ENVIRONMENT DESIGN GUIDE

GREEN ROOFS – UNDERSTANDING THEIR BENEFITS FOR AUSTRALIA

Susan Loh

Summary of

Actions Towards Sustainable Outcomes

Environmental Issues/Principal Impacts

The increased growth of cities is intensifying their impact on people and the environment through:

- increased use of energy for the heating and cooling of more buildings, leading to urban heat islands and more greenhouse gas emissions
- increased amount of hard surfaces contributing to higher temperatures in cities and more stormwater runoff
- degraded air quality and noise impact
- reduced urban biodiversity
- compromised health and general well-being of people

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Consider green roofs early in the design process in consultation with all stakeholders to enable maximised integration with building systems and to mitigate building cost (avoid constructing as a retrofit).
- Design of the green roof as part of a building's structural, mechanical and hydraulic systems could lead to structural efficiency, the ability to optimise cooling benefits and better integrated water recycling systems.
- Inform the selection of the type of green roof by considering its function, for example designing for social activity, required maintenance/access regime, recycling of water or habitat regeneration or a combination of uses.
- Evaluate existing surroundings to determine possible links to the natural environment and choice of vegetation for the green roof with availability of local plant supply and expertise.

Cutting EDGe Strategies

- Create green roofs to contribute positively to the environment through reduced urban heat island effect and building temperatures, to improved stormwater quality, increased natural habitats, provision of social spaces and opportunity for increased local food supply.
- Maximise solar panel efficiency by incorporating with design of green roof.
- Integrate multiple functions for a single green roof such as grey water recycling, food production, more bio-diverse plantings, air quality improvement and provision of delightful spaces for social interaction.

Synergies and References

- Green Roofs Australia: www.greenroofs.wordpress.com
- International Green Roof Association: www.igra-world.com
- Green Roofs for Healthy Cities (USA): www.greenroofs.org
- Centre for Urban Greenery and Ecology (Singapore): http://research.cuge.com.sg
- *Environment Design Guide*
  - DES 53: Roof and Facade Gardens
  - GEN 4: Positive Development – designing for Net Positive Impacts
  - TEC 26: Living Walls – a way to green the built environment

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The benefits of green roofs have been well documented over the last twenty years and yet their implementation in Australia has been slower than in other developed countries. This paper goes beyond the EDG introductory paper DES 53: Roof and Façade Gardens written some years ago, and looks at recent developments in green roofs and the benefits they can offer the built environment. It also describes some examples successfully implemented locally and overseas, and points out some elements that can be considered for their successful implementation in Australia.

Note: There is a glossary at the end of this paper.

Keywords:
green roof, rooftop garden, urban greenery, Urban Heat Island (UHI), vegetation

Figure 1 Proposed Chongqing Tower, China

Ken Yeang's proposal exemplifying his idea of ecological design by incorporating vegetation into a building to function as part of the ecosystem thus providing the green infrastructure such as green roofs, that can reuse rainwater, purify the air, add biodiversity or aid in the cooling of the building (Source: TR Hamzah and Yeang Sdn. Bhd, 2009)

1.0 INTRODUCTION

It is by design that we make buildings use more energy to keep cool or warm, and it is thus by design that we turn this around to make our buildings use less energy, contribute to cleaner air and to make them places that are more pleasant to live and work in.

Green roofs should not be seen as merely contributing to the functional performance of buildings by helping to lessen energy demand through the lowering of surface roof temperature. Green roofs provide important ecological services to cities though stormwater retention, lowering of urban heat island (UHI) temperatures, increased biodiversity, improved air quality, reduced noise, better aesthetics, and promotion of well-being.

This paper expands on the information DES 53: Roof and Façade Gardens by looking at some of the new developments in green roof design. It is not meant to be an exhaustive discussion on the topic but points to some of the recent research on the benefits of green roofs that are encouraging their current uptake in many cities.

Figure 2: Marina Barrage Dam, Singapore

This three-in-one facility serves as a tidal barrier to keep seawater out of Singapore's largest freshwater reservoir, enables flood control and also provides recreational space. (Source: PUB, Singapore's national water agency, 2008)

2.0 TYPES OF GREEN ROOFS

2.1 Definition

Put simply, a green roof is a roof with vegetation integrated into its design. The term 'green roof' usually refers to an engineered system, thus many people would exclude lichen growing on roofs unintentionally. Since the advent of green roofs, a green roofs industry has developed and many other variations of green roofs now exist.

The North American not-for-profit industry association, Green Roofs for Healthy Cities (GRHC) define green roofs as a system that "is an extension of the existing roof which involves a high quality water proofing and root repellent system, a drainage system, filter cloth, a lightweight growing medium and plants."(Green Roofs for Healthy Cities, 2008) Please see the aforementioned DES 53 for illustrated profiles of various green roof systems.

There are two main categories into which green roofs are divided: extensive and intensive. Currently, there is much debate as to what technically constitutes an extensive or intensive green roof as new improvements in the green roof systems allow for greater variations of use. Increasingly, what distinguishes an 'extensive' or 'intensive' roof system is whether the green roof is being used for amenities or user activities.

