Sprouting greenroofs in New Zealand

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Greenroofs are roofs that grow plants. Just like conventional roofs they are waterproof – a series of membranes seal the building, keeping the weather out and the occupants dry. Unlike conventional roofs, the plants and growing media provide benefits, ranging from noise and energy insulation to storm-water mitigation and animal habitat – and they also look great! The ancestor of modern greenroofs is the thick Scandinavian and Irish turf or sod roof, once common because sod was inexpensive and readily available. The parents of modern greenroofs are roof gardens in which plants are grown either in irrigated containers or relatively deep beds (Fig. 1) to enhance aesthetics and provide passive recreational space.

Fig. 1 Intensive greenroof on carpark roof used for amenity and recreational space, Eden Valley commercial building, Auckland.

Some London Parks are greenroofs, for example, the Jubilee Gardens in Canary Wharf (Gedge and Kadas, 2005). Roof gardens include New Zealand's most famous greenroof, on Kawakawa's Hunterwasser toilets (Fig. 2). They are technically described as *intensive greenroofs*. A heavily reinforced roof supports a relatively deep substrate growing a range of plants that are not very different from those found in landscaped areas. Such greenroofs require regular weeding, maintenance and are tended, and usually irrigated.

Fig. 2 Kawakawa's Hunterwasser greenroof (front view).

Extensive greenroofs are lightweight, cover the majority of a roof, and are not usually designed to be walked on. Their lightness (75 to 150 kg/m^2 saturated mass) comes from a combination of a shallow substrate (50 to 150 mm) and low density – they have dry weights of 0.5 to 0.8 T/m^3 compared with common natural soils that weigh in at 0.9 to 1.3 T/m^3. Extensive greenroofs are much cheaper than intensive greenroofs and roof gardens because additional structural support, needed to hold up the roof, is minimised and maintenance is low as these roofs are planted with dense, wind and drought-resistant groundcovers (<200 mm high) and generally not irrigated. Extensive greenroofs can provide the following benefits:

- cost savings by extending the life of the underlying roof, and insulating the building. The insulation helps the building stay warmer in winter and cooler in summer (Wong et al., 2003)
- sound insulation – both substrate and plants absorb sound waves
- stormwater reduction – the substrate acts like a sponge to absorb, delay, and slowly release stormwater, therefore reducing peak loads on city drainage infrastructure, especially during small storms and in summer (Fig. 3). These stormwater benefits are the key driver of greenroofs in many countries

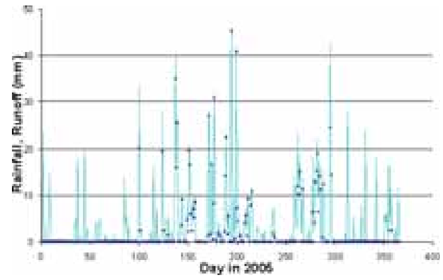

Fig. 3 Modelled storm-water runoff from the 150 mm deep Waitakere Civic Centre greenroof that stores 24 mm of plant-available moisture. The pale blue line shows the rainfall on each day from 1 January to 30 December 2005. The dark blue dots show how much of the rainfall would have seeped from the roof. The model shows this non-irrigated, extensive greenroof would have captured 680 of the 1300 mm of rainfall in 2005, including nearly all the rainfall between November and March.

- moderation of the urban 'heat island' effect by evaporative cooling, lower heat absorbance and reduced reflectance compared to conventional roofs (Wong et al., 2003)
- refuges for insects, plants and birds. In Europe some greenroofs are designed to mimic natural ecosystems, especially riversides and alpine meadows. Greenroofs can support a diverse insect community (including rare species), and ground-nesting birds (e.g., skylarks, lapwing and little-ringed plover), keeping them safe from disturbance (Brenneisen, 2003; Gedge and Kadas, 2005). In New Zealand, greenroofs could create surrogate sand dune, cliff, braided river bed, and lava flow ecosystems
- filtering dust and pollutants from air passing through the plants

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- aesthetic benefits – helping buildings blend into adjacent natural environments (Fig. 4) or enhancing otherwise barren rooftops, especially in densely populated areas (Fig. 5).

