Living Roofs for Living Cities

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Introduction

The term "*Living Roof*" refers to a wide range of systems developed to provide a growing medium for vegetation on roofs of buildings and structures, acknowledging the natural variation of system appearance and dynamics (e.g. as plants thrive or go dormant). Originating from historical applications for insulation and interior thermal benefits, living roofs are now increasingly recognised for the wide range of other tangible and intangible benefits that they offer.

Morphum Environmental believe integrating living roofs into new and existing structures opens opportunity to provide meaningful benefits to the local environment, community, and businesses. Whilst living roofs are a relatively new 'technology' in New Zealand, they have a long history internationally where they are increasingly being designed for in highly built up urban centres. For those committed to sustainability and environmental stewardship, living roofs could provide a powerful and engaging marketing tool to communicate this to consumers.

There are numerous technical and aesthetic considerations which can influence the site specific design of living roofs. These considerations (such as structural redundancies) will directly influence the type of roof system used and the 'look' of the living roof. Through clever design, the structure (growth medium) and plant selection can vary across the roof to optimise the visual impact whilst being mindful of structural boundaries, maintenance, capital costs, receiving environment and specific local biodiversity.

The following provides a high level snap shot of some of the design and performance attributes of typical Living Roofs.

Background

A living roof typically consists of multiple layers (Figure 1), each of which plays an important role in the overall system function. Not shown in Figure 1 is a building insulation layer which is typically considered by an architect in the design of the building structure, rather than as a component of the system that sits atop the roof deck.

Figure 1. Typical Living Roof Composition

Two main living roof categories are defined based on substrate depth: intensive (≥200 mm depth, 300–1000 kg/m^2) and extensive (≤150 mm depth, 70–170 kg/m^2). The shallow substrate for an extensive living roof limits the plant height and species that can be grown without irrigation but extensive living roofs are better suited for retrofit application due to lighter weight (structural) requirements compared to their intensive counterparts.

Benefits

In the New Zealand context, living roofs are typically recognised as a water sensitive design (WSD) technology for stormwater management. However, living roofs achieve multiple benefits which operate at a range of scales. Some are only apparent when relatively large numbers of roofs are greened in a neighbourhood or region, while other benefits are realised at a single building scale. Living roof benefits can be loosely divided into three overlapping categories (Table 1):

- Amenity and aesthetic benefits,
- Environmental benefits, and
- Economic benefits.

Table 1. Benefits of Living Roofs

<table>
<tr><th>Benefit Type</th><th>Public Benefit / Large Scale</th><th>Private Benefit / Smaller Scale</th></tr>
<tr><td rowspan="4">Amenity and Aesthetic Value</td><td colspan="2">Amenity value as a recreational space*</td></tr>
<tr><td colspan="2">Amenity value by reducing visibility of buildings and structures in natural landscapes (e.g. coastal, rural and mountainous landscapes)</td></tr>
<tr><td colspan="2">Food production*</td></tr>
<tr><td colspan="2">Aesthetic value/ Quality of Life* - therapeutic effects such as stress reduction, lowering blood pressure, relieving muscle tension and increased positive feeling. Benefits occur if the roof is accessible, but also if it is merely visible from adjacent living or office space.</td></tr>
<tr><td rowspan="6">Economic Value</td><td>-</td><td>Increased roof life through solar protection</td></tr>
<tr><td>-</td><td>Increased insulation and energy efficiency through reduced air-conditioning costs</td></tr>
<tr><td>-</td><td>Use as a tool for green building assessment (such as LEED or GreenStar) and public relations (using the building to present an environmental attitude)</td></tr>
<tr><td>-</td><td>Increased building value via ease of tenanting</td></tr>
<tr><td>-</td><td>Decreased hospital stay via faster recovery</td></tr>
<tr><td>-</td><td>Increase fire resistance of the roof</td></tr>
<tr><td rowspan="5">Environmental Value</td><td>Biodiversity/ wildlife value
▪ Provide urban habitat
▪ Conserve/restore endangered habitat & vegetation types
▪ Create green space networks linking larger habitat patches for more mobile species
▪ Aid visual green space continuity</td><td>-</td></tr>
<tr><td colspan="2">Stormwater management#
▪ Reduce runoff volume and peak flow rates
▪ Delay runoff (increase time to peak flow)
▪ Act as a source control, prevents reticulated network overflows</td></tr>
<tr><td>Air pollution
▪ Filter airborne particles
▪ Absorb gaseous pollutants
▪ Release oxygen</td><td>-</td></tr>
<tr><td>Urban heat island effect
▪ During daylight hours, air temperature is cooled through the process of evapotranspiration
▪ Overnight, the amount of heat radiated from dark/ hard roof surfaces is reduced</td><td>-</td></tr>
<tr><td>-</td><td>Noise pollution
▪ Absorbs sound
▪ Lower frequencies absorbed by the substrate
▪ Higher frequencies by the vegetation</td></tr>
<tr><td colspan="3">* Potential value at both the public and private scales dependent on individual roof design, location and/or accessibility.
Stormwater management by living roofs may benefit the building owner in locations where incentives are in place (i.e. increased floor area or reduced stormwater management costs when living roofs are installed).</td></tr>
</table>

