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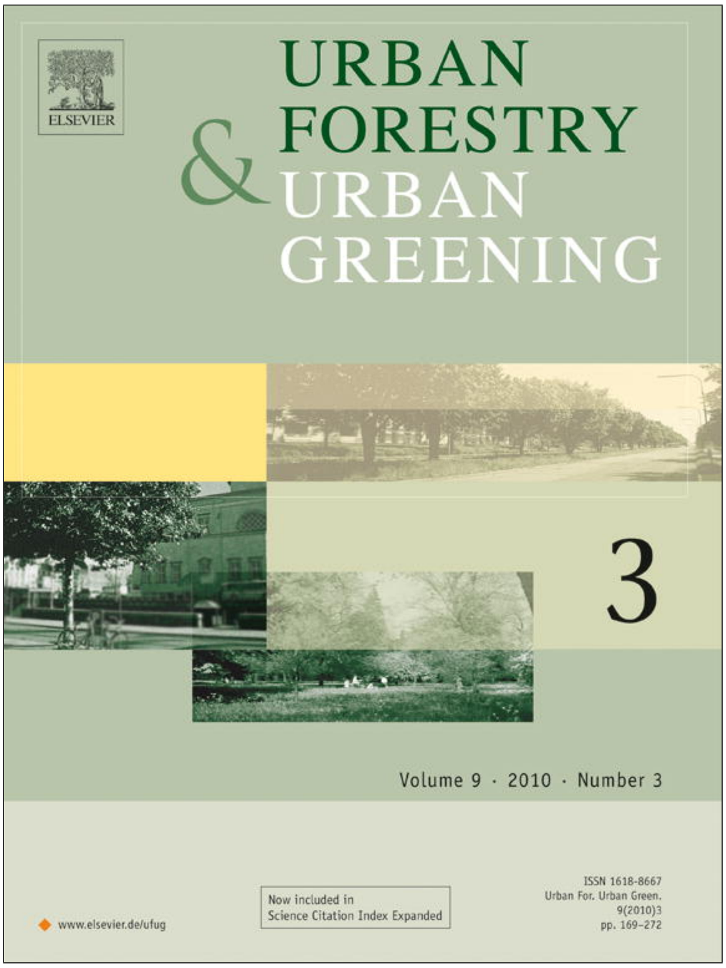

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Green roofs for a wide brown land: Opportunities and barriers for rooftop greening in Australia

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ABSTRACT

There is increasing public, industry and government interest in establishing green roofs in Australian cities due to their demonstrated environmental benefits. While a small number of green roofs have been constructed in Australia, most are roof gardens or intensive green roofs. Despite their potential as a climate change adaptation and mitigation tool and their widespread use in the northern hemisphere, there are very few examples of extensive green roofs in Australia. One of the major barriers to increasing the prevalence of extensive green roofs in Australia is the lack of scientific data available to evaluate their applicability to local conditions. Relying on European and North American experience and technology is problematic due to significant differences in climate, available substrates and plants. This paper examines green roofs in Australia, discusses the challenges to increasing their use and the major information gaps that need to be researched to progress the industry in Australia.
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Introduction

Green roofs are an important technology and planning tool that can be used to help urban centres respond to climate change and improve urban environmental quality. Also referred to as living roofs or roof gardens, green roofs are roofs and podiums with vegetation growing in a specifically designed substrate. They have multiple demonstrated environmental benefits at a variety of scales. Benefits for individual buildings include increased roof life (Kosareo and Ries, 2007), insulating properties that lead to greater energy efficiency through reduced summer cooling and winter heating costs (Sailor, 2008) and attenuation of inside and outside noise levels (Van Renterghem and Botteldooren, 2009). Green roofs can improve the local environment by providing biodiversity habitat (Brenneisen, 2006), reducing stormwater flows (VanWoert et al., 2005; Carter and Jackson, 2007) and improving the quality of roof runoff water (Berndtsson et al., 2006). Unlike other water sensitive urban design measures they do not require additional space as they are already part of the building footprint.