Extensive green roofs: Multi-national non-profit organisations such as the International Green Roofs Association (IGRA) describes extensive green roof systems as being typically characterised by shallower system profiles of 60-200mm depth, with a weight of 60-150kg/m², with lower capital cost , no added irrigation and lower maintenance (IGRA, 2009).

Intensive green roofs: IGRA also describes intensive green roof systems as those characterised by system profiles ranging from 150 to 1000mm in depth, with a weight of 180-500kg/m² and able to support a wider range of plants, though demanding more maintenance.

Variations

Some variations of the above are:

- **Brown roofs:** are a low maintenance roof made of gravel or recycled material such as crushed brick or concrete with small amount of soil providing habitat for certain types of plant and insect life, and some moss covered roofs.
- **Wetland green roofs:** are roofs that function as a wetland ecosystem usually in conjunction with grey water recycling of the building they cover.
- **Rooftop gardens:** are where planting is not integrated into the roof system, and thus are technically not classified as green roofs. However, sometimes there is no clear distinction as some rooftop gardens have an amount of intensive or

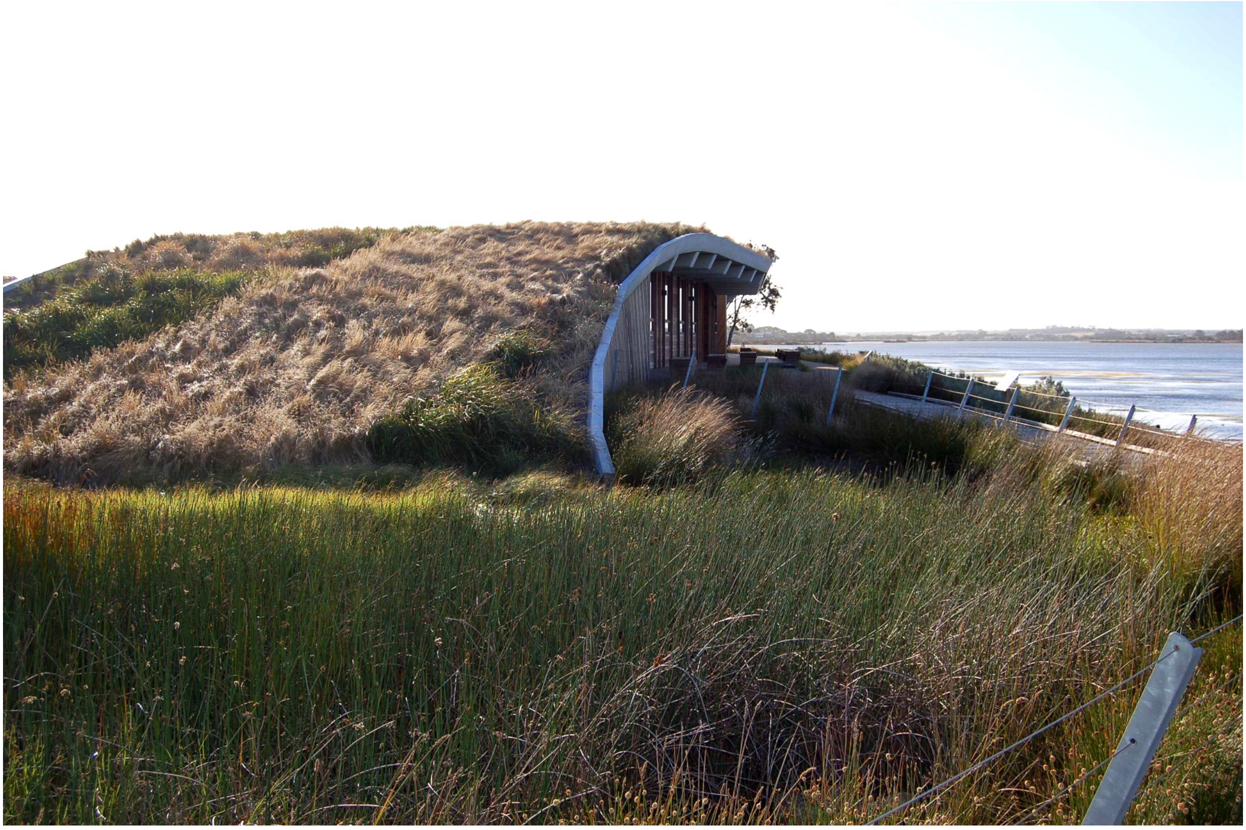

Figure 3: Marine and Freshwater Resource Institute of the Department of Public Infrastructure in Queenscliff, Victoria
(Source: Sidonie Carpenter, 2008)

extensive planting together with container planting and permeable surfaces. Green roofs are not just confined to rooftops but include gardens built on building podia, 'sky gardens' (a Singaporean term) which can occur at mid-levels of building and also apartment balcony gardens.

- **Urban agriculture:** includes examples of rooftops being used for aquaponic or hydroponic food production using either intensive green roof systems or equipment situated on rooftops. When cultivation uses containers, then the term 'green roofs' is used loosely.

Some of these systems are installed as pre-cultivated vegetation blankets rolled out on site or constructed and planted by hand when insitu on roofs. Interlocking modular systems are recently trialled overseas.