Figure 2. Examples of New Zealand living roofs with varying design purposes

Kaitiakitanga & Living Roofs

Māori have a spiritual association with the land. The widely-held belief is that through the phases of creation a physical and spiritual element was created when Ranginui (the sky father) and Papatūānuku (the earth mother) were separated by their children. Once the parents were separated their children occupied and flourished in the various realms created; Tāne Māhuta covering the land, Tangāroa the oceans, Tūtewehiwehi the fresh water rivers and lakes, and Tawhirimātea the air space between their separated parents. A consequence of the separation of Ranginui and Papatūānuku was that each would grieve for the other, and so rainfall is Nga Roimata

O Ranginui (the tears of Rangi) while the wellsprings Nga Puna Tapu O Nga Atua (the weeping of Papa).

The physical and spiritual elements evolving from the creation of the world are bound by mauri. Mauri is the essence or life force that provides life to all living things and the potential to support life to water and land; it was passed from Ranginui and Papatūānuku to their children. Mauri establishes the inter-relatedness of all living things. Mauri should not be altered to the extent that it is no longer recognisable, that is, the essential character of a site must not be changed as a result of human intervention. Due to their spiritual origins, water from rainfall and springs is considered sacred and is only suitable for human use after it has travelled over Papatūānuku. The basic premise is that once used, water should be returned to Papatūānuku if the mauri of that water is not suitable for the subsequent use.

Māori values of guardianship aim to retain the integrity of the receiving water and surrounding environment, thus maintaining the mauri of the water and ecosystem as a whole. Living roofs demonstrate compatibility with both current Western sustainable design principles and traditional Māori values. Peak flow and volume control by living roofs help achieve water sensitive design goals to maintain a site's predevelopment hydrology, but also adhere to the ethic of kaitiakitanga. Rainwater and associated contaminants are managed onsite rather than being piped and discharged directly to the receiving water body at accelerated flow rates and increased volumes, negatively affecting the mauri of the water. Although a living roof is not directly connected to the earth, the substrate is of the earth. In addition to stormwater management benefits, living roofs provide aesthetic, amenity, and biodiversity value, improve urban air quality and reduce the heat island effect (Table 1) further enhancing the mauri of what may otherwise be stark conventional urban developments. A treatment train approach (integrating infiltration practices, for example) would add further value in meeting traditional Māori principles.

Living Roof Performance

Stormwater volume reduction

Field monitoring of extensive living roofs shows a substantial contribution to site runoff volume control with international studies reporting 49–80% of precipitation retained over extended periods of data collection. Multiple extensive living roofs ranging in depth from 50 mm – 150 mm have been monitored across Auckland. Results show 39-57% less cumulative runoff from living roofs than from a conventional roof surface at the same site.

Excellent performance for small storm events is usually observed, with reduced retention in very large, infrequent events. The median runoff depth across all of Auckland's monitored living roofs for rainfall events from 2–25 mm was 1.9 mm while the mode was 0.03 mm. In other words, during the majority of rainfall events, there was no meaningful runoff from any of the living roofs monitored.

The excellent performance of extensive living roofs in Auckland is attributed to a combination of substrates designed with moderate to high water-holding capacity and plant coverage, and most storms having less than 25 mm rain per event. Slightly reduced retention performance on an individual-event basis was observed during the few very large storms (i.e. greater than 75 mm rainfall) and in winter when ET is suppressed; however, significant runoff reductions were always observed compared to conventional roof surfaces.

Across individual studies, climate factors such as rainfall depth and intensity, antecedent dry period, solar radiation, relative humidity, temperature, and ET influence performance as do substrate moisture storage capacity and depth.

Stormwater peak flow reduction

Peak flow reduction reported in literature from an individual living roof ranges from 31–87%. Median peak flow reduction per event for Auckland's extensive living roofs ranged 62-90%, depending on the site.

In practice, the configuration of vertical and horizontal flow paths in a living roof influence the peak flow control provided. A granular (aggregate) drainage layer may provide greater peak flow reduction compared to a synthetic drainage layer, as runoff has to flow through a porous media to reach the gutter. The horizontal distance to a roof's vertical drainage system (e.g. scuppers and downspouts) and the roughness of the drainage layer may also influence peak flow attenuation.