On a city-wide scale green roofs can mitigate the urban heat island effect (UHI) through cooling due to increased evapotranspiration thus reducing energy use and carbon dioxide emissions (Skinner, 2006; Alexandri and Jones, 2008). They can also sequester carbon (Getter et al., 2009).

Two types of green roofs are widely recognised; intensive and extensive. Intensive green roofs can support complex vegetation communities including groundcovers, small trees and shrubs in substrate depths greater than 20 cm. They are often designed as roof gardens for human use and usually require irrigation, maintenance and additional structural reinforcement of the roof (Oberndorfer et al., 2007). Extensive green roofs, sometimes referred to as ecoroofs, have substrate depths less than 20 cm, require minimal or no irrigation and are generally planted with low growing succulents and stress tolerant herbaceous species (Dunnett and Kingsbury, 2004a; Oberndorfer et al., 2007). In the last two decades there has been substantial expansion of extensive green roofs in Western Europe and North America, mainly through retrofitting to existing buildings (Oberndorfer et al., 2007). However, this expansion has largely been restricted to temperate regions of the northern hemisphere. In regions unfamiliar with green roofs, such as Australia, there remain many potential barriers to their more widespread adoption.

Barriers include a lack of standards, high costs when green roof installers are inexperienced, few demonstration examples to inspire and give confidence to developers considering a green roof and a lack of relevant and reliable research to provide

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confidence in the economic and environmental benefits of green roofs (Dunnett, 2006b; Pantalone and Burton, 2006). The last barrier is particularly relevant to countries such as Australia, which has a very different climate to the temperate regions of the northern hemisphere where green roofs are more common. Relying on northern hemisphere research, experience and technology is problematic, due to significant differences in rainfall, temperature, available substrates and suitable vegetation. This may introduce unacceptable levels of risk and unnecessary expense to development projects considering green roofs. This paper examines green roofs in Australia, the status of the industry and discusses information gaps requiring research. While the paper uses Australian examples, the issues identified and research required to overcome implementation barriers are common to most countries without an established green roof industry.

Methods

Literature relating to green roofs in Australia was sourced from bibliographic databases, university library catalogues and the internet. Additional information was collected through discussions with members of the Australian green roof industry. Site visits to green roofs in Melbourne and Sydney were undertaken.

Green roofs in Australia

Although our national parliament is covered by a carpet of turf grass (Fig. 1a), Australia has been slow to adopt green roofs in comparison to other developed countries. This is despite Australia having much to gain. It is one of the most urbanised nations in the world with 87% of the population living in urban areas (Australian Bureau of Statistics, 2003). Almost two thirds of the population is concentrated into five sprawling major cities (Australian Bureau of Statistics, 2003) most of which have hot dry summers. Cities in hot dry climates have the most to gain from expanding the total area of green roofs as this will mitigate urban temperatures and reduce energy demand (Alexandri and Jones, 2008).

Whilst there are some green roofs in Australia, to date these are nearly all intensive green roofs. Of the larger intensive green roofs, many have been built over car parks, including sports stadiums such as the Melbourne Cricket Ground. One of the earliest examples of an Australian intensive green roof is the South Lawn at The University of Melbourne (Fig. 1b). Built in 1972, the roof garden supports trees and expanses of turf whilst covering parking for hundreds of cars. Other intensive green roofs include Brisbane's South Bank Parklands which has large sections of intensive green roof including a series of swimming pools that cover car parks and, the National Gallery of Victoria that has an attractive sculpture garden on an intensive green roof (Fig. 1c). From the 1990s some hotels and apartments across Australia have incorporated intensive green roofs in their design to provide private passive recreation and amenity space for residents and guests. Examples include Melbourne's Crown Casino which has a distinctive geometrically designed roof garden, accessible to hotel guests, and M Central apartments in Sydney (Fig. 1d). More recently, developers of office buildings such as 30 The Bond in Sydney (Fig. 1e), the Department of Primary Industries building at Queenscliff (Fig. 1f) and Council House 2 (CH2) in Melbourne (Fig. 1g) have improved the environmental ratings of their buildings by including green roofs.

