		0.00
	Rain water			0.00
Fertiliser	Seasol			0.01
	Fish emulsion			0.00

safety of these common fertilisers as far as lead is concerned, it should be noted that these findings came from a very small sample size that is not representative to all Seasol and fish emulsion fertilisers. Systematic sampling from a number of sources is required before the heavy metal safety of any fertilizer can be concluded with confidence.

The results shown in Table 2 indicate that there were no detected lead levels found within the substrate samples collected and analysed in 2014 in any of the beds. The only detected levels of lead in the 2014 substrate analysis were found in the drained water from bed 1, at an average lead concentration of 0.02 mg/kg. In contrast, bed 2 had no detected levels of lead in the drained bed water. It should be noted that the source of lead could have derived from rainwater, tap water, Seasol and/or fish emulsion, or as a residual contaminate from the soil. As in the case of this trial experiment, the fertilisers, rainwater and tap water had a sample size of one.

Table 2: The final average lead concentration collected from samples in 2014 and analysed via MP-AES in the 5 different substrate types and drained bed water of the Gumal, Science and DAB sites.

Final 2014 Substrate Heavy Metal Analysis

	Type	**Site**	**Bed**	**Average Lead Concentration (mg/kg)**
Substrate	Lucerne mulch	Gumal	1	0.00
			2	0.00
	Compost soil mix	Gumal	1	0.00
			2	0.00
	Engineered substrate	Gumal	1	0.00
			2	0.00
	Brick mix	Science	1	0.00
	Vegetable herb mix		2	0.00
	Vegetable herb mix	DAB	1	0.00
			2	0.00
Water	Drained bed water	Gumal	1	0.02
			2	0.00

Table 3 shows the beetroot, cabbage, cauliflower, celery, Chinese cabbage and rocket lead concentrations per bed within the plant at a cellular level and on the outer surface of the plants' edible segment of 2013 and 2014 crops. It should be noted that the samples originally analysed in 2013 were re-analysed in 2014 and their results were averaged between the two. The ANZFSC has outlined a safe consumption limit for edible crops; 0.3 mg/kg for brassicas, 0.2 mg/kg for cereals, pulses and legumes, and 0.1 mg/kg for vegetables excluding brassicas. The initial 2013

Table 3: The average initial and final lead concentrations at the Gumal, Science and DAB sample sites for analysis years 2013 and 2014 between beds 1 and 2. The initial plants used at the 2013 Gumal site was beetroot, cabbage, cauliflower, celery, Chinese cabbage and rocket. The 2014 Science site consisted of eggplant, beetroot, lettuce and basil whereas the DAB site consisted of basil, spinach and celery. The vegetables are compared between the different plant areas (within and the outer surface) of each bed.

Gumal lead levels within all crops were found to be higher than the ANZFSC limit. The highest recorded lead level was found to be 21.22 mg/kg on the outer surface of the celery planted in bed 1. The highest lead level within a plant was 13.16 mg/kg in bed 2 of rocket.

The average lead concentration per bed for crops grown at the Science rooftop and DAB rooftop in 2014 were all found to be below detection limits. This reflects the substrate lead content that also was found to be zero in the Science and DAB sample sites.

		Initial 2013 Heavy Metal Vegetable Analysis		
Location	**Bed**	**Plant Type**	**Plant Area**	**Average Lead Concentration (mg/kg) Per Bed**
Gumal	1	Beetroot	Within plant	0.80
	2	Beetroot	Within plant	1.32
	1	Beetroot	Outer surface	4.21
	2	Beetroot	Outer surface	1.78
	1	Cabbage	Within plant	4.76
	2	Cabbage	Within plant	0.91
	1	Cabbage	Outer surface	0.24
	2	Cabbage	Outer surface	0.20
	1	Cauliflower	Within plant	2.52
	2	Cauliflower	Within plant	2.25
	1	Cauliflower	Outer surface	6.86
	2	Cauliflower	Outer surface	0.00
	1	Celery	Within plant	0.30
	2	Celery	Within plant	0.23
	1	Celery	Outer surface	21.22
	2	Celery	Outer surface	2.89
	1	Chinese Cabbage	Within plant	2.52
	1	Chinese Cabbage	Outer surface	0.48
	1	Rocket	Within Plant	3.28
	2	Rocket	Within Plant	13.16
	1	Rocket	Outer surface	5.05
	2	Rocket	Outer surface	8.41

		Final 2014 Heavy Metal Vegetable Analysis		
Location	**Bed**	**Plant Type**	**Plant Area**	**Average Lead Concentration**

				(mg/kg) Per Bed
Science	1	Eggplant	Outer surface	0.00
	2	Eggplant	Outer surface	0.00
	1	Eggplant	Within	0.00
	2	Eggplant	Within	0.00
	1	Beetroot	Outer surface	0.00
	1	Beetroot	Outer surface	0.00
	1	Beetroot	Within	0.00
	1	Beetroot	Within	0.00
	1	Lettuce	Outer surface	0.00
	2	Lettuce	Outer surface	0.00
	1	Lettuce	Within	0.00
	2	Lettuce	Within	0.00
	1	Basil	Outer surface	0.00
	2	Basil	Outer surface	0.00
	1	Basil	Within	0.00
	2	Basil	Within	0.00

Location	Bed	Plant Type	Plant Area	Average Lead Concentration (mg/kg) Per Bed
DAB	1	Basil	Outer surface	0.00
	2	Basil	Outer surface	0.00
	1	Basil	Within	0.00
	2	Basil	Within	0.00
	1	Spinach	Outer surface	0.00
	2	Spinach	Outer surface	0.00
	1	Spinach	Within	0.00
	2	Spinach	Within	0.00

1	Celery	Outer surface	0.00
2	Celery	Outer surface	0.00
1	Celery	Within	0.00
2	Celery	Within	0.00

2.2.3 Conclusion on testing

Whilst the heavy metal concentrations found within and on the surface of the plants in this study are not definitive results, it is likely that the initial vegetable crops effectively phytoremediated the soil, thereby removing possible trace concentrations of lead from the substrates and accumulated it within the plants. If a commercialized variant of urban farming were to be adopted in the future, it could become common practice to treat the first crop harvest as a sacrificial phytoremediator then subsequent crops can be treated as consumer ready thereafter. However, it is of utmost importance that the possibility of a sacrificial phytoremediator be explored and experimented further before considered to be common practice. It is also clear that there was substantial variability amongst samples; unfortunately the small sample size available for this work was inadequate to accurately attribute high lead concentrations to any specific component of the gardens, although the substrate appears most likely as the primary source.

It is difficult to determine whether the lead found within the lucerne, soil and compost mixture, and engineered substrate may have originated from, as it is unknown where these different types of commercially available substrates were originally collected from prior to the introduction onto the consumer market. Furthermore, systematic sampling from a number of sources is required before the heavy metal safety of the substrates used at each site can be concluded with confidence. It is of interest that the brick mixture made up of a heterogeneous mixture of coir bark, perlite P400, Canadian peat, 0–8 mm composted pine bark, all trace elements, calcium nitrate, coarse granular dolomite, gypsum, superphosphate, zeolite 1-3 mm and magrilime, was found to have no trace concentrations of lead. Many of the brick mixture's constituents can be considered as a waste material that could be expected to have a lead concentration. One such explanation for the lack of lead contaminate is the absence of substrate replication, thereby not providing an reliable representation of heavy metal contaminates within the brick mixture. It is also important to note that different types of substrates were used between the three sites. Therefore it is difficult to ascertain whether the lucerne, soil and compost mixture and the engineered substrate initially used at Gumal would have a higher or lower lead concentration if implemented at the other two sample sites. Likewise, the substrates used at the Science rooftop and DAB courtyard rooftop along with same the types of beds should be replicated at different sites in order to provide a more reliable indication on whether those substrates will have an alternate lead concentration. Similarly, insufficient samples of fertilizer and water were available to confidently demonstrate their safety.

It is recommended in future studies that a procedural sampling approach be adopted that analyses al components of urban farms over a long period of time, with significant spatial replication. The study by Lawson and Mason (2001) collected weekly wet deposition and throughfall rain samples and analysed the samples for total lead amongst other commonly found heavy metal contaminates. As a result, they found comparable lead concentrations to those measured in the region of study. It is particularly important that rain samples be collected and analysed over a period time as the dynamic atmospheric conditions may alter lead concentrations in the water. A more accurate representation of heavy metal presence would be to analyse rainwater that was collected initially then systematically thereafter. This could have illustrated a trend of lead concentrations within rainwater over the course of the study, thereby showing any subsequent lead concentration changes over a period of time. As far as we can conclude from our results, however, it appears that rainwater is not a likely source of significant quantities of lead.

The general conclusion to be drawn from this pilot experiment is that there may be considerable quantities of lead present in vegetable gardens planted in new substrates within city limits. It also appears that this lead may be substantially removed by planting a sacrificial first crop. We thus propose that an expanded survey be made of urban farming materials to determine whether they pose a real health risk to urban farmers. This trial study has provided a sound pathway for future experiments that should consist of multiple garden beds scattered around multiple locations within Sydney's metropolitan area.

2.3 UTS Staff Student Garden Club

This part of the qualitative research aims to understand aspirations and motivations of members of UTS Gardening Club in growing food in a garden space located on the rooftop of Gumul Student Housing building at UTS in Sydney CBD. It focuses on outlining what are probable expectations and satisfactions of members at an early stage of the garden and how that could guide participation and management in an educational institutional setting.