Fig. 4 Greenroofs on toilet blocks at Maori Bay on North Auckland's west coast, successfully blend the structures into the adjoining natural setting of a regional park.

Fig. 5 Beesonline creates recreational space with herbs and lawn species. *Selliera radicans* would be an alternative species that requires no mowing but would not be as tolerant to foot traffic. Surface water drains to grates that have outlet boxes protruding from the right hand side of the building.

Greenroofs may not afford much treatment of storm-water as runoff tends to include contaminants, particularly phosphorus, which may be released during establishment and if fertilised with readily soluble fertilisers or over-fertilised. However, overseas studies indicate greenroofs can act as filters, and the majority of contaminants in runoff from greenroofs are in lower concentrations than typically found in other urban runoff (Berndtsson et al., 2005).

Barriers to commercial greenroofs in New Zealand

Extensive greenroofs, such as those used in Germany for 30 years or more, are undergoing a renaissance in northern Europe, and becoming a new trend in urban design (Berndtsson et al., 2005). Most greenroofs in New Zealand are on domestic dwellings built by their enthusiastic owners (Fig. 6), and are often regarded as 'fringe'. New Zealanders enthused by seeing the benefits of greenroofs overseas face large challenges to get greenroofs built on commercial buildings in New Zealand, even though greenroofs are already scattered around New Zealand. Planners and Territorial Local Authorities have found if difficult to promote greenroofs for New Zealand commercial buildings because of a lack of existing sites where these roofs can be seen and tested, and without specific local cost/benefit information.

Fig. 6 A sloping greenroof on a domestic dwelling in Canterbury supports pasture grasses, mosses, lichens and native orchids. A skylight protrudes through the lower roof and a chimney through the upper roof.

The key barriers to more widespread adoption of greenroofs in New Zealand are the same as those identified for the United States by Beattie and Berghage (2004a) and Happe (2005). These barriers include:

- Lack of technical knowledge on what substrates and plants available in New Zealand are suitable for use on greenroofs. Sedums, exotic succulents, are the most common plant used for extensive greenroofs overseas, however, there are no native New Zealand sedums, and many sedums are potentially weedy in certain New Zealand environments
- Until 2006 there was no greenroof industry that could supply purpose-grown plants and undertake the whole greenroof installation. As a result, greenroofs were constructed by multiple, small contractors. This increased project management costs, and inexperience meant contractors' quotes were very conservative (i.e., inflated)
- Costs and benefits had not been quantified for New Zealand conditions. Most benefits of greenroofs accrue to the occupier of the building, not the builder or developer, and are medium term. There is a high cost to being at the leading edge. Greenroofs in Europe are relatively low-cost (c. $US 40/m²) compared to New Zealand and the United States where the industry is young (c. $US80–200/m², Beattie and Berghage, 2004b). Research on greenroofs has been developed mainly in Germany and published in German; there is little research in peer-reviewed scientific journals (Beattie and Berghage, 2004a)
- People have a general aversion to new technology they cannot experience before adoption. A common misconception is that greenroofs leak or are expensive to maintain. Greenroofs do not leak if suitable waterproof membranes are used (like any building) and are installed properly (like any building). Unlike most roofs, greenroofs are usually flood tested before drainage and substrate are laid.

Faced with these barriers, Waitakere City Council and Auckland Regional Council independently decided to support research, installation and monitoring of the first (to our knowledge) extensive New Zealand greenroofs on large commercial buildings: the Waitakere Civic Centre, and the School of Engineering at the University of Auckland city campus.

Research to overcome the barriers

Substrates

The media used in greenroofs need to balance the engineering requirement of light weight and rapid permeability (roofs must not flood), with water and nutrient storage for plant growth, and cost. We decided the ideal substrate would be locally sourced, and should meet the following specifications, which generally conform to the German Greenroof Standards:

- a saturated weight of less than 100 kg/m² (Auckland University) and 230 kg/m² (Waitakere City)
- hydraulic conductivity greater than 100 mm/hour at installation to avoid ponding and potentially avoid the need for a drainage layer. This means plant roots maintain adequate aeration.