There are very few extensive green roofs in Australia. The authors only know of the un-irrigated 20 m^2 experimental extensive green roof with a substrate depth of 125 mm that they have established at the Burnley campus of The University of Melbourne and an irrigated extensive green roof installed on a toilet block in Elizabeth Bay, Sydney (Fig. 1h). Extensive green roofs have great potential as a climate change mitigation strategy as they can be retrofitted to existing roofs without the need for structural upgrades. However, technical difficulties regarding growing plants in shallow substrates in a dry and variable climate need to be overcome and are discussed further below.

Like other areas with dry or Mediterranean climates the green roof industry in Australia is in its infancy and some parts of the product supply chain are not well serviced. Most of the large international green roof drainage layer manufacturers, with a strong market presence in Europe and North America, do not have local distributors in Australia but there are a number of local companies selling prefabricated plastic drainage layers and others selling irrigated capillary mats and synthetic foam layers. The nursery industry has been slow to recognise green roofs as a business opportunity. There are no specialist green roof plant suppliers and established growing media suppliers have been reluctant to introduce new materials for green roof substrates into their production lines. Consequently, there is a limited range of suitable plants and the growing systems required to propagate commercial quantities are not in place. There are also very few experienced green roof installers or maintenance contractors. These factors can increase the difficulty and expense of constructing green roofs. Because the industry is risk adverse high profile projects may be required to provide a proof of concept and demonstrate business opportunities.

Despite the nascent nature of the industry, there has recently been a surge of interest in green roofs in Australia and the industry may experience rapid growth if the barriers to their implementation can be overcome. Green roofs have been advocated by Australian urban climatologists as a measure to mitigate the urban heat island effect and reduce electricity demand (Skinner, 2006). Architects are now regularly including green roofs and walls in proposals and designs, sometimes with little understanding of the technical challenges involved. Planners and policy makers are also becoming increasingly aware of green roofs as a tool for improving the quality of the urban environment. Green roofs are frequently advanced as a water sensitive urban design tool (Victorian Department of Infrastructure, 2002) and as additional biodiversity habitat in cities (City of Melbourne, 2003).They are recommended as a means of reducing the urban heat island effect by decreasing cities' reliance on air conditioning and increasing energy efficiency (Brisbane City Council, 2006; Committee for Melbourne, 2008). However, these recommendations and policies have not translated into financial incentives likely to stimulate the green roof industry (Carter and Fowler, 2008) or take the form of regulations that have encouraged the construction of green roofs in Switzerland and Germany (Peck and Wieditz, 2003).

While the absence of policy incentives is a barrier to the widespread uptake of green roofs, policy makers are likely to be reluctant to include green roofs in building codes and planning guidelines until there is quality data assessing their costs and benefits in an Australian context. This requires successful green roof examples which can be monitored and objectively evaluated—something Australia is currently lacking. Northern hemisphere experience suggests that basic research to identify appropriate substrates and plants and their impact on the urban water cycle is required before green roofs can be successful (Dunnett and Kingsbury, 2004a). Once these essential foundations are in place, the environmental benefits of green roofs can be assessed.