Semi-structured interviews based on a carefully designed questionnaire survey with a total of seventeen questions were conducted with the UTS Gardening Club members. Survey questionnaire, consent form and information sheet are attached at the appendix no 1. Ethics approval from UTS Human Resource Ethics Committee (HREC) was sought prior to conducting interviews. The maximum duration of the interviews ranged between thirty to forty minutes. At the initial stage of setting up the rooftop garden, a total of eight interviews were conducted after obtaining consents from the respondents.

2.3.1 Research outcomes

2.3.1.1 Previous experience in growing food

Half of the respondents came from families who grew vegetables and interestingly the other half, did not come from families who had any experience in growing vegetables. 75% of the respondents had previous experience in growing food and ranged from fairly extensive experience as a keen gardener to a basic gardener. The participants have and had been growing herbs, indigenous plants, flowers and different types of vegetables and fruits in local and overseas conditions. Previous experience in growing food was linked through parents to grandparents at an intra-generational level but also at inter-generational level to friends, colleagues and families in other community gardens and food production spaces. Only 25% did not have any previous experience in growing food in any types of gardening spaces.

2.3.1.2 Motivations to growing food

There are different motivations to joining the UTS roof top garden club. Two types of motivational aspects: *personal* and *professional* are important for joining the UTS Gardening Club.

The *personal* motivations include: learning new gardening techniques, sharing and enhancing individual knowledge; meeting people and making friends; harvesting good quality and nutritious food; doing physical exercise; getting out of the office to an outdoor place and relaxing with nature, natural light and fresh air and engaging with immense joy and happiness associated with growing food. There are lack of growing spaces for residents of inner city Sydney living in apartments and smaller residences due significant compact nature of urban form. The rooftop garden acted as a magnet as it provides the residents access to a valuable space for growing food. Other important motivations is commitment to adopt sustainable lifestyle practices such as worm farming, carbon footprint reduction in growing own food and onsite composting etc. As these are possible on a rooftop garden in a dense urban setting, the rooftop garden has become a suitable place to translate thoughts into reality. Some of the respondents have very good knowledge of permaculture principles and practices. This knowledge has motivated them to consider the rooftop garden as a useful platform for incorporating those principles within their daily life practices. Cultural reflections and memories of growing food connect to distant and local homelands; food efficient settlement planning; associations of community and individuals with food production. Dreams and aspirations to regenerate those memories and identities locally resonated through the voices of respondents.

At an institutional level, the *professional* motivations include: utilising the roof garden as *'a catalyst'* and *'neutral space'* for people engagement within the university; generating sustainability awareness within staff and student community; creating new contacts and professional linkages in an informal way and observing the process how the roof top garden connects to wider social change. Potential contributions of the garden towards improving health, wellbeing and satisfactions even when a short time spent by staff and students away from desk in the garden are considered highly beneficial. Growing food in UTS rooftop garden is considered as an excellent process for establishing a well-knit working community. Location of the garden in the workplace is seen as meaningful, convenient and positive as this requires reasonably shorter time commitment and brings together and allows interactions with colleagues and students from very various parts of the university which is otherwise unlikely.

Growing own food, learning and sharing knowledge and creating a connected community and identity are most important motivations to join this rooftop garden club.

2.3.1.3 Expectations, satisfaction and influences.

There are huge expectations from UTS Gardening Club members as to what they would like to grow on the rooftop garden. The UTS Gardening Club members aspire to grow vegetables, fruits, indigenous edible plants (e.g. warrigal greens) and medicinal herbs which are responsive and well adjusted to the seasonal micro climate variability, sunlight access and wind surges on the rooftops. Some of the choices of vegetables and fruits are: green leafy vegetables (like lettuce), tomatoes, eggplants, sweet potatoes, zucchini, cucumber, green beans, corn, squash, pumpkin and all year round vegetables (e.g. cabbage and brassica), strawberries, lemon and some tropical fruits such as papaya. The culinary herbs include: thyme, rosemary, basil, oregano, sage, parsley, coriander, marjoram or deal and fennel and some medicinal plants such as chamomile and turmeric. Herbs are viewed to be more appropriate to grow on the roof top as more expensive to buy than vegetables. Hairloom varieties of vegetables are preferred to hybrid and normal varieties. Suggestions to include easy growing flowers such as nasturtium for aesthetic values and for attracting bees and butterflies and specially marigold flower for its soil composition improvement potential and medicinal values on the roof top garden. Exotic vegetables, okra, cucumber and eggplant were suggested by students coming from multicultural backgrounds.

Only 13% of the respondents did not know anyone in the Club but rest 87% per cent knew someone in this UTS Gardening Club which is an important influencing factor to join. A total of 25% of all the respondents did not know anyone from other garden clubs. Rest 75% of all the respondents had known a number of people from other gardening clubs and community gardens. 33% out of these 75% respondents did have a negative experience in other garden clubs but that did not influence their decisions to join this rooftop garden club. 67% of respondents out of these 75% respondents who had a positive experience are influenced by their friends and colleagues and families from other garden clubs and gardens to join this rooftop garden club.

2.3.1.4 Time Commitment

Potential time commitment for growing food on the roof top garden varies from couple of hours per fortnight up to five hours per fortnight. Some members are enthusiastic to commit a couple of hours per week on a regular basis. Some of the access issues are reported as the garden club is located on the student housing and requires security card to access. This is one of the limiting factors to engage in gardening activities in this rooftop garden. When the garden was set up initially and at the time of conducting interviews, the food grown on the roof top garden could be harvested only by the students living in that housing and other garden members who devoted their time could not harvest the food. This was one of the major constraints which came up very frequently in the interviews with the UTS Gardening Club members. It is important to mention that this control was applied at the initial stage of setting up this garden to encourage more students to be involved and harvest food grown on the rooftop garden. This restriction has been lifted now and both UTS Gardening Club members and students are free to harvest the food grown on this rooftop garden. However, these views show that ability to harvest grown food is an important driver in encouraging people to participate in the rooftop garden. In addition to these, there are difficulties in maintaining and watering the plants in an intuitional rooftop garden due to significant changes in time commitments during vacation time and end of and early in the year.

2.3.1.5 Management and financial contributions

Management of the garden ideas include: regular planning meetings, allocation of responsibilities to different members according to their expertise and someone within the garden members with a very good experience to take a leadership role to make decisions. Also there should be clarity around how decisions are made; the principles that underpin those decisions and consultations and consensus of all members are important. Strategies should be developed to address various challenges in different phases of a roof top garden. Organizing different tasks such as management of garden beds; solving land tenure issues; provide guidance on how to grow different plants; promote whole hearted participation; access to garden and freedom to grow various produces according to personal choices and sharing experiences through events are vital parts of overall management of the garden.

Some respondents thought small financial contributions would be fine for participating in the garden club while others thought it would be better to keep this participation free of financial contributions as it could lead to problems and hard for some students to contribute. A suggestion was made that the university should take the responsibility to finance this unique initiative. Costs could be minimized by creating seed banks from which seedlings could be grown, bringing plants from home, using fertilizer/worm tea from worm farms which would keep the contributions down to a few dollars in a month. Members could volunteer to donate more time which could waive a part of their financial contribution to the garden fund.

In summary, the garden members' key expectation is that UTS Gardening Club on the rooftop would become a pioneering model of social change in Sydney CBD. UTS Gardening Club members aspire to achieve this through sharing knowledge, creating a well-knit informal university community; providing opportunities for education and training; understanding practicalities of growing food, offering easy access to growing own food in workplace; organising efficient rooftop garden management and extending this initiative to the surrounding communities in inner city Sydney.

2.4 Calculating the carbon footprint of food grown on demonstration beds.

Currently, fresh food consumed in cities is trucked great distances. It has been estimated that the cost of transport of a $1 supermarket lettuce head is around 40 cents (Midmore, 2011). Using the Australian Greenhouse Office (AGO) Factors and Methods Workbook it is possible to calculate that a diesel-powered truck (manufactured post 2004) with an average carrying capacity of 24 tonnes has an average fuel consumption of 2.10 Km/litre and average CO^2 emissions of 42.8 kg/tonne. The University of Queensland conducted a 'lifecycle assessment study' of lettuce using a technique approved in 1998 by Standards Australia (Kershaw, 2008). It concluded that to transport a 1kg lettuce would create 0.0005 kg CO^2emissions/kg lettuce/km.

Initially it was intended that the carbon footprint of growing vegetables in our demonstration rooftop gardens might be easily calculable by keeping a log of trips made to and from the gardens, however, once the gardens had been constructed, except for the several replantings, almost all journeys over the 389 days to date, were made by pushbike and by walking. There were obviously elevator rides, and a log was kept, but as a conceptual model of urban rooftop farming, where it is assumed the food would be consumed in situ, this seems somewhat irrelevant because if the gardens were being maintained by residents of the building, then those elevator rides would be incorporated into a daily routine anyway regardless of whether there was a rooftop garden or not.

However, this almost zero carbon output can be compared to the carbon footprint calculations of a commercially grown foodstuff which is trucked from a market garden/farm to a depot, from a depot to a retailer and then once purchased it is transported to a residence, quite often by car, train or bus. The Australian Greenhouse Office calculates petrol as producing 2.7 kilograms of greenhouse gas (GHG) emissions per litre combusted, and it calculates diesel as producing 2.9 kilograms of greenhouse gas emissions per litre combusted. If an average inner city car consumes 8 litres/100 kms (or 12.5 kms per litre) and a typical short round trip from home to purchase vegetables of 6 kms is assumed, then approximately 1.296 – 1.392 kilograms of GHG emissions is produced per trip. Based on a weekly shopping trip, total transport GHG emissions are 67.392 - 72.384 kgs of GHG emissions per annum. It is also worth noting that it is estimated that the vegetable industry contributes close to 60% of the GHG emissions within horticulture (Deuter, 2008) and this figure includes cultivation as well as transport.