2.2 Examples of Green Roofs

2.2.1 Extensive green roofs

The shallower soil profile of extensive roof systems generally have less intensive planting such as grasses etc., which are easier to maintain. Therefore extensive roof systems have been used for larger area roofs such as the Ford assembly plant in Dearborne, Michigan, USA which has an area of about 4 hectares. Roofs such as these usually support a limited number of species of drought tolerant plants such as native grasses, or succulents, such as sedum. They usually require lower maintenance than intensive green roofs and can be designed to simulate the flora and fauna that have been displaced by the footprint of the building For example, the roof of the headquarters of Ducks Unlimited in Winnipeg, Canada was specifically designed to mimic the surrounding prairie grassland and these grasses are even burnt every few years (without harming the roof or ducks) to mimic the natural cycle of the ecosystem.

Though functional in nature, the recently constructed Marina Barrage dam in Singapore with a green roof of 20,000m² of cow grass also adds to the aesthetics of the city.

Australian examples of extensive roofs include the Marine and Freshwater Resource Institute of the Department of Public Infrastructure in Queenscliff, Victoria, which has a green roof rising from ground level, and the lawn of Australia's Parliament House. This is perhaps the most well-known extensive green roof, although some disagree that this fits into the definition of an extensive green roof.

There are other interesting uses for extensive green roofs such as a golf practice range on top of an industrial building in Birkenwerder, Germany or using cables for an 8000m² suspended green roof of wildflowers and grass for a school by Jourda and Perraudin in Lyon, France. Less novel examples of green roofs can be seen covering downtown underground car parks in Brisbane's Southbank and Perth's Central Park. These have sections of intensive and extensive green roofs over underground car parks.

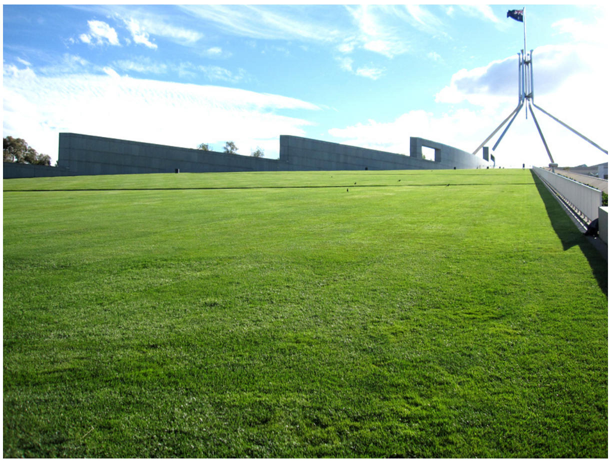

Figure 4 Parliament House, Canberra

(Source: the author, 2008)

2.2.2. Intensive green roofs

Intensive green roof systems with their deeper substrate (soil or other growing media) allow cultivation of more herbaceous plants and even shrubs and trees, for example, Chicago City Hall has 2000m² of green roof with 20,000 herbaceous plants of 158 varieties. The Banco Santander in Madrid (built 2004) and Chicago Millennium Park (built 2004) are probably the world's largest intensive green roofs with an area of close to 10 hectares each.

Figure 5 An intensive green roof added to an existing carpark, Punggol housing estate, Singapore

(Source: National Parks Board, Singapore)

Figure 6 Densely planted intensive green roof on Sydney Conservatorium of Music

(Source: the author, 2008)

The Housing and Development Board of Singapore has successfully greened many desolate multi-storey car park rooftops with intensive green roofs so that they create green oases for the densely populated housing towers that overlook them such as in Punggol and Jurong Estates (see Figure 5).

The idea of manicured green roof lawns is being replaced by examples such as the Marine and Freshwater Resource Institute of the Department of Public Infrastructure in Queenscliff, Victoria (Figure 3) and the Sydney Conservatorium of Music (Figure 6).

Some projects require more coordination and pre-planning as the green roof may need to be integrated with many other building systems. One such example is the one hectare of green roof on the California Academy of Sciences, San Francisco which is covered with 1.7million native plants, 60,000 photovoltaic cells and numerous automatically motorised skylights. A more extreme terrain example is that of the unique Subaru all-wheel 1300m² roof garden driving track (built 2005) in Singapore which allows for cars to be test driven on different terrains which include mud tracks and a waterfall tunnel.

2.2.3. Variations of green roofs

Brown or eco-roofs

The top of Barclay's Bank headquarters at Canary Wharf, London has been retrofitted with a brown roof where three habitats are being monitored by University College, London. The roofs which are constructed of planting such as sedum, gravel beds and grassland offer increased local biodiversity on the roof as they become home to black redstart birds, ladybirds, grasshoppers, insects and other invertebrates.

Wetland green roofs

The John Deere Works in Mannheim, Germany (built 2003) treats 100 000 l of waste water per day in its 41m² rooftop wetland system. This thriving wetland ecology not only cleanses waste water before discharge to the sewerage system but also serves to 'biofilter' the building's waste water for re-use in either gardens or back within the building, for toilet flushing.