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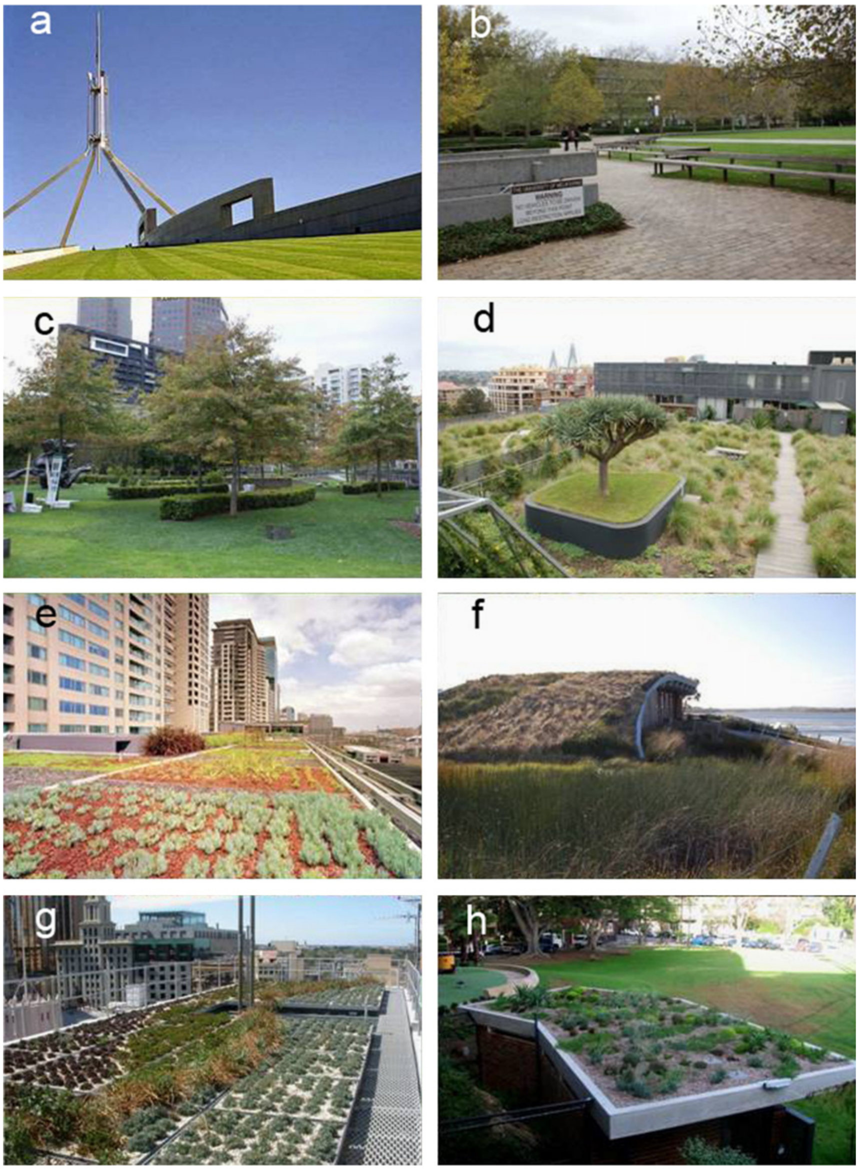

Fig. 1. Australian green roofs, photo credits in brackets. (a) Parliament House, Canberra (Hillmanimages.com), (b) South Lawn, University of Melbourne, Parkville Campus (Kirsten Raynor), (c) National Gallery of Victoria, Melbourne (John Rayner), (d) M Central, Sydney (Sidonie Carpenter), (e) 30 The Bond, Sydney (John Gollings, Source: Australian Institute of Architects), (f) Department of Primary Industries, Building Queenscliff (Sidonie Carpenter), (g) East Core roof , Council House 2, Melbourne (John Rayner), (h) Elizabeth Bay Toilet Block, Sydney (Stuart Tyler Fytogreen).

Substrates

Green roof substrates need to be lightweight, chemically and physically stable, hold adequate amounts of water and nutrients for plant survival, but also be free draining so plant roots do not become saturated (Rowe et al., 2006). For these reasons most substrate mixes tend to be dominated by mineral-based components (Beattie and Berghage, 2004). In Europe, these include recycled crushed brick and roofing tiles, steel mill slag and light expanded clay aggregate (LECA). These materials are also utilised extensively in North America, along with pumice and heat expanded shale and slate (Rowe et al., 2006). In Australia, many of these components are either not available, difficult to access or too expensive for use. LECA, for example, is used in hydroponics and interior landscape mixes in Australia, but its bulk and importation costs make it prohibitively expensive for green roof applications. Our own research in Melbourne has shown two products with great promise for use in green roof substrates as the main component. Different grades of scoria (i.e. tuff) can have excellent physical properties and are a comparatively cheap mineral component for use in green roof substrates on the proviso that there is consistency in supply and quality. Similarly, furnace bottom ash, mainly produced from the burning of coal for electricity, has been processed, graded and marketed as 'Envir-o-Agg', focussing on use in agricultural and industrial applications. However more research is needed, particularly to better define the 'ideal properties' that substrates can be measured against to ensure minimal levels of performance.