2.5 Model Sydney CBD potential for urban food production

The city of Toronto in Canada has estimated that 10% of the cities fresh fruit and vegetables could be produced within the city boundaries (MacRae et al, 2010). This includes food grown at ground level as well as rooftop production. The climate in Ontario is less temperate than NSW and the growing season is considerably shorter, and potentially the total amount of food production could be higher. It is probably impossible to calculate accurately the amount of food Sydney could produce, given the numerous variables to consider. It is dependent on the policies in place to support urban food production, and on practical issues such as soil contamination and food safety. This estimate is made on the basis of one years' growing experience only on three different sites at UTS Broadway Campus and it is acknowledged that weather is very variable and the amount of food that can be grown will also vary. The figures below are simply estimates of the total amount of food grown has been aggregated across the three sites for a selection of six different vegetables. These six vegetable were selected as they were the most successful in our demonstrations beds.

The City of Sydney LGA has a population of 169, 505 in 2011 (ABS, 2011) and covers an area of 25 km^2. Based on Stovin, (2010) roofing areas can account for 40-50% of the impermeable surfaces in urban locations and here our estimate is based on 45% of the 25 km^2 being roof space of which 15% is suited to green roof retrofit (Wilkinson & Reed, 2009). Therefore a total estimated area of 1.6875 km^2 (or 168.75 hectares) is available for food production.

The vegetables that were grown were quantified by an aggregate of their weight and quantity. The Gumal student housing gardens had two demonstration beds divided in half resulting in four beds with the same vegetables replicated in each. This created a growing area of 4.32 m^2 each. Taking the World Health Organisation's recommendation that we should eat around 0.5kg of fruit and vegetables per day (five portions) the daily amount potentially available would supply Sydney LGA with xx% of its daily intake.

In the initial summer planting of 2013, the Gumal gardens produced 6 Cos lettuce per bed i.e. 24 lettuces with an average weight of 500 grams. Most of the broccoli initial main flowering heads weighed in at approx. 300 grams with subsequent flowerlets of varying weight being continually harvested until the plants set seed. There were four to six broccoli per bed. There were five celery planted per bed and these were harvested at an average weight of 600 grams.

The silverbeet was harvested on a more or less weekly basis and with 4 mature silverbeet plants per bed a combined bunch of leaves of between 750 grams and 1 kilo was produced from all the beds. Similarly throughout the subsequent plantings, silverbeet proved to be a hardy rooftop garden contender with regular harvesting.

Each bed produced vegetables of varying quality and weight but the same variables did not apply to each type of vegetable and some vegetables fared better than others which was possibly due to the different substrates and locations which had different levels of sunlight. There were four cabbages per bed and they varied quite considerably with 1.5 kgs being the heaviest recorded. Capsicums were not particularly prolific or large, but had a lot of flavour, and similar results were noted from the tomatoes and eggplants. The zucchinis never really matured enough to be considered a success.

Table x: 3 month sample of vegetables by quantity and weight on Gumal rooftop

Vegetable	Quantity	Average Weight (grams)	Total weight produced (kgs)
Cos Lettuce	24	500	12
Broccoli Tops	20	300	6
Cabbage	16	1,200	19.2
Celery	20	600	12
Silverbeet	20	800 x 8 weeks	16
Kale	20	180 x 8 weeks	3.6

Table 4 shows the total amount of vegetables that we estimate could be grown on retrofitted rooftops in the City of Sydney LGA.

Vegetable	Total amount per annum per metre squared	Total amount per hectare	Total amount of plants potentially grown on all suited Sydney LGA rooftops	Number produced per person (Sydney LGA population 169, 505).
Lettuce	12	202500	810,000	4.78
Broccoli Tops	9	151875	455,625	2.69
Cabbage	9	151875	455,625	2.69
Celery	16	270000	1,080,000	6.37
Silverbeet	9	151875	607,500	3.58
Kale	6	101250	303,750	1.79

These estimates are for total production if all available space was given over to a single crop. However some estimates are conservative. For example lettuce grown hydroponically would yield significantly higher quantities.

2.6 Stormwater mitigation from elevated rooftop vegetable gardens.

The elevated garden beds on the Gumal rooftop had a drainage hole at one end and a 90 litre plastic storage box underneath with millimeter gradations marked. A rain gauge was positioned on the edge of the roof as far as possible away from plant and fixtures. The following table represents the data collected.

Date	Rainfall	Bed 1 volume	Bed 2 volume
2-Aug 2013	4.5mm		4mm
4-Aug		4mm	4mm
7-Aug	0.5mm		
10-Aug	11mm	24mm	18mm
12-Aug		2mm	4mm
20-Aug		2mm	3mm
1-Sep		3mm	4mm
7-Sep			3mm
11-Sep		0mm	3mm
20-Sep		5mm	0mm
3-Oct		4mm	4mm
11-Oct		3mm	3.5mm
14-Oct		0mm	1mm
29-Oct	4.5mm	0mm	0mm
11-Nov	30mm	3mm	1mm
13-Nov	15mm	20mm	15mm
Both beds leaking after 2 days heavy rain. Outlets blocked. Problem remedied.		3mm	2mm
1-Dec	2mm	10mm	
6-Dec	25mm		
19-Dec	90mm		
20-Dec		full tub	10mm
31-Dec		20mm	20mm
27-Jan 2014	30mm		
28-Jan		10mm	20mm
12-Feb	1mm		
20-Feb	40mm		
5-Mar	30 mm	30mm	15mm
12-Mar	10mm	1mm	5mm
13-Mar	30mm	10mm	5mm
22-Mar	10 mm	60mm ??	50mm ??
7-Apr	20mm	0mm	0mm
10-Apr	5mm	30mm	40mm ??

24-Apr	32mm	10mm	20mm

These findings proved inconclusive and unlikely due to a number of factors including the failure of the drains during massive pluvial events in early November 2013. Even after this was rectified, anomalies kept presenting with data collection due to other sprinklers from adjacent gardens spraying onto our test beds.

From 31st May 2014 to the 9th September 2014 rainfall data were collected, by simulating the rooftop garden beds on Gumal. The gardens/gauges were isolated from extraneous watering so that the tubs were exposed to full and unfettered precipitation influx. We installed two plastic storage boxes 300 mm x 300 mm x 200 mm deep both with a central drainage hole suspended over 1 litre measuring jugs with milliliter gradations. One box was filled with a growing medium with parsley growing in it, which was identical to the Gumal rooftop garden bed, and the other remained empty so as to simulate a rain gauge. The following table is the data collected.

Date	**Parsley garden (ml's).**	**Empty tub (ml's).**	**Differential**	**Comments**
31/05/14	650	1000	-450	
5/05/14	200	750	-550	
6/06/14	1000	1000	0	Soil saturated from previous rain
9/06/14	250	250	0	
10/06/14	600	1000	-500	
11/06/14	250	0	+250	Assumed to be post pluvial seepage
14/06/14	50	400	-350	
1/07/14	150	100	-50	
13/08/14	1000	150	+850	Soil saturated from previous rain
17/08/14	1000	1000	0	
18/08/14	1000	250	0	Many days of heavy rain
19/08/14	200	200	0	
1/09/14	0	250	-250	
2/09/14	150	200	-50	
9/09/14	100	300	-200	

It would appear from these results that the tub simulating a vegetable garden with the same depth substrate as our test gardens, has been absorbing stormwater immediately after rainstorms but only until reaching saturation point whereupon the garden drains the same amount as the rainfall captured in the naked tub and continues to seep the excess water absorbed well after the rain event has passed. Nonetheless it plays a significant role in initial runoff volume control.

Given that an area of xx km is estimated by xx to be suited to green roof retrofit in the Sydney LGA, it is estimated the following of vegetables could be produced.

Sara to extrapolate re: Sydney rooftops ?

2.6.1 Nutrient leakage

An element of the seepage tanks employed on Gumal is the runoff which was tested for nutrient saturation. The beds appear to be significantly reducing the first flush effect of rainstorms, however there was a large volume of dark brown liquid that accumulates in the holding tanks as seepage well after the rain event. This runoff could potentially be high in Nitrogen and Phosphates from the organic fertilisers being employed. The tests undertaken in October 2014 revealed that …

Test results go here

These nutrient rich wastes if not collected, would enter the stormwater or drainage system. This could be a barrier to rooftop farming as this garden runoff could contribute to algal blooms in ponds, wetlands and local waterways.

2.7 Model Sydney CBD potential for reduction in carbon footprint from food produced

Once the data for carbon footprint of different foods is established, as well as estimate of the total quantity of food, which might be grown on Sydney's rooftops, the team will be able to make some estimation of the total reduction in carbon food.

2.8 Production of 'how to' guides

The guides are found in Appendix 2.

3.0 Financial Reporting

This section of the progress report outlines the expenditure on the project. $19,610 was released by the City of Sydney in November 2013 and April 2014. A sum of $19,610 has been spent as follows;

Task	**City of Sydney Spend**
Set up Costs: Garden Beds, Soil, Substrate, membrane, drains, tank/fittings/plumbing, irrigation/timer, weather station and gauges	4025.5
Labour	1231.8
Operational costs/ Fees: Ongoing garden maintenance and logging of data	1224.5
To establish a UTS Staff/student 'gardening club' to maintain and monitor food production and to evaluate its social impact on individuals and organisational groups	508.72
To evaluate the social opportunities and social impacts of the installations through a building user perception study pre and post installation.	491.18
To test food grown for contaminants and pollutants.	2000.1
To calculate the carbon footprint of the food grown on the roof and compare this to supermarket counterparts.	0
	9481.8

4.0 Photographs

The following images show the six rooftop garden bed installations at UTS.