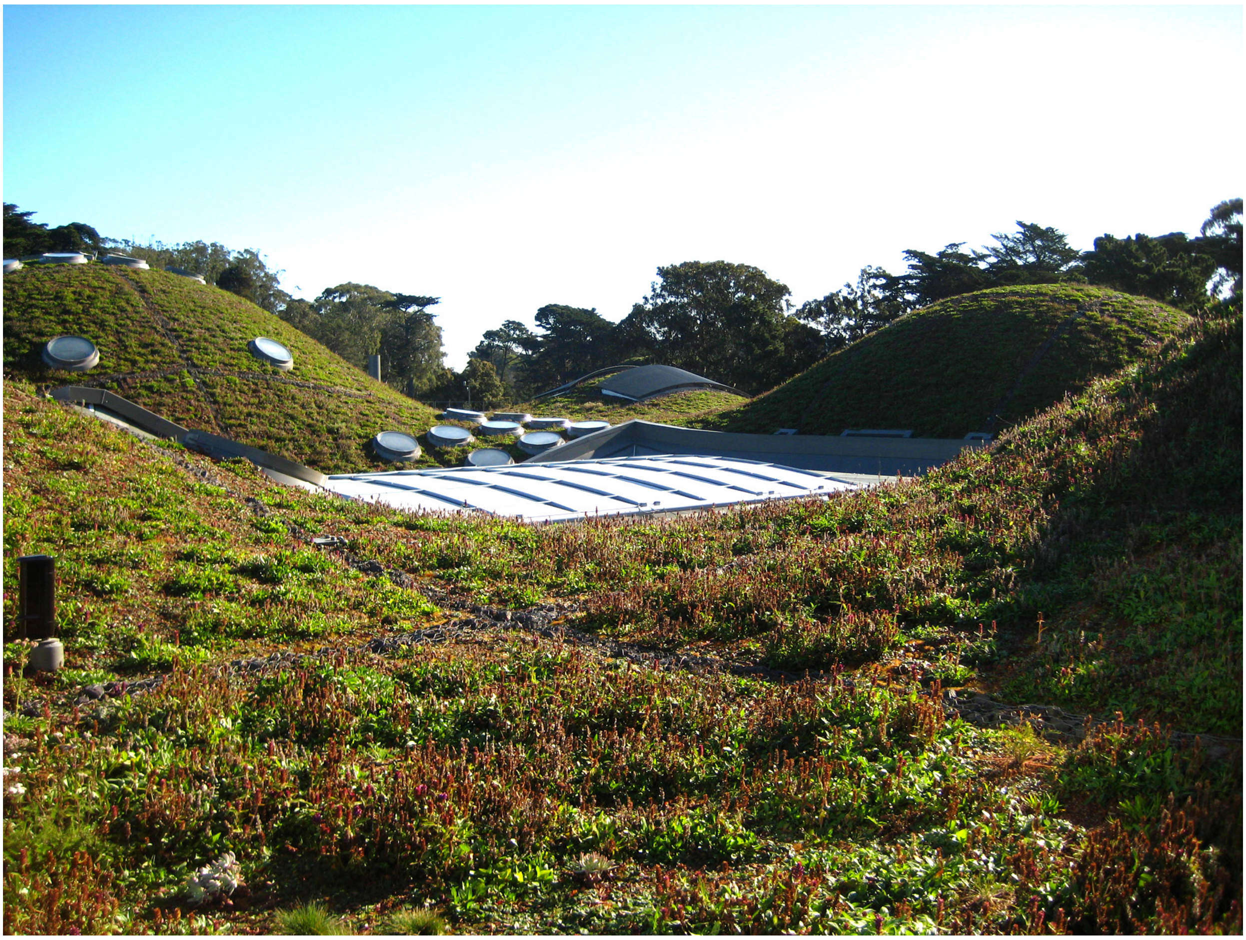

Figure 7 Skylights integrated into the roof of the California Academy of Sciences, San Francisco
(Source: © Renzo Piano Building Workshop, photo Shunji Ishida, 2008)

Sometimes smaller modular systems akin to 'living machines' or filtration units that use organic processes to cleanse waste water are placed on rooftops to recycle the building's greywater for rooftop vegetation. One example of this is the 'GROW' or Green Roof Water Recycling System, being tested at Cranfield University, UK which is "a tiered garden of low growing, flowering, native plants, whose roots can perform the same cleansing function as a reed bed" (Water Works, 2009).

Roof gardens for food production

The increasing emphasis on the value of growing and eating local food has provided an opportunity for using the roof for food production. While ambitious projects, like the incorporation of wet paddy fields on roofs of buildings in eco-cities such as Liuzhou in China, are proposed by William McDonough and Partners; there are smaller rice fields being planted in Japan's Roppongi Hills Keyakizaka mixed use office/retail/residential complex. This has 13,000m² of green roof with both intensive and extensive sections and varying soil profiles of 30mm to 1200mm to accommodate a landscape consisting of ponds, an organic vegetable garden and a rice field that produces 60kg of organic rice per year.