Aeration is important, because many drought-tolerant plants are intolerant of 'wet feet'

- more than 20 mm moisture stored immediately after watering
- moderate bearing strength, able to support foot-traffic (construction and maintenance staff) without crumbling or overly compacting
- minimal shrink/swell and slow development of hydrophobicity so the substrate absorbs water evenly and consistently
- moderate ability to store and supply nutrients for plant growth without leaching high concentrations of nutrients
- materials that are readily available in New Zealand. Substrates based on pumice, zeolite, bark and compost/soil mixes were compared with expanded clay (Fig. 7), a product imported from Germany that is widely used in European greenroofs and by some New Zealand hydroponic growers.

Fig. 7 *Disphyma australe* (New Zealand iceplant) growing in a substrate containing expanded clay balls.

The physical properties of substrates measured in laboratory tests, where small volumes were sourced and then mixed by hand, changed when mixed in commercial volumes. Pumice, and some compost products, had significantly different moisture contents and particle size distributions when supplied by the tonne, rather than in 40 litre bags. Wet pumice and composts release water when fiercely mixed together in industrial mixers, with the final mixes having poorer structure, and being heavier than anticipated. Fortunately, all four substrates installed were lighter than the specified saturated weight maxima. Zeolite and expanded clay, being relatively dry products, created lighter mixes that were easier to handle than straight pumice/compost mixes. Alternatively, components of substrate mixes could be stored under cover, or mixed in late summer, to avoid high moisture contents.

All mixes tested had adequate nutrient storage. Mixes with composted bark needed a slow-release nitrogen fertiliser to help the plants establish, whereas mixes with compost created from fresh greenwaste required no initial fertiliser, but generated a tea-coloured leachate with a high nitrogen concentration when first spread. This leachate would pollute waterways. Mixes with natural soils leached less nitrogen, but contained a large and diverse annual and perennial weed population, including legumes (clover and gorse) and grasses

Plants

The plant species suitable for greenroofs depend largely on the local climate, type and depth (moisture storage) of the growing medium and maintenance expectations, in particular, whether irrigation is available. Plant species suitable for greenroofs need to establish a dense, weed-resistant groundcover in a droughty and very exposed environment. The German standard requires a minimum 60% cover after one year. Sedums, succulent plants in the Crassulaceae family, are the main genus grown on extensive greenroofs in Europe and the United States. They are established from seed, plant fragments, small plugs, or instant mats (Fig. 8).

Fig. 8 A sedum mat is rolled out on the University of Auckland roof, creating an instant mosaic of vegetation. The lower photo shows the mat after several weeks.

Sedum acre, *S. album*, *S. reflexum* and *S. telephium* are probably the most common species used, however some sedums are weeds in New Zealand, e.g., *Sedum acre*, and none are native. The research had twin aims; to find native plants with high survival and cover on the Auckland extensive greenroofs in the absence of irrigation, and, for the Auckland Regional Council project in which sedums were planted along with natives, to quantify the spread and comparative performance of sedums. In addition to survival and cover, Waitakere City specified that the preferred species would also:

- be native to New Zealand, and preferably sourced from the Waitakere Ecological District
- be able to be used to create an aesthetically attractive landscape, through variety of texture, colour and/or form and reflect seasonal changes through fruits, flowers or foliage changes, as the roof is overlooked by an adjacent wing of the building
- be readily available from nurseries, so others could easily adopt the greenroof technology
- provide habitat or food (nectar or fruits) for native insects and/or birds.

A field trial over summer 2005/06 identified *Coprosma acerosa*, in its most prostrate form, *Disphyma australe*, *Libertia peregrinans*, *Calystegia soldanella* (sand dune convolvulus) and *Festuca coxii* as the most drought-tolerant of 15 native species tested. Both *Coprosma* and *Libertia* were susceptible to collar-rock (wind damage) if seedlings were not planted deep enough, or, for *Coprosma*, were not a sufficiently prostrate form. Coprosmas were pruned after planting to remove the most upright growth and to reduce 'sail' area. Unfortunately, growers were unable to supply adequate numbers of *Calystegia* or native crassulas. *Crassula sieberiana* was harvested from scoria walls around Auckland. Only a grower associated with a specialist greenroof company was able to supply large numbers of plugs and small native plants (Fig. 9D) that could be planted in substrates as thin as 50 mm without removing large volumes of the root ball. The same company provided pre-grown sedum mats for the Auckland University greenroof (Fig. 8). These mats achieved a very high plant cover almost immediately, mirroring the results of Swedish researchers Emilsson and Rolf (2005).