Plate 6 Science roof December 2013

Plate 7 Science roof December 2013

Construction completed and first crop planted out in the raised timber bed.

Plate 8 Science roof January 2014 – Wicking bed four weeks after planting

Plate 9 Gumal bed 2 December 2013

Plate 10 Gumal Staff Student Garden Club Beds – December 2013

Plate 11 View of Gumal Roof and Staff Student Garden Club Beds – December 2013

Plate 12 Gumal Staff Student Garden Club Wormeries and Compost April 2014

Plate 13 DAB Vertical Garden December 2013

Plate 14 DAB Vertical Garden December 2013 – self irrigating system powered by solar panel and pump

5.0 Additional unexpected opportunities

5.1 Research collaborations

As a result of the rooftop gardens three research opportunities have arisen. Firstly a post doc structural engineering researcher, Dr Renato Castigilia Feitosa, from the University of Sydney has contacted Sara Wilkinson and they are now working on a separate project, which evaluates the thermal performance of roofs planted with succulents. A refereed paper was presented at the ZEMCH conference in Londrina Brazil in June 2014.

Secondly Dr Tanya Latty, an entomologist, from the University of Sydney contacted Sara Wilkinson to see whether she could visit the sites and do a count of pollinators for her research on urban bee populations. The visit was made in February 2014 and as a result of discussions Tanya has submitted a successful City of Sydney Environmental Grant application in 2014. A relationship has been established and agreements made that further testing of the UTS can be undertaken as part of the new COS project.

Thirdly two members of the UTS Dirt Club, Dr Ilaria Vanni and Dr Angela Giovanangeli, from the Faculty of Applied Social Sciences in UTS submitted a City of Sydney Environmental Grant application in 2014 to extend this research to an indoor environment and to explore the social impacts of such installations.

Finally a research book contract has been issued by Wiley Blackwells for a book titled Building Resilience in Urban Settlements: Green Roof Retrofit. The book will feature the rooftop garden research supported in this project as well as others outside of Australia. Academics and researchers from three Sydney universities across seven disciplines including planning, environmental management, built environment, social sciences, entomology, toxicology and horticulture are collaborating. A team of 17 academics from three countries (Australia UK, Brazil) and 3 continents (Europe, Australia and South America) will write the 11 chapter book in 2015, with publication in 2016.

5.2 Educational opportunities

A number of students in various faculties have used the rooftop gardens for assignments. In April a journalism student, Leyla Saaret, interviewed Sara Wilkinson about the VGarden at DAB. In Semester 2 2013 an Industrial Design in DAB did a major project on wormeries.
In April 2104 one of the UTS Journalism lecturers also invited Sara Wilkinson as a guest to be interviewed by the post graduate journalism students. Unfortunately Sara was in Melbourne at the time and unable to participate but she is happy to contribute in future.

5.3 Media

A number of media opportunities have arisen whereby the team have been able to mention the City of Sydney Grant and rooftop garden research. These are as follows;

1. 26th March 2014 Hothouse Space event at the Powerhouse Museum Sydney

2. 202020 Vision Launch 7th November 2013 Sydney Lines Goods, Sydney.
3. Fifth Estate. 17th July 2013 - www.thefifthestate.com.au/archives/52193/Move over green walls, edible walls are coming through.
4. August UTS U Magazine. Urban oasis Link: http://www.newsroom.uts.edu.au/news/2013/08/urban-oasis?utm_source=gk_7&utm_medium=gk&utm_campaign=urban_aug13
5. Costa Giorgiadis from the ABC's Gardening Australia visited the gardens and has expressed interest in producing a segment for his show.

5.4 Visits

A number of tours have been given to national and international visitors. On the 11th April 2014 Andrew Ridge (City Farm Manager) and Raewyn Broadfoot (Community Gardens) from the City of Sydney toured the rooftops with Peter Morton from the Powerhouse Museum.
In September 2013 a group of visitors from China toured the rooftops.
In December 2013 Dr Paul Osmond from UNSW toured the rooftop – and a joint application for funding from OEH has been submitted for further green roof research.
In May 2014 a group of Koreans visit the rooftop along with Ms Suzanne Dunford from the NSW Office of Environment and Heritage (OEH). Dr. Ha, team leader from the Republic of Korea's Climate Change Adaptation Centre (KACCC) will visit with Ms Jihye Choi and Ms Seul Li Bin. KACCC are researching the Health impacts of heatwaves which is seen as the climate change most likely to affect the country, and the potential of integrative management of relevant adaptation plans for climate change (through adaptive management and social learning).

6.0 Conclusions

This report has outlined work undertaken on the project, 'Urban food production in the CBD on rooftops'. It has shown that six demonstration beds have been established on three rooftop locations on the UTS campus. The garden club has been established at Gumal Student Housing and is very active and engaged and continues post project. The testing of the plants, soils and water used on each of the sites was conducted and showed bio-remediation occurred.

The carbon footprint of the food grown was shown to be very low especially compared to supermarket purchased vegetables. The reductions in stormwater run-off showed that water run-off is slowed unless the water is already at saturation point. If adopted on a wide scale such attenuation of stormwater could reduce flash flooding. However it is recommended that rainwater storage is adopted wherever possible to reduce consumption of potable water.

In modelling Sydney's CBD potential for urban food production that could arise from wide scale urban food production, it is seen that the results could be very variable as we are basing our estimate one a single year's production.

The 'How to' guides are provided in appendix 2.

Two refereed conference papers were produced from this research and presented in Brazil in June 2014 and in New Delhi in September 2013. An abstract outlining the social impact of urban food production has been accepted for an international conference in July 2015.

This research is leading to further outputs such as the research book and also further research applications to further knowledge and understanding of the impacts of urban food production for the Sydney and NSW community.

Appendices Refereed Conference Papers

1. Wilkinson, S. J., Ghosh, S. and Page, L. 2013. Options for green roof retrofit and urban food production in the Sydney CBD. RICS COBRA New Delhi, India. 10th to 12thSeptember 2013. ISSN 978-1-78321-030-5.

2. Wilkinson, S. J., & Page, L. 2014. Exploring the potential for urban food production on Sydney's rooftops. Zero Energy Mass Custom Homes 2014 International Conference 4th - 6th June 2014, Londrina - Paraná, Brazil. http://www.zemch2014.com.br/index.html Paper submitted March 2014.

OPTIONS FOR GREEN ROOF RETROFIT AND URBAN FOOD PRODUCTION IN THE SYDNEY CBD

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ABSTRACT

The benefits of retrofitting existing buildings with vegetated roofs are environmental, economic and social. Economic benefits include lower construction costs, lower running costs, and reduced costs of borrowing whilst the social gains include retention of familiar landmarks, and cultural capital. Environmental gains include retention of embodied carbon, and the re-use of existing materials. The environmental benefits are improved thermal performance and reduced heat loss and heat gain in buildings. This can lead to reduced operational energy costs for owners and tenants, providing economic benefits. However, the environmental social and economic gains are not perceived sufficient to persuade many owners to retrofit green roofs. Social, psychological and therapeutic gains occur when the roof is visible to users and is used for social interaction and relaxation. As an alternative food production system, green roofs could promote a shorter food supply chain, contribute to healthier communities and create local jobs and notably reduce the carbon footprints of food production. A little explored environmental gain in Sydney is the retrofit of roofs for urban food production. No empirical research has been conducted into the plant species best suited to urban food production, including native food plants, and the optimum substrate composition and depth, required to suit the NSW climate. The barriers and opportunities for urban food production in a high-density urban environment also require investigation.

Keywords: retrofit, green roofs, urban food production, Sydney.

INTRODUCTION

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“Roofs can represent up to 32% of the horizontal surface of built-up areas” (Frazer, 2005) and many have the potential to become urban farmland. There are many successful examples established overseas such as “Eagle Street Rooftop Farm” which is has over 500 square metres of intensive green roof sustaining an organic vegetable farm located on a warehouse rooftop in Greenpoint, Brooklyn, USA (Rooftop Farms, 2013). The utilisation of existing urban horizontal spaces as farmland increases the food security of a city. As global temperatures rise and crops fail, and droughts become more frequent and severe, it will become increasingly desirable to equip urban dwellers with the ability to cultivate food, or to encourage urban farmers to produce food locally. Concomitant to these outcomes, are the social benefits and the financial and environmental imperatives. A green roof offers a building and its surrounding environment many benefits. These include storm-water management, improved water run-off quality (Mentens,2006; Hilten, 2008) improved air quality in the urban canyon (Yang, 2008:88), longer durability of a roof skin (Kohler, 2002:91) increased efficiency of energy use in buildings (Castleton, 2010:62) and a reduction of the urban heat island effect (Takebashi, 2009:92). Other benefits also include enhanced architectural interest and biodiversity (Castleton, 2010:62) as well as re-introducing the natural world into the anthropogenic environment.

This paper discusses the potential for utilising modular, intensive green roof technology to create rooftop vegetable gardens on existing buildings with a view to minimizing food miles, shortening the supply chain and reducing the carbon footprint of growing and transporting food. The research considers the economic and environmental benefits of *retrofitting* existing buildings with green roofs for owners and investors, and the desirable social and psychological impacts on the inhabitants including the potential betterment of the community by utilising roof space for urban agriculture.