Rooftop gardens

Several penthouses and restaurant hotels use rooftop gardens whereby vegetation may not be fully integrated into the roof of the building but is partly grown in containers. Australian examples include the M-Central Apartments in Pyrmont, Sydney which offer its 400 residents pleasant rooftop surroundings with its 2600 m² roof garden. Similarly, in Melbourne, Freshwater Place residential tower in Southbank has 1600m² of rooftop garden above its car park. These examples also include elements of both intensive and extensive green roof systems and aside from lowering building temperatures they provide opportunities for the social interaction of building users.

Combination of green roof and other systems

With the maturing of the green roof industry, bolder designs combining green roofs and green walls that are being proposed will change the way our buildings will function and the way our cities will look. Figure 1 shows a design by the office of the architects Ken Yeang, which integrate green ramps from green roofs to skygardens upon a high-rise tower.

Figure 8 View of green roof with skylights from the underside of the California Academy of Sciences, San Francisco

(Photo: ©Tim Griffith, 2008)

3.0 BENEFITS

Green roofs provide benefits both to the building owner, building operator, the building users, and the general public. The installation of green roofs provides economic benefits to the owner and operators primarily through reduced building energy consumption and extension of the life of the roofing membrane, which in turn, defers the need for more frequent reroofing. In addition, wider benefits such as reduced Urban Heat Island effect (UHI) or the social benefits of improved health as these benefits offered by green roofs indirectly affect the individual and general public.

Research has shown that incorporating green roofs into building design has several benefits such as:

- better insulated buildings
- lower roof temperatures, which lower energy costs for cooling and UHI
- improved storm water retention and water quality of run-off
- improved urban air quality
- reduced noise penetration
- increased urban biodiversity and support for urban food agriculture
- aesthetic appeal with associated health and well-being benefits

3.1 Lower Temperature, Lower Energy Costs and Lower UHI

Research indicates there are credible benefits of lowering the temperature of a building and its surroundings which in turn lowers a building's energy costs as well as urban heat islands temperatures.

Building Temperature

With the help of plants and the growing media, green roofs insulate the buildings they cap from the surrounding air temperature and direct solar heat gain, which in turn modifies the internal temperature of the building to the extent that the building can have significant energy savings in heating and cooling. The City of Chicago's 1900m² test plots show a 10°C difference between the green roof and the nearby black tar roof (City of Chicago Department of Environment, 2008) while research carried out by the National University of Singapore showed that the "maximum temperature decrease caused by plants was around 30°C " (Wong, 2003).

Urban Heat Island

Together with the lowering of building temperatures, green roofs also lower surrounding ambient temperature aided by the evapotranspiration from leaves and the moisture retained in the growing media. (Evapotranspiration describes evaporation from both plant and soil surfaces and transpiration of water from plants when they 'breathe' or transpire). A study showed that the evaporative cooling effect from a roof lawn garden was estimated to have a 50 per cent reduction in the heat flux to surroundings with a temperature difference of 30ºC (Onmura, Matsumoto, and Hokoi, 2001).

A National Research Council study in Canada (Liu and Bass, 2005) modelling Toronto, found that if green roofs made up 1 per cent of total land area of Toronto or 6 per cent of total roof area with green roof area of 6.5 million m², the reduction in the UHI would be 1-2ºC (Liu and Bass, 2005). The placement of photovoltaic panels on green roofs has been found to have a double benefit in that the panels shade the roof from excessive sun exposure and high evaporation, thus reducing drought stress of plants and allowing for a wider range of planting choices from full sun to half shade (Kohler, Wiartalla, and Feige, 2007) The cooling effect from evapotranspiration of green roof planting enables a 6 per cent higher efficiency of photovoltaic panels which is calculated to pay back within 5 years.

Shadowing plants with larger horizontal foliage Leaf Area Index (LAI) reduces heat flux on the roof (Del Barrio, 1998), but designers should note when choosing species, that plants that offer better shading from heat gain may offer little insulating ability for retaining warmth if desired.

Protected Roof Membranes

A very credible benefit to greening the rooftop is the ability of the green roof to protect roof membranes against ultra-violet radiation and extreme temperature fluctuations. The life of a roof membrane has been shown to be extended due to the protection offered by a green roof (Liesecke (1989) as quoted in Peck and Kuhn, 1999). A longer life span for a roof membrane not only gives the building owner savings, but will also reduce landfill waste.

3.2 Improved Stormwater Retention and Water Quality

Beyond their insulating properties, green roofs are becoming a topic of interest for their ability to retain rainwater, control run-off, recycle water and clean water on-site.

Studies have been conducted for cities such as Washington DC (2005) and a report for the City of Portland (1997) shows that annual discharge can be reduced by 11-15 per cent if half of their downtown buildings had green roofs (Beckman as quoted in Peck and Kuhn, 2001). Furthermore, zero discharge is quite feasible if green roofs are used in combination with other water management strategies. For example, a typical 300mm deep green roof in temperate climates can reduce total annual runoff by 85 to 95 percent (Milwaukee Metropolitan Sewerage District) and the Pottsdammer Platz office tower complex in Berlin has almost no stormwater runoff as a result of use of green roofs.