Stormwater Quality

Unlike most ground-level stormwater devices, a living roof usually "treats" only the rain falling directly over its surface. Thus, the primary sources of potential contaminants in living roof runoff is limited to atmospheric deposition, and the materials comprising and used to manage the living roofs, their runoff, and underlying buildings themselves. In sites with roof-mounted air-conditioning units using copper piping, discharges of water may be elevated in copper. Copper adornments are likely to have similar effects, if allowed to come into contact with rain water.

Living roofs should primarily be considered as a tool for runoff volume and peak flow reduction, with some associated benefit in contaminant mass reduction, rather than as a specific water quality control tool.

Air Pollution

Polluted air is directly attributed to declines in human health. The most common health related symptoms of air pollution are increased occurrences of respiratory illnesses such as asthma and a greater incidence of cardiovascular disease.

There has been much published on the ability of plants to clean the air, but little specific to living roofs. While general conclusions cannot be made, studies in a number of cities demonstrate clear benefits, or potential for benefits, for air quality with widespread implementation of living roofs:

- If 20% of all industrial and commercial roof surfaces in Detroit, MI, were traditional extensive sedum living roofs, over 800,000 kg (889 tons) per year of NO_2 (or 0.5% of that area's emissions) would be removed.
- In Singapore, sulphur dioxide and nitrous acid were reduced 37% and 21%, respectively, directly above a living roof.
- 2000 m^2 of uncut grass on a living roof can remove up to 4000 kg of particulate matter. As a gasoline powered automobile produces approximately 0.01 g of particulate matter for every mile driven. ***If a vehicle is driven 10,000 miles per year, then one square meter of living roof could offset the annual particulate matter emissions of one car.***

- Results assessing the effects of living roofs on air pollution in Chicago showed that air pollutants were removed at a rate of 85 kg/ha/yr with ozone accounting for 52% of the total followed by NO_2 (27%), particles of 10 µm or less (14%), and SO_2 (7%).
- If 20% of all existing "living roof ready" buildings in Washington, DC, installed living roofs, the resulting plantings would remove the same amount of air pollution as 17,000 street trees

Carbon dioxide

Living roofs can play a part in reducing CO_2 in the atmosphere in two ways:

1. Carbon is a major component of plant structures and is naturally sequestered in plant tissues through photosynthesis and into the soil substrate via plant litter and root exudates.
2. Living roofs reduce energy needs by insulating individual buildings and by mitigating the urban heat island effect.

A living roof will eventually reach a carbon equilibrium (plant growth = plant decomposition), but initially this man-made ecosystem will serve as a carbon sink.

In the U.S., buildings are responsible for 38% of carbon dioxide emissions. When the effects of living roofs on the energy balance of an individual building are modelled, a 2% reduction in electricity consumption and a 9–11% reduction in natural gas are demonstrated. A generic building with a 2000 m^2 living roof would result in annual savings ranging from 27.2 to 30.7 GJ of electricity and 9.5 to 38.6 GJ of natural gas, depending on climate and living roof design.

Noise reduction

Conventional roofs are generally hard surfaces so the potential to reduce sound pressure from roads and other sources in these areas by implementing green roofs is promising. Vegetation in combination with the growing substrate will absorb sound waves to a greater degree than a hard surface.

Because living roof growing substrates tend to be coarse, sound waves enter the pore space and are attenuated by the numerous interactions with the substrate particles. Relative to a conventional roof the reduction is most pronounced at frequencies in the range from 500 to 1000 Hz with a maximum reduction of 10 dB. Increasing substrate depth improved noise reduction up to a depth of 15–20 cm.

Many variables influenced noise attenuation including the width–height ratio of the street canyon, façade absorption, diffuse reflection, and building-induced refraction of sound. On the inside of a building noise levels also depend on façade insulation, the sound pressure level outdoors, and whether windows are open or closed. Thus living roofs can have a positive influence on buildings near airports, industrial areas, and in urban settings.

Synergies with photovoltaic cells

Living roofs and photovoltaic cells are complementary technologies that improve each other's performance. The photovoltaic cells function 10-15% more efficiently due to the cooler microclimate above a living roof, while the living roof vegetation benefits from areas shade demonstrating improved growth and foliage density.

Conclusion

Morphum's strong passion for Environmental Engineering solutions and understanding of site specific biodiversity and ecological contexts, combined with Living Roof experience, will enable clients to capitalise on the unique opportunity to provide some solid environmental benefits. As a high profile and potentially highly visible initiative, Living Roof installation could provide significant marketing value, particularly as an early 'trail blazer' in the New Zealand market where the implementation of Living Roofs has been somewhat slow compared to many international geographies.

Morphum would welcome the opportunity to discuss Living Roofs further. Design specifications are site specific; Morphum can offer variability in outcomes to suit individual sites based upon climatic variability, structural capacity, desired functionality, and aesthetics.

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