Research Question

There is a growing body of research on urban food production and retrofitting of existing buildings. However much of the empirical research has been undertaken in cities outside of Australia which have quite different climatic conditions. This research addresses the questions (a) *what are the barriers and opportunities that exist in respect of urban food production in the Sydney CBD*? Secondly, *what are the options in respect of retrofitting green roofs (extensive and intensive) or vegetated roof top gardens?* The objective is to identify the gaps in knowledge for the city and to establish a research agenda to close the knowledge gaps.

Research Method

This initial stage of the research comprises a desktop study and literature review. The aim is to gain a deeper understanding of the factors that act as barriers and opportunities with respect to urban food production within the Sydney CBD. Secondly the literature review highlights the experiences of others in respect of options regarding the specification of vegetated roofs. The initial scoping of the research agenda follows an inductive and qualitative approach to research (Silverman, 1997).

THE CASE FOR RETROFIT

The built environment is responsible for around 40% of global carbon emissions and has a significant role to play in attempts to mitigate anthropogenic climate change (UNEP, 2006). 87% of the buildings that the UK will have in 2050 are already built (Kelly, 2008) and with only 1-2% added to the total stock of buildings typically in global cities; retrofit of existing buildings for sustainability is a priority. Retrofit is defined as;

‘the process of modifying something after it has been manufactured. For buildings, this means making changes to the systems inside the building or even the structure itself at some point after its initial construction and occupation’ (City of Melbourne, 2013).

This is a broad definition, and the modification of an existing building to accommodate a green roof falls within this definition of retrofit. There are social, economic and environmental benefits associated with green roof retrofit. Social benefits include the retention of existing structures familiar to the local community (Bromley et al, 2005). Social sustainability is important, though challenging to measure and compare to economic and environmental benefits. Often retrofit exists as part of urban regeneration and allows development of the new alongside the old (Bullen, 2007). Retrofit is not always possible or desirable especially where it is not possible to achieve the standards required in contemporary legislation. Another social benefit from a retrofitted green roof is the perception of a closer relationship to the natural world, "the biophilia phenomenon" (Kellert and Wilson, 1993). Finally the aesthetics of the roof may be enhanced through green roof retrofit. There are very strong environmental benefits of retrofit (Douglas, 2006). Particularly the retention of existing carbon, as well as cost benefits derived through lower operational costs achieved through energy savings (Bullen, 2007). Demolition is wasteful of resources that typically end up in landfill. Retrofitting with green roofs could reduce the urban heat island effect whereby temperatures are typically up to five degrees higher than the surrounding suburbs (Williams, 2010:60). The thermal performance of the roof is improved with the installation of a green roof, reducing energy consumption and carbon emissions. Storm-water run-off may be reduced through green roof retrofit and rainwater harvesting may be employed to reduce potable water consumption for toilet flushing, clothes washing and garden watering. The economic benefits are that retrofit is cheaper than new build if the construction form is straightforward (Bullen 2007), and that costs of finance tend to be lower as the building may remain occupied during retrofit (Highfield, 2000). Where the build quality is poor, costs may be more expensive (Bullen, 2007). Property values are enhanced with retrofit projects (Chau et al, 2003). With green roof retrofit, maintenance costs are reduced and new employment opportunities created.

Suitability for a green roof retrofit is reliant on aspects such as the roof size, type and pitch. Additional requirements include good drainage, lightweight growth media, waterproofing, additional structural support, rainwater harvesting and the use of drought or heat tolerant plants. Longevity of the structure, drainage and waterproofing system is essential because replacement costs are high. Green roofs are designed to last a minimum of 50 years, which is approximately twice the life cycle of a roof covering such as bituminous felt. Criteria taken into consideration when deciding whether a roof is suitable for retrofitting are: position of the building, location, orientation of the roof, height above ground, pitch, load bearing capacity of the roof, preferred planting palette, sustainability and maintenance. The first six criteria are physical attributes and the last three are related to client desires and maintenance. With rooftop gardens, the criteria are similar; however the membrane has more exposure and will require periodic maintenance and eventual replacement. The advantage of the rooftop garden is that the installation is potentially re-locatable, reusable and cheaper.

GREEN ROOFS

Green roofs can be separated into three main categories, extensive, intensive and vegetated rooftops (or rooftop gardens). Extensive roofs, aka ecoroofs, have substrate depths less than 20cm, require minimal or no irrigation and are generally planted with low growing succulents and stress tolerant herbaceous species (Obendorfer, 2007; Snodgrass, 2006:39). Intensive green roofs, have greater variations in substrate depth, typically with depths of more than 20cm, and may host a greater variety of plants and shrubs. Rooftop gardens are typically small containerised garden beds interspersed with hodological and recreational spaces utilizing varying depths of substrate with a higher organic component than extensive and intensive rooftops. This enables them to sustain a wider variety of plant species, including fruit and vegetable crops. Rooftop gardens provide a fecund amenity and a desirable aesthetic and are usually designed as places of recreation for building users, whilst incorporating some of the environmental and economic benefits of intensive green roofs without being physically incorporated into the permanent structure. It is difficult to provide accurate costing for the installation of any of these types of green roof, due to case by case variables such as site access and utilisation of cranes/goods lifts.

Factors which can escalate costs for green roofs retrofits include increased structural loads, whereby the slab needs to support the weight of wet soil, planting and planter walls (Lend Lease 2013). In some cases the structure might need upgrading e.g. columns and foundations. Waterproof testing of the membrane is generally required, and perimeter fall protection may need upgrading e.g. provision of balustrades, depending on whether the area is designated accessible. If the roof is accessible for general use, better egress than standard roof access specification is required, such as additional lighting and signage. Furthermore designers, due to their lack of familiarity with the specification, often prefer to have some 'insurance' in the design in relation to falls, membrane quality and drainage which can inflate costs (Lend Lease 2013). Another factor influencing costs can be the installation of additional rainwater harvesting equipment. However, insulation costs may, in theory, be reduced due to the thermal properties of the rooftop substrate and vegetation. Costs include hard landscaping such as planter walls, secondary membranes, drainage cell, paving and shade structures and soft landscaping items such as soils, mulch, planting and irrigation. Additional maintenance costs occur during the building lifecycle. The current view in Australia is that green roofs are expensive and often value engineered out of a design on the basis of affordability (Lend Lease 2013).

Urban Food Production

As millions face starvation globally and the proliferation of food waste becomes endemic, a recent report released by the Institution of Mechanical Engineers estimated "that 30-50% (or 1.2-2 billion tonnes) of all food produced is lost before reaching a human stomach" (Fox, 2013). Some reasons are poor engineering and agricultural practices, inadequate transport and storage infrastructure. Urban rooftop farming has the potential to ameliorate some of these problems by shortening the food supply chain. One advantage of growing food close to consumers is reduced carbon miles. Currently, fresh food consumed in cities is transported to great distances. It is estimated that the cost of transport of a $1 supermarket lettuce is around 40 cents (Midmore, 2011). Rooftop agriculture has the potential to create healthier communities in alimentary and psychological ways. Urban rooftop agriculture could provide access to fresh, healthy, nutritious produce due to reduced time spent in transit and storage. City dwellers and workers are increasingly detached from nature, and this contributes to rising stress levels and dissatisfaction with contemporary society (Shepard, 1995). Kellert and Wilson *in Zubevich* (2003) claimed that "humans have a profound need for regular contact with the natural environment for continued wellbeing". "Rooftop gardening means taking up an inspiring, ecological and productive activity, and developing new links with the food chain, the seasons, the environment and the community" (Germain, 2008).

A supplementary social benefit of rooftop agriculture may be community volunteer programmes whereby residents and workers engage in food production. An example is the Eagle Street rooftop farm in Brooklyn New York (Rooftop Farms, 2013) which operates a small community supported agriculture (CSA) program and an onsite farm market which caters to area restaurants. It utilises trained interns and urban farming apprentices and hosts volunteers during growing seasons. In partnership with Growing Chefs the farm hosts educational and volunteer programs to bring city-dwellers closer to their food source (Growing Chefs, 2013). Although there are many successful examples of urban agriculture in the northern hemisphere, it is surprising that Sydney has so few examples of rooftop urban food production and to date, no empirical studies as to its viability. Sydney is located in a temperate climatic zone with rainfall spread throughout the year. Annual meteorological data for 2012, showed 1213.6mm of rainfall, a mean maximum temperature of 22.7°C and a mean minimum of 14.4**°C** (BoM, 2013). Sydney's annual average of sunshine is almost seven hours a day (City of Sydney, 2013). Sydney's rainfall averages 11 wet days per month, and over 40% falls between March and June.

New South Wales Government Agencies and the University of New South Wales have been developing climate change forecasts for the NSW State Plan regions and Sydney's weather is projected to be hotter over all seasons (2 to 3^0 C); with summer rainfall projected to increase by 20-50% and winter rainfall projected to decrease. The pattern of the El Niño-Southern Oscillation cycle is projected to continue but with higher temperatures than currently experienced. El Niño years are likely to continue to be drier than average and become hotter. La Niña years are likely to continue to be wetter than average and also to become warmer. In El Niño events, water stress is projected to be more intense due to higher temperatures. During La Niña years, storms with heavy downpours are projected to be more frequent (Dept. of Environment and Climate change NSW, 2008). Given these predictions of climate change impact on Sydney's growing seasons, rooftop farmers will need to adapt their taxonomical palette.