As well as slowing stormwater run-off, green roofs can filter run-off before discharge to storm drains and thus lessen the strain on downstream water systems. They can also be designed as part of the building's integrated water management system functioning as part of onsite greywater recycling In smaller to moderate rain events green roofs have been shown to capture pollutants borne by rainwater to give up to a 95 per cent reduction of cadmium, copper and lead, and 16 per cent reduction in zinc (City of Chicago, 2003).

3.3 Improved Air Quality

Plants are known to capture and remove pollutants such as nitrous oxides, sulphur oxides, carbon dioxide, ozone and particulate matter and can act as an urban biological filter together with street trees (Wolfgang Ansel, 2006). Recent studies done on green roofs in Chicago show that a total of 1675 kg of air pollutants were removed by 19.8 ha of green roofs in one year. Of this 52 per cent of the total was ozone, 27 per cent was nitrogen dioxide , 14 per cent was very smaller particulates (known as PM10) and 7 per cent was sulphur dioxide (Yang, Yu, and Gong, 2008). Similar studies have also been conducted in Singapore with comparable results (Tan & Sia, 2005.).

Steven Peck (president of the North American not-for-profit industry organisation, Green Roofs for Healthy Cities) quotes studies done by Minke in 1982 and Johnson in 1996 to show that increasing greenery helps to improve air quality where 1.5 m2 of uncut grass with a leaf surface area of 150 m^2 on a roof could create enough oxygen to meet the needs of one human over 1 year, and 10 m^2 of grassed roof is purported to remove 2kg of particulates per year which would contribute actively to better air quality of our cities (Peck and Kuhn, 1999).

3.4 Reduced Noise

There are not as many studies conducted for noise quality as there are for air. A study done by Minke (1982) showed that a 20 cm layer of substrate together with 20-40 cm layer of thick grass had a combined insulation value equivalent to 15 cm of mineral wool insulation (Peck and Kuhn, 1999). Peck also quotes another study done by Hooker which shows a decrease of 40 decibels was achieved with a green roof with a 12 cm substrate where the growing medium was successful in dampening low frequencies.

A recent Belgian study showed that an extensive green roof with 20 cm substrate angled at 30°C was able to absorb 8 decibels more than a 30°C rigid roof for heavy traffic (VanRenterghem and Botteldooren, 2008).
It is reported that Schiphol International Airport in Amsterdam utilises a green roof of pre-vegetated sedum mats for acoustic dampening.

3.5 Increased Urban Biodiversity and Ecosystem Services

The choice of providing a green roof habitat that offers spontaneous colonisation of native species may be considered by some as just growing weeds, however green roofs that mimic surrounding ecology provide a similar habitat for certain endangered types of birds, butterflies and various species of invertebrates. Providing green or brown roof areas can be seen as a way of compensating for the damaged surrounding landscape.

Green roofs can be used as 'stepping stones' to provide a corridor to connect urban centres as part of a larger system of wildlife corridors and thus encourage urban biodiversity. Graeme Hopkins working with Adelaide City Council advocates this type of "bushtop" living roofs in the Adelaide CBD to contribute to the urban ecosystem.

The use of green roofs may be a good choice if compliance with environmental policies is required. The ability of green roofs to support wildlife has helped with nature conservation or environmental requirements of some Swiss and German planning acts and local Biodiversity Action Plans of various UK cities. Some points can also be gained by several green building accreditation tools such as LEED and Green Star.

By providing eco-services such as filtration and slow release of stormwater, improved air quality, potential urban food production and places for community and social interaction, they contribute to the positive development of our cities and increase our shared ecological base (Birkeland, 2007). Depending on the type of vegetation used on green roofs, they can help reverse some of the damage of the ecological footprint due to the construction of the building and an increase in urban green infrastructure.

An integrated design approach to green roofs could include energy production, greywater recycling and production of food on-site In this manner, green roofs can be effectively used to increase ecosystem services in an urban context.

3.6 Urban Agriculture

The same roof can be used for food production to increase the social capital of less resilient neighbourhoods or as a means to secure a food supply without transportation costs. The Fairmont Hotel chain in Canada (US Green Building Council - Cascadia chapter) is said to produce about CDN $30,000 worth of vegetables and 136kg of honey for its restaurants a year from its green roofs, and the green roof of Changi General Hospital is calculated to be capable of producing SIN$40 million worth of food for use in the hospital (Changi General Hospital).

Dr Midmore of the Central Queensland University is researching how green roofs can be part of a closed system food-chain where food consumed on the ground floor is returned as compost to aid food production on the roof of the same building. Geoff Wilson of Urban Agriculture Network Australia promotes green roofs as opportunities for greater food security and reduced living costs (Urban Agriculture Network Australia).

3.7 Aesthetic, Health and Well-being Benefits

To date, the social benefits that greenery offers to occupants or passers-by are rarely accounted for. However, this view is changing rapidly, with increasing research indicating improved worker productivity or faster patient recovery due to therapeutic benefits derived from horticultural surroundings. Recent studies show that the average Australian worker takes 8.62 days of sickness benefit per year and this costs employers a staggering $27 billion/year (The Courier Mail, 2008). Interest in green walls and green roofs as a possible means to make the workplace more desirable or productive is growing among organisations. The City of Melbourne announced that council workers had increased their productivity by 10.9 per cent in their first year of occupation of its new world standard innovation CH2 office building, – partly because they had a green space in which to relax (Craig, 2008).