Installation and monitoring

Installing a greenroof can be a fast process: the substrate for both greenroofs, one 500 m^2 and the other 200 m^2, was largely installed in one day – which is beneficial because a crane is needed to transport and suspend the tonnes of substrate above the roof to prevent overloading (Fig. 9A, 9B) Planting sedums and small natives (Fig. 9D) at about 18 plants/m^2 was also fast, the slowest step being laying out according to the planting plan. Using PB3 seedlings was slow (Fig. 9C, 9E), as up to half the potting mix needed to be removed before planting, and the excess mix removed from the roof. All native plants were thoroughly soaked before planting, and the roof watered after planting. Watering also created a surface layer of coarse pumice, expanded clay balls and/or zeolite that acted as a protecting layer. On the Waitakere roof a thin (5 to 10 mm) layer of expanded clay was spread over the surface to ensure such a layer was created (Fig. 7). Both roofs were unscathed by a large storm (c. 1 in 10 year event) in September 2006 when more than 100 mm of rain fell over 24 hours.

Fig. 9A–E Installation of a greenroof on the Waitakere Civic Centre.

Fig. 9A A crane delivers substrate in bags weighing about 1 tonne each.

Fig. 9B Substrate must be unloaded without bags resting on the roof (the bags are too heavy). In the foreground interlocking sections of a rigid drainage board can be seen. An overlying filter cloth protects ensures substrate does not block up the drainage board. The Auckland University greenroof used a thinner, lighter, flexible drainage mat with built-in filter fabric. Both drainage materials physically protect the underlying membranes from damage.

Fig. 9C and **Fig. 9D** The Waitakere roof was divided into four zones, each with a different planting plan: the parapet edge with a high proportion screening plants; upstands with plants tolerant of foot traffic; pergola edge containing *Muehlenbeckia complexa*; and bulk planting. Plant brokers could only supply standard plant sizes (PB3 and PB5) – the native plants used on the Auckland University roof (Fig. 9D) were much more suitable as they were smaller and did not need root trimming before planting into the shallow substrate with reduced transplant shock.

Fig. 9E Waitakere Roof about four months after establishment. The grass *Festuca coxii* and spiky orange *Libertia peregrinans* (New Zealand iris) screen the parapet edges with *Coprosma acerosa* (sand dune coprosma), while *Pimelea prostrata* is the grey groundcover with white flowers interspersed with the bright green *Disphyma australe* (New Zealand iceplant), *Dichondra repens* (Mercury Bay weed), *Selliera radicans*, and *Acaena microphylla* (bidibid).

The performance of both roofs is now being monitored and compared with adjacent conventional roofs. The primary performance measures are hydrological (storm water detention and runoff volume) and plant performance. Insect abundance and diversity will also be quantified using methods suited to such windy environments and low-stature vegetation – spiders, bees and butterflies are already using the Waitakere roof. The range of plants and substrates will be refined in glasshouse and laboratory trials.

Conclusion

Construction and monitoring of two extensive greenroofs have been funded by Waitakere City Council and Auckland Regional Council to provide quantitative information to help overcome barriers to adoption of greenroofs on commercial buildings in New Zealand. We hope to look down from the Sky Tower in five years time and see a proliferation of living roofs absorbing and slowly releasing stormwater, providing habitat for birds and insects, helping to reduce the noise, heat and energy demands of cities. With your help and enthusiasm for planting we are looking forward to the day that green roofs endow our cities with a network of biodiverse stepping stones.

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Useful websites

www.greenroofs.net
www.greenroofs.co.nz
www.landcareresearch.co.nz
www.livingroofs.org

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