As of June 2010, Sydney houses 182,000 people. The CBD has an approximate area of 25 km^2 and a population density of 6780.2/km^2 (City of Sydney, 2013). Based on other studies on the potential for green roofs retrofit (Osmond, 2012), it is possible that 17-20% of Sydney rooftops could accommodate intensive green roofs. There are over 17.5 million square metres of built form within the Central Business District (CBD) of the City. Whilst no data exists regarding the potential for vegetated rooftop gardens, given that there are 17.5 km^2 of roofs with a 20% intensive green roof potentiality factor; approximately 3.5 km^2 of roof space is available to support urban agriculture in containerized garden beds (Osmond, 2012).

Barriers

Plants grown on rooftops will be subject to extreme environmental conditions. In Sydney these will include extreme temperatures and wind velocities. January 2013 saw several of Sydney's hottest days with temperatures exceeding 45 degree Celsius (BoM, 2013). Such extreme weather will cause tremendous stress on food crops. With climate change predictions assuming hotter and drier summers, rooftop agriculture in Sydney will require constant maintenance and/or the installation of sophisticated watering systems. Another barrier to rooftop agriculture may be the physical harm to plants caused by predators such as the Sulphur-crested Cockatoo and the Brush-tailed Possum both of which can be found in abundance in and around urban Sydney. To date, little research has been conducted into the humane control of native vermin on rooftops and ways of protecting urban food crops. Another under explored potential barrier could be the effect of rooftop flue emissions on edible plants. Pollution abatement is often cited as being one of the benefits of green roof technology. Airborne particulates are caught within the vegetation and the pollutants are filtered naturally through the planting systems. More research needs to be undertaken on the potential side effects of consuming vegetation that may have filtered airborne pollutants.

The institutional or organizational barriers to rooftop installations include concerns with regards to health and safety of building users going onto roof spaces. There are issues with regards to liability and some organizations are more risk averse than others. Observations and field investigations of 19 vegetated roofs in the United States revealed unsafe access for workers and equipment, a lack of fall-protection measures, and other site-specific hazards (Behm, 2012). The installation of a green roof requires that large amounts of materials are transported often, through the building to the roof. Access is also required for maintenance of the roof garden. Other owners are reluctant to allow people onto roof areas because they perceive this to be a security issue, although the increase in rooftop recreation areas such as bars, spas, cinemas and wedding venues may reflect a change in perceptions. There are opportunities for the roof space to be leased to gardeners and become income generating as a result (Pop-up Veggie Patch Melbourne, 2013). The Pop-up Veggie Patch Company in Melbourne charge $25 per week to users for a single raised bed, approximately 2.25 metres squared. It is possible that institutional green roof sub-leases could be developed to cover owner liability, as well as to incentivize and encourage a greater take up for roof top food production.

Research Gaps

The literature review has identified a number of gaps in knowledge in relation to green roof retrofit in Sydney CBD and urban food production. These gaps are as follows;

1. Limited reliable installation and maintenance costs data is available exacerbated by variations in specifications.
2. Unknown reduced running costs to owners.
3. Unknown value of income generated through leasing rooftops for food productions.
4. Viability and demand for green roof sub-leases.
5. Amount and types of food which can be grown in the CBD.
6. Amount and types of pollutants potentially absorbed by vegetation grown on rooftops.
7. Carbon food miles and energy savings related to urban food production.
8. Enhanced alimentary value of rooftop food compared to supermarket equivalent and associated public health improvement potential.
9. Reductions in food waste and related carbon savings in the overall food supply chain.
10. Biophilial benefits to building users and participants in urban food production
11. Understanding community willingness to sustainable behaviour change for actively participating in rooftop food production.
12. The extent to which predicted climate change/weather patterns will affect the amount, growing cycles and types of food which may be produced.
13. The extent and degree of O.H. and S. issues facing owners and users.

Conclusion

This paper has demonstrated, through an extensive literature review that numerous environmental social and economic benefits exist, however, little or no empirical evidence relates to Sydney. Moreover there are a number of barriers which might affect the economic and environmental viability of green roof retrofits and further research is required to determine the exact nature and degree of these barriers. Urban food production on retrofitted green roofs may be cost effective but it seems that this is more likely to comprise roof gardens rather than intensive and extensive vegetated roofs. If income can be generated through sub leases, owner/institutional barriers may be overcome. The barriers relating to access and security may be found to be somewhat spurious given the recent proliferation of rooftop recreation areas. An action research approach needs to be carried out that should include the establishment of several containerised rooftop vegetable gardens with varying substrate depths and types, growing a wide range of edible plants. Ideally these gardens can be retrofitted to a building/buildings that have a fresh food outlet that is willing to provide green waste for the creation of compost and vermiculture on site, to facilitate in a sustainable fashion, the ongoing soil enrichment required by organic vegetable production. These sites should be equipped with climate/weather monitoring equipment for the collection of data, Excess water runoff from the gardens should be recorded, post pluvial events, to compare other hydrological data collected from the site. An inventory should be kept of foods grown and quantities. Another component is an analysis of the carbon footprint and carbon miles of the food produced. Where possible, if these pilot projects can involve volunteering from the building's users; interviews with the volunteers will be conducted to understand the perceived degree of social benefits derived from interacting with the gardens.

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ZEMCH Paper

EXPLORING THE POTENTIAL FOR URBAN FOOD PRODUCTION ON SYDNEY'S ROOFTOPS.

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Abstract

There are environmental, economic and social benefits of retrofitting rooftops on city buildings for food production. Environmental benefits include lower carbon food miles, potential reductions in building related operational carbon emissions, reductions in the urban heat island, increases in bio-diversity and reductions in storm-water run-off. Economically, the benefits are reduced roof maintenance costs, lower running costs and direct access to fresh food. Thirdly the social or community gains are the creation of spaces where people can engage in growing food. Psychological and therapeutic gains accrue when people engage with natural environments. However there are barriers which include perceptions of greater risk of building leaks, high costs of installation and maintenance, and access and security issues.

Although the technology to design and install food production on rooftops exists, the uptake and the demand have not been high to date. Overall, the gains are not deemed sufficient and in Sydney Australia, the existing numbers of food producing rooftops are testimony to this observation. This research reports on three rooftops set up in 2013 in Sydney which are producing food. The social, economic and environmental aspects and physical aspects of the installation are described in this paper.

Keywords: Green roofs, Sydney, urban food production, case studies.

Introduction

As millions face starvation globally and the proliferation of food waste becomes endemic, a recent report released by the Institution of Mechanical Engineers estimated "that 30-50% (or 1.2-2 billion tonnes) of all food produced is lost before reaching a human stomach" (Fox, 2013). Some reasons for this amount of wastage are poor engineering and agricultural practices, inadequate transport and storage infrastructure. Urban rooftop farming has the potential to ameliorate some of these problems by shortening the food supply chain. One advantage of growing food close to consumers is reduced carbon miles. Currently, fresh food consumed in cities is transported great distances. It is estimated that the cost of transport of a $1 supermarket lettuce is around 40 cents (Midmore, 2011). Rooftop agriculture has the potential to create healthier communities in alimentary and psychological ways. Urban rooftop agriculture could provide access to fresh, healthy, nutritious produce due to reduced time spent in transit and storage.

In addition there is evidence that city dwellers and workers are increasingly detached from nature, and that this contributes to rising stress and dissatisfaction with contemporary society

(Shepard, 1982). It is posited that "humans have a profound need for regular contact with the natural environment for continued well-being" (Kellert and Wilson *in Zubevich* 2003). In summary "Rooftop gardening means taking up an inspiring, ecological and productive activity, and developing new links with the food chain, the seasons, the environment and the community" (Germain, 2008).

A complementary social benefit of rooftop farming may be community volunteer programmes where citizens and workers engage in food production. An example is the Eagle Street Rooftop Farm in Brooklyn New York (Rooftop Farms, 2013) which runs a small community supported agriculture program and an onsite farm market which supplies local restaurants. Trained interns, urban farming apprentices and host volunteers provide the labour during growing seasons. In partnership with Growing Chefs the farm holds educational and volunteer programs to bring city-dwellers closer to their food source (Growing Chefs, 2013). Given that there are many successful examples of urban agriculture in North America, Cuba, Canada and Germany, it is surprising that Sydney has so few examples of rooftop urban food production and to date, no empirical studies as to its viability.

Some barriers to rooftop food production include perceptions of greater risks of building leaks, high costs of installation and maintenance, and access and security issues. Property practitioners and built environment professionals have little direct experience of urban agriculture and; as a result, are sceptical and risk averse. There are questions about financial viability of such enterprises in Australia, even though viable, successful rooftop farms exist in cities such as New York where climatic conditions preclude food production during winter months.

Sydney is located in a temperate climatic zone with rainfall spread throughout the year. Annual meteorological data for 2012, showed 1213.6mm of rainfall, a mean maximum temperature of 22.7°C and a mean minimum of 14.4°C (BoM, 2013). Sydney's annual average of sunshine is almost seven hours a day (City of Sydney, 2013). Sydney's rainfall averages 11 wet days per month, with over 40% falling between March and June. With a population of 4,391,674 for Greater Sydney in the 2011 census (ABS, 2014b), Sydney is growing at a rate of 1.7% per annum with two-thirds of New South Wales population living in the city. Furthermore Sydney has the highest density in Australia with 8800 people per square kilometre in Sydney's east and 7900 people per square kilometre in Sydney City's west. By comparison to other global cities Sydney's density is high, Mexico City has 8400 people per square kilometre, London 5100 people per square kilometre, Paris is lower still at 3550 people per square kilometre and Los Angeles has a population density of 2750 people per square kilometre. With increasing urban density and a growing population the disconnection to the natural environment is set to increase. Furthermore the demand for food is also increasing. One part of the solution may be urban farming on rooftops.