Provision of access to enjoy green roofs is greatly appreciated by many for social interaction or just for a quiet spot. Green rooftop gardens can provide a safe and pleasant space for building occupants and there appears some correlation can be made between greenery and behaviour, recovery and even a sense of community (Kuo, 2001).

Under green building rating schemes such as the Green Building Council of Australia's Green Star rating, points are available for green roofs or indoor plants, which is further incentive for the greening of buildings. While the basis of such greening projects may have more to do with worker productivity or green marketing by companies than pure concern for the environment, many environmentalists are happy to see the growing number of urban greening projects such as green roofs and green walls instead of the otherwise rooftop 'HVAC desert'.

4.0 CHALLENGES FOR THE AUSTRALIAN CONTEXT

Similar to any emerging technology, the growth of local knowledge and the industry for local climate are challenges for green roofs. Support for green roof research within local climatic conditions and the dissemination of such information within Australia is being prioritised with such organisations as Green Roofs Australia (Green Roofs Australia, 2008).

The Australian not-for-profit, membership-based organisation, Green Roofs Australia, held its inaugural conference in 2007. At that conference, Steven Peck, president of Green Roofs for Healthy Cities, identified 4 areas of research needed for green roofs in Australia:

- identification of plants suitable for Australian green roofs
- the need to integrate water supply into design due to drought conditions
- solar panel integration
- preparation for an overall increase in temperatures due to climate change.

4.1 Understanding Local Species and Climate

Countries such as Germany, the USA and Singapore where the green roof industry is more established have produced databases of plants suitable for green roofs (Centre for Urban Greenery and Ecology in Singapore, 2008). Due to the difference in climate and local growing conditions, this knowledge is not directly transferable to Australian conditions, however current plant trials are being conducted at the University of Melbourne to ascertain what plant species can be grown successfully on green roofs in Australia (University of Melbourne, 2008, Gardening Australia, 2008 (ABC, 2008). As most green roofs have low-depth substrates and experience high temperatures, many overseas plant growers for the green roof industry are looking at Australian drought tolerant plant species and succulents for possible use in overseas green roofs. General advice is given to avoid plants with invasive roots such as some bamboo and other deep rooting species.

A myriad of factors determine suitable plant selection; a few of them being design intent, aesthetics, use, local climate, plant survivability, availability soil depth, maintenance and of water and the type of green roof. In the coming years, as more plant trials in various climatic zones of Australia yield their valuable results, there will be greater confidence in the selection of plants appropriate for the type of system, climatic conditions, maintenance and intended use of the roof.

4.2 Education

Due to the fledgling nature of the Australian green roof industry, many involved in the design and construction of the built environment are unaware of the number of successful examples of green roofs in Australia that have existed for some years. Green Roofs Australia has recognised a hesitance by industry to pursue green roofs and is aiming to disseminate information that is relevant to Australia, and plans to start a national accreditation program for green roof design and installation based on the GRHC example.

The FLL Guideline (Landscape Development and Landscape Construction Research Society) first published in 1995 in Germany is the most comprehensive document to date and establish a set of standards and quality criteria for the planning, execution and upkeep of green roofs. Australia could also adopt and adapt some of these FLL standards for future reference as many other countries such as USA, Singapore and others in the EU have done. Currently, a modest set of guidelines have been initiated by the Australian Institute of Landscape Architects (AILA, 2009).

Greater success can be achieved when an integrated design methodology brings an inter-disciplinary team together from the start of a project, with the intention of designing the green roof to form part of a building's integrated ecosystem, instead of the traditional method of compartmentalised design. Green roofs are often viewed by project managers as soft landscaping and therefore considered a 'nice-to-have' which will be easily cut from the budget. However, viewing them accurately as a building system and integral to the building rather than as a retrofit item will affect their costing more favourably.

5.0 CONCLUSION

The tangible benefits of using green roofs have been verified by over 20 years of research in several countries, on green roofs constructed over the span of 30 years or more. The cost of specifying a thicker layer of insulation instead of a green roof may be cheaper; however, will restrict the benefits achieved solely to a reduction in energy usage and does not offer cost savings for longer lasting roofing. Furthermore, other public benefits like stormwater and urban heat island mitigation, improved air and noise quality, increased biodiversity, community enjoyment and worker well-being are not factored in, though these are beneficial to society and to the ecology shared by all.

Australia is lagging behind other developed countries in adopting green roofs as part of our design and green urban infrastructure. We are now in a fortunate position to benefit from the many years of overseas research and technical know-how that allows for green roofs to be adapted to an Australian climate and context without having to start from the beginning. Continued support of plant and technical research within local context and climatic conditions would contribute to more successful green roof installations. Designers and developers should formulate a working relationship with government and local councils and vice versa to encourage better outcomes with green roof incentives or strategies in order to reap the many benefits discussed above, there needs to be a significant number of green roofs in an area so that the sum of each roof's contribution can produce a significant impact on our environment and air and water quality. This big picture view of greater long-term and socially shared benefits should be considered as we move into a realm of more interconnectivity where many green roofs in one city can make a difference and many cities with green roofs will have a real effect on climate change.