Research Aim

There is a growing body of research into the benefits or otherwise of specifying new or retrofitting green roofs to existing buildings for food production. However much of the empirical research has been undertaken in cities outside of Australia, in Europe and the northern hemisphere which has quite different climatic conditions. This research evaluates three different approaches to rooftop food production in Sydney. The objective is to use an empirical study to identify the gaps in knowledge for the city and to establish a research agenda to close the knowledge gaps.

Rooftop garden bed designs

Some of the options available for rooftop agriculture include portable containers, raised beds and vertical garden units. The issues to consider are access, portability, cost and the types of vegetables and plants to be grown.

Containers come in various forms, are typically smaller than raised beds, and are easily portable. By using containers that would otherwise go to landfill, rooftop gardeners can recycle on garden plots of varying shapes and sizes. Milk crates with hessian sacks, recycled plastic wading pools, buckets, packing crates and recycled wooden pallets are examples. Container gardening allows growers to take their project with them should they be required to relocate and this can be useful when renting property. The factors to consider when creating a container bed are drainage and root depth. The most important aspect to consider when using recycled containers is toxicity and all treated and painted timbers should be avoided as well as plastics that contain solvents, PVC and high density polyethylene (HDPE).

The wicking bed derives its name from the cloth that is placed between the soil and a water reservoir inside the garden container that works much like a wick in an oil lamp. By giving the plants access to water at their root zone, when and where they need it, it reduces the potential for plants to become water stressed. Furthermore less water is wasted as evapotranspiration and the gardener does not need to water the plants as frequently. A simple way of building a self-watering garden bed or sub–irrigated garden is to use a plastic pond which is positioned directly onto the waterproof membrane of the roof. A hose is attached to an overflow outlet and the excess water is channelled to a drain. This type of garden bed has a very minimal impact on the surface of the rooftop. The weight is reduced by using agricultural pipe below the growing medium, separated by a layer of geo-textile fabric.

Another option is to elevate or raise the garden beds, and having a working height of 1100 mm from roof level is more comfortable than traditional gardening methods. This is a good solution for those who have mobility issues and furthermore, there is less direct contact with the roof membrane which is reassuring to some owners and property managers. The drainage can be channelled by hose from the garden bed outlet to stormwater pipe outlets which should ameliorate concerns about potential roof leaks or staining on tiles. Raised garden beds can be heavy and create point loads on the roof and therefore careful thought is required with regards to the design and construction of the trestle. There are proprietary garden beds such as those made from recycled UV stabilised plastic which are lightweight and easy to transport to the roof top, as well as kit form corrugated zincalume which are relatively lightweight and portable. Other options include timber framed beds manufactured in-situ.

There is a range of vertical garden beds produced and sold in hardware stores. Transportation to and accessibility of the roof top has to be taken into account with this option. Some systems may be good for growing herbs and flowers, but if gardeners are intending to use a spare north facing wall to grow food, which generally requires seasonal replanting, the ease of removal and planting out of new vegetables and the root zone depth required need to be considered when choosing a vertical system. The majority of vegetables grown by urban farmers are seasonal, and the plants will need replacing quite often as the seasons change and they either get picked or die off. A planting system that has inadequate sized apertures can be difficult to plant out. Some vertical planter systems accommodate small garden pots, and though convenient; it does limit planting to those with shallow root systems. There are vertical garden systems which have deep troughs that can be used to grow some very large vegetables and herbs. Due to the shallow depth of the growing mediums in most vertical gardens, they require more frequent watering and run the risk of water stress. The installation of a drip irrigation system on a 24 hour timer can provide reliable watering.

Each garden has different advantages and disadvantages. With each; accessibility, transportation and the load bearing capacity of the roof structure has to be considered. Orientation and access to sunlight, the availability of water and a power supply should also be scrutinised. Finally, cost and any issues regarding the comfort for the gardeners are decision factors as the working height of the bed affects gardeners comfort.

Research methodology

This research uses empirical evidence derived from growing plants and vegetables on three different rooftops at the University of Technology, Sydney (UTS), in New South Wales Australia in 2013 and 2014. Three different types of rooftop garden beds are described in three illustrative case studies below.

The research is qualitative, sharing the three basic assumptions identified by Patton (1980) of being naturalistic, holistic and inductive. Naturalism involves seeing the phenomenon in its natural occurring state, in this case by visiting the three sites to observe what has taken place. The holistic aspect involves looking at the whole problem to develop a more complete understanding of the influencing factors and variables with regards to three different approaches to rooftop food production in Sydney. The inductive approach is derived from the literature review whereby a picture of the problems and issues emerge as the researcher becomes more familiar with the topic area. The literature review identified which areas needed to be addressed.

An advantage of case study research is that it is a flexible and adaptable method which can be adapted during the research (Robson, 2003). With this research three different types of beds are evaluated on three different roofs and so it is not possible to make exact comparison on outputs. However that is not to say that the conclusions which may be drawn from the study are not valid.

A limitation of the case study technique is that the researcher does not sample widely enough and that studies may represent the peripheries and not the average (Robson, 2003). However Yin (1989) observes that case study is concerned with analytical and not statistical generalisation. Care was taken to ensure conclusions drawn are noted as being analytically general rather than statistically representative in any way. The criticism of case study as a 'soft option' was rejected as the method requires preparation, knowledge of procedures (in this case food production on Sydney rooftops) and analytical skills (Robson 2003). It is soft in the sense that no hard and fast rules exist for the researcher to follow.

The means of data collection was through observation and direct experience which was deemed most suitable because it allowed the researcher to collect identical data from each site (Moser and Kalton, 1979). Records were kept on bio-diversity, watering, weather, bed costs, planting, dates, fertilisers used and crop yields.

Case studies

The first task was to find suitable roofs on the University campus. After a number of visits to rooftops it was found that there were issues such as accessibility, where one had a series of narrow steps out onto the rooftop. Another had a telecommunications mast which precluded any other activity on the roof. A third roof was discounted as it was heavily overshadowed and poorly orientated to the suns path. The property managers were also a significant factor and finally the team met one who was also a gardener. This staff member was helpful and knowledgeable and took the team to several potential roofs before a joint decision was arrived at with the Gumal roof described below. The Science Faculty are involved in this research and had test beds on their roof and permission was given to position another bed on their roof. Finally the researchers' home faculty have a roof space directly outside the staff kitchen and the DAB Faculty Manager gave permission to site the V garden beds here.

Science Roof

This roof is located at 7th floor level on the corner of Harris Street and Thomas Street in Sydney. The roof faces north-west. The roof construction comprises reinforced concrete with an impervious covering. The roof is protected with walled structures approximately three metres high to three sides and a glazed screen to the Thomas Street elevation. The garden bed chosen for this site was a plastic wicking bed.

The bed was a pond purchased at a cost of $280. It has a 320 litre capacity and the dimensions are 1500 mm x 750 mm x 300 mm high. The reservoir in the bed is created by laying 100 mm agricultural drainage pipe across the bottom of the pond. A short section of tube is positioned vertically from the bottom of the pond up to the top (in a place where the overflow is visible). This is the filler tube and a section of agricultural pipe is used. A hole, to accommodate a 30 mm threaded tank outlet, is drilled into the pond shell at the height presented by the top of the agricultural pipe, here 100 mm from the base. The outlet has a washer to eliminate leaks. The overflow outlet was located as close as possible to the rooftop drain to minimise the trip hazard created by a hose. A layer of geotextile fabric was placed on top of the agricultural pipe and poked down slightly between random sections of the agricultural pipe to prevent the soil and roots from entering the reservoir and to allow the capillary or wicking action to irrigate the garden bed. Plate 1 shows the bed immediately following planting in December 2013.

The bed was filled with a mixture of soil and compost to a depth of approximately 200 mm. It was top dressed with a compressed pelletised organic seaweed fertiliser (Seamungus). The bed was filled with water through the vertical filler tube until it overflowed from the outlet. It was topped up over the two days while the soil conditioned and after this initial phase it was topped up with 30 - 40 litres of water every five to six days. The bed was planted with a mix of eggplant, zucchini, basil, carrots, beetroot, lettuce, chilli, capsicum, silverbeet, celery, rocket, mizuna and marigolds. After planting, the bed was mulched with lucerne hay and fertilised topically fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was applied typically once a month. The bed was planted out in December 2013 which is summer in Sydney Australia. The total cost of the bed was $412 plus labour.

Plates 1 Wicking Bed on Science Roof.

Gumal Student Housing

This roof is located at 9th floor level on Broadway in Sydney. The roof faces south east. The roof construction is reinforced concrete with an impervious tiled covering. The roof is designed for access and has a concrete perimeter wall approximately 1200 mm high 600mm wide and 800 mm deep which is planted out. There is lift access to level 9. It is exposed and open to the wind and sun. The garden bed chosen for this site was a recycled plastic raised bed supported on a timber frame trestle. The UV resistant recycled plastic was extremely light, easily assembled and its dimensions were 3300 mm long x 1200 mm wide x 300 mm deep. See plates 2 and 3.

A 3600 x 1200 mm trestle was constructed from 90 x 45 mm treated pine frames, braced with galvanised strapping tied together using a 90 x 45 mm treated pine rail top and bottom. The frames were prefabricated off site to minimise the noise impact during construction, and for easier transportation. Two sheets of ply 1800 x 1200 mm formed the top of the trestle and supported the plastic framework for the bed.

Plate 2 Gumal under construction. **Plate 3 Gumal bed planted out.**

A layer of food grade rubber waterproofing membrane, ethylene propylene diene monomer (M-class) rubber (or EPDM) was placed over the timber trestle as weather protection. The plastic pod was positioned on the membrane and a bead of food grade silicone sealed the base of the garden bed and held it in place. At one end a floor drain was installed and sealed with silicone, and using a spirit level and some small plastic wedges, the end of the trestle furthest from the floor drain was raised slightly to facilitate drainage. A layer of 20 mm drainage cell sheeting was placed across the floor of the bed with a layer of geo-textile fabric laid over the drainage cells to keep the soil and plant roots from blocking the drain. A layer of fine gravel 20 mm deep was laid onto the geo-textile fabric, followed by another layer of geo-textile fabric. The bed was divided into two sections for different growing media; one was filled with an organic composted cow poo and garden soil mixture and the other a lightweight engineered substrate with a mixture of coir bark, perlite P400, Canadian peat, 0-8mm composted pine bark, all trace elements, Calcium Nitrate, coarse granular Dolomite, Gypsum, Superphosphate, Zeolite 1-3mm and Magrilime. Both beds were top dressed with a compressed pelletised organic seaweed fertiliser (Seamungus), and mulched with lucerne hay. Both were fertilised topically fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was applied topically once a month.

The beds were planted out with eggplant, zucchini, basil, carrots, beetroot, lettuce, chilli, capsicum, silverbeet, celery, rocket, mizuna and marigolds. These beds were planted out in November 2013 and the costs for the beds was $1350.62 plus labour.

Vertical Gardens.

This roof is located at 5th floor level on Harris Street in Sydney. The roof faces North West. The roof construction comprises reinforced concrete with an impervious tiled covering. The roof is designed for access and has a concrete parapet wall approximately 1200 mm high and 200 mm deep to one side. Two sides are flanked by buildings which rise to a height of 7 floors and 20 floors. The remaining edge has a metal framed glazed fence and over looks an internal courtyard at fourth floor level. The roof is enclosed on all sides by tall buildings. In summer months, when the sun is high there are around six hours of direct sunlight on the roof, however in winter months there is minimal direct sun. Furthermore the buildings do encourage very high wind levels at times. There is lift access to level 5 however there are steps out onto the roof terrace area which made transportation less easy. The garden beds used on this site were supplied by V

Gardens in Sydney. The beds have a timber frame and a large base bed with a series of metal framed horizontal trays to a height of 1600 mm. The horizontal trays are approximately 150 mm deep. One bed has a self-watering system on a 12 volt timer which utilises a submersible 12 volt pump and drippers. It is powered by a battery which is recharged by photovoltaic cells and the sun. The reservoir at the base of the garden houses the submersible pump and acts as a wicking bed for the lowest garden. The second bed is identical in design apart from the irrigation system and wicking bed. See plate 4.

These beds were planted with a variety of herbs including basil, mint and oregano and vegetables such as lettuce, eggplants, silverbeet, and capsicums. Larger root vegetables such as carrots and beetroots were grown in the base bed. The beds were planted out in November 2013.

Plate 4 V Gardens on DAB Level 5 roof

Results and interpretation

Social

There has been considerable interaction and interest from staff within the faculties where the beds are sited around the university. This interest is focussed on what has been planted, and whether anyone can join in to water the plants and harvest the food. Without prompting, staff in the DAB put up a wall calendar with a pen in the staff kitchen to record whether the plants had been watered. When watered, the staff member or person simply ticks the date and others know when the plants have been watered. It is a simple system and few plants died despite a record breaking hot, dry Sydney summer. People ask and talk about the plants regularly and will often describe the meals they have cooked with the plants and the flavour of the herbs and vegetables they have used. Other staff such as security guards also expressed interest in the rooftop gardens, imparting tips and guidance where they think it needed. One staff member, upon learning that the beds were an experiment to see what could be grown on Sydney rooftops, noted that 'this is why the Cubans survived and the North Koreans starved to death'. They have given advice also about the timing of the watering and care of the plants. Students approach the researchers when attending the gardens at Gumal and chat freely about the plants. One student this semester, a journalism student from Germany decided to write about the gardens for her assignment.

Industrial design students have used the gardens and rooftop agriculture in their major design projects. Overall the social interactions are high and positive.

Economic

The costs of the beds varied as described above. Furthermore the amount of growing space also differed between the three roofs. The costs are reasonably affordable, although it would take many years to grow sufficient food to pay back the initial costs.

Environmental considerations

The three locations experience different weather conditions to some extent. For example the Gumal rooftop is exposed to sun and high winds, which scorched the plants on a number of hot summer days. The beds needed more watering due to accelerated evapotranspiration. The Science roof however was sheltered from wind on three sides as described, and the plants received more shade during the hottest months resulting in less leaf burn and water stress. High winds were experienced in the DAB roof area and although the V Garden's construction, with the weight centred at the base meant that neither structure was affected by the winds, some of the larger vegetables were badly battered on these occasions. The DAB roof is surrounded by high buildings on all four sides and consequently during autumn and winter periods less direct sun is experienced on the roof and this will effect production rate. However in the summer the plants here have more respite from the effects of intense heat and direct sunlight.

In terms of thermal performance, the installation of rooftop gardens should inevitably result in some reductions in cooling loads. Due to the inherent thermal properties of shading, the temperature under the raised bed was significantly cooler and this provided a reduction in the temperature of the roof covering. With the wicking bed and its direct surface contact, higher levels of thermal performance would be expected. No data was recorded on temperatures in the rooms directly below the beds though this might be worth exploring in the future. Given the absorptive properties of the growing mediums, there was as was to be expected, a noticeable diminution in the amount of water entering the rainwater drainage systems of each of the roofs as a result of the installation of the garden beds. The Gumal beds had plastic tanks sited below the drainage outlet and this allowed the researchers to ascertain the approximate amounts of pluvial runoff from the beds compared to rainfall recorded in a rain gauge. The science roof beds drained onto the roof and into an open drainage channel. No silting of the drains occurred on any of the roofs as the geotextile fabric ensured only water passed through the textile.

With regards to attracting bio-diversity, as soon as all three roofs were planted insects appeared. Native and European bees were spotted on all sites. On the Gumal roof a group of cockatoos visited the site on the first day and uprooted the majority of the plants. Protective screens of wire mesh were fixed temporarily to deter the birds. Both yellow and orange lady beetles encamped within just a few weeks and within all the beds worms are seen on a regular basis. No actual tests have been conducted on air quality around the beds but it should be the case that the air should have higher levels of oxygen and lower carbon dioxide as the plants photosynthesise.

Physical and location

Access to all three roofs varied. Gumal, because it was always intended for public access had amenable conditions from the basement car park through to the rooftop. There are convenient water and power sources on this roof too. The recycled plastic garden beds were delivered in a long tube which was lightweight and could fit in the passenger lift. The prefabricated trestle frames and the pine sheet were heavy and cumbersome but these also could fit in the lift, as did the substrates and membranes. The 3600 mm rails had to be carried up the fire stairs. Once assembled these beds were very heavy and not easily relocated.

With the science roof access was via a goods lift from the car park to level 7. However due to the sensitivity and security concerns of the science labs, special access had to be negotiated for the researchers and no public access was possible. With the DAB roof top there is lift access to the floor but the space planning and configuration of offices meant there was a circuitous route to get the V Garden to the roof top. Fortunately the units are not too heavy for two people to carry. The DAB roof does not have a water or power supply and therefore water has to be transported from the adjoining staff kitchen to the gardens. Although a solar powered pump on the larger bed with the wicking bed provides irrigation to that bed, it does require topping up with water on a regular basis. Table 1 summarises the three bed types and their performance in respect of the categories described above.

	Bed 1 – Science roof wicking bed	**Bed 2 – Gumal raised bed**	**Bed 3 – V Garden**
Transportability and assembly.	Very easy.	Difficult. Some carpentry skills required.	Units easily transported with 2 people and a trolley but location presented a challenge.
Ease of working.	Low to ground.	Easy.	Very easy.
Costs / metre square of growing area.	Medium.	Very High.	High.
Ease of watering	Easy.	Manual, every other day in summer.	Easy.
Plant growth	Very good.	Varied.	Good.
Water usage	Low.	Medium to high.	Medium.
Exposure to wind	Low.	High.	high
Exposure to excessive summer sun/heat	Medium.	High.	Medium.
Bio-diversity attracted to bed	Very Good.	Very good.	Good.

Conclusions and further study

This research reports on three rooftops set up in 2013 in Sydney which are producing food. The social, economic and environmental aspects and physical aspects of the installation are described in this paper.

Despite varying conditions on all three rooftops, production over the summer period in 2014 was good. There were different challenges with all three roofs with the physical environment and environmental conditions. The social impacts were overwhelmingly positive in all respects. Economically there is variation in the costs of the beds and amount of skill and labour required for installation and set-up, however there are options to suit most budgets.

This project did not test any of the plants grown for the presence of heavy metals and this work is currently underway and will be reportedly in a following paper. Further funding is being sought to measure and ascertain the impact on thermal performance on buildings of the rooftop beds.

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Appendix 1 Survey questionnaire, consent form and information sheet social impact of UTS Staff Student garden club

Appendix 2 How to guides