BIOGRAPHY

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APPENDICES – GREEN ROOFS EXAMPLES AND RESOURCES

Organisations	
Green Roofs Australia	http://greenroofs.wordpress.com/
Green Roofs for Healthy Cities US	www.greenroofs.org
International Green Roof Association:	www.igra-world.com
The Green Roof Centre, Sheffield, UK	www.thegreenroofcentre.co.uk
Centre for the Advancement of green roof technology, BCIT (British Columbia Institute of Technology),	http://commons.bcit.ca/greenroof/
Centre for Urban Greenery and Ecology, Singapore:	http://research.cuge.com.sg
Urban Agriculture online	http://www.urbanag.org.au/index.html
Other resources:	
Greenroofs.com	www.greenroofs.com
FLL (Landscape Research, Development and Construction Society) Germany	www.f-l-l.de/english.html
RESEARCH INSTITUTIONS	
University of Melbourne	http://visions.unimelb.edu.au/episode/47
Central Queensland University	http://urbanagriculture.wordpress.com/2007/02/15/fresh-roof-food-from-urban-wastes/
Centre for Architectural Ecology, BCIT, Vancouver	http://commons.bcit.ca/greenroof
Green Roof Research program at Michigan State University, USA	http://www.hrt.msu.edu/greenroof
The Green Roof Centre of Excellence, Neubrandenburg, Germany	www.gruendach-mv.de/en/index.htm

Extensive and intensive green roofs and rooftop gardens:	
AUSTRALIA	
Extensive and intensive green roofs and rooftop gardens:	
Parliament House, Canberra	
Southbank, Brisbane	
Central Park, Perth	
Marine and Freshwater Resource Institute of the Department of Public Infrastructure in Queenscliff, Victoria	www.lyonsarch.com.au
Old Kent Brewery site, Chippendale, Sydney (construction proposed to start in 2009)	http://axiomas.wordpress.com/2008/04/22/frasers-broadway-australia%E2%80%99s-greenest-development
	www.frasersbroadway.com.au/broadway/po.htm
M-Central apartments in Pyrmont , Sydney	
Freshwater Place residential tower Melbourne	
Sydney Conservatorium of Music, Sydney	
Readers Digest Building, Sydney	
Council House (CH2), Melbourne	
ASIA	
School of Art, Design and Media, Nanyang Technological University, Singapore	http://www.inhabitat.com/2008/01/23/amazing-green-roof-art-school in-singapore/
Subaru Showroom, Singapore	www.greenroofs.com/projects/pview.php?id=519
Roppongi Hills Keyakizaka, Japan	www.aila.org.au/sustainablecanberra/003-greenR/default.htm
Amsara Day Spa, Singapore	

NORTH AMERICA

Ford assembly plant, Dearborne, Michigan, USA
Ducks Unlimited, Winnipeg, Canada
Chicago Millennium Park, Chicargo, USA
Chicago City Hall, Chicargo, USA
www.artic.edu/webspaces/greeninitiatives/greenroofs/main.htm
Toronto City Hall, Toronto, Canada www.toronto.ca/greenroofs/index.htm
ManuLife Centre, Toronto, Canada www.toronto.ca/greenroofs/what.htm
California Academy of Sciences, San Francisco, USA
www.calacademy.org/newsroom/releases/2005/Holcim_award.php
Palomar Medical Centre, Escondido, California water
http://commons.bcit.ca/greenroof/publications/2007_grim.pdf

EUROPE

Golf practice on roof, Birkenwerder, Germany
School, by Jourda and Perraudin architects, Lyons, France
Banco Santander, Madrid, Spain
Hundertwasser Waldspirale, Austria
Barclay's Bank HQ, Canary Wharf, London, UK
John Deere Works, Mannheim, Germany
www.deere.com/en_US/compinfo/media/pdf/reports/ehs/ 2003envreport.pdf
GROW www.wwuk.co.uk/grow.htm

Examples of Urban Agriculture

Urban Agriculture Network, Australia
http://urbanagriculture.wordpress.com/2007/02/15/fresh-roof-food-from-urban-wastes
Green Potato project, NTT, Japan
http://afp.google.com/article/LeqM5gPCyKOMnSpptp6VQ0C4JUxdLG6uA
Changi Hospital, Singapore
Fairmont Hotel, Vancouver, Canada
Roppongi Hills Keyakizaka, Japan www.aila.org.au/sustainablecanberra/003-greenR/default.htm

FURTHER READING

Hopkins, G, 2006, *Bushtops and Living Walls*, a Winston Churchill Memorial Trust fellowship report
www.churchilltrust.com.au/res/File/Fellow_Reports/Hopkins%20Graeme%202005.pdf
Johnson, C, 2004, *Greening Cities: Landscaping the Urban Fabric*, Sydney, NSW: Government Architect's Publications
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Earth Pledge Foundation, 2005, *Green Roofs: Ecological Design and Construction*, Schiffer Books, Pennsylvania, USA.