Intensive green roofs constructed in Australia have tended to use potting or nursery container mixes based largely on combinations of sand and organic components, such as pine bark. In some cases this has resulted in poor plant performance over time, particularly where highly organic substrates have decomposed and compressed with age (John Rayner, personal observation). More recently, a few proprietary green roof substrate mixes, some based on synthetic products, have become

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available (Anon, 2007). However, there is little research or independent performance data to support their use in un-irrigated or minimally irrigated extensive green roofs and they remain largely untested. Substrates will also vary according to the availability of component materials in different parts of Australia. Given these constraints, it is prudent that Australian green roof designers develop substrates in collaboration with horticultural and soil scientists and suppliers of landscape soils based on properties, availability and cost of local materials

Due to the lack of any accepted specifications, guidelines and/or standards for green roofs in Australia, published guidelines from overseas, such as those of the German Landscape Research, Development and Construction Society (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) guidelines) can be used, if adapted for an Australian context. Due to key differences in testing methodologies and agreed performance levels, standards will need careful translation to Australia. Australian climatic conditions may also require the development of new standards. Temperatures in parts of urban Australia, in particular, are very different to Europe, with maxima of 90 °C recorded on roofs. The long-term effect of these extreme temperatures on the physical, biological and chemical properties of substrates, particularly those made from synthetic materials, needs assessment.

Given the increasing variability of rainfall and temperature across large parts of Australia, a key research question will be to determine the minimum substrate parameters required for plant survival and growth. Depth of substrate is generally a useful indicator for this. In temperate Europe and North America, substrate depths of 3 cm can support *Sedum* species and moss but if increased to 5–8 cm a wider range of succulent species, grasses, herbs and sub-shrubs can be grown. Depths of 30–50 cm will allow many perennials and shrubs to survive (Dunnett and Kingsbury, 2004a). The drier summers, greater variability in rainfall and increasing periods of water deficit in many Australian cities may require greater substrate depths and supplementation with minimal irrigation for various plant life forms to survive. For example, succulents may require 15–20 cm substrate depth, while grasses and herbs may require depths of 30 cm or more. However, it is unlikely any plants will grow in less than 5 cm of substrate under Australian conditions without intensive irrigation. It might be possible to increase substrate water holding capacity by addition of water holding additives or related materials but this requires further research.

Plants

A major barrier to the widespread uptake of extensive and semi-extensive green roofs in Australia is the lack of plants that have a proven ability to survive and be aesthetically pleasing under local climatic conditions. To survive in temperate, northern hemisphere green roofs, plants need to be adapted to heat, cold, sun, wind and water deficit and be tolerant of some root inundation (Snodgrass and Snodgrass, 2006). Similar criteria will apply to roofs in Australian cities, although plants will not require tolerance to freezing winters. In many places plants will require much greater tolerance to longer and more extreme periods of water deficit stress.

The group of plants most widely used on northern hemisphere extensive green roofs are *Sedums*. This is due to their shallow rooting, tolerance to cold and water deficit, variety of colour forms and ready propagation and establishment from seed, plugs, cuttings or as pre-grown vegetated mats (Snodgrass and Snodgrass, 2006; Getter and Rowe, 2007). There are concerns about the suitability of many plant species used widely in northern hemisphere green roofs in an Australian climate, in particular some *Sedum* species and cultivars. Many members of the genus exhibit a range of photosynthetic pathways and many can switch their photosynthetic pathway from C3 to crassulacean acid metabolism (CAM) during periods of water stress (Borland and Griffiths, 1990; Castillo, 1996). This allows the plants to open their stomates at night and therefore reduces water loss. However, *Sedum* species have a relatively weak CAM potential compared to other facultative CAM plants (Castillo, 1996) and, when water stressed, may need relatively low temperatures (e.g. <20 °C for *Sedum acre* L.) either during the day or at night to perform CO_2 exchange (Kluge, 1977). If night time temperatures remain relatively high, as can occur during Australian summers, particularly in cities subject to the urban heat island effect, plants will not fix CO_2 during the night and therefore they will be unable to maintain a positive carbon balance. This can lead some *Sedums* to collapse and die in extended periods of hot weather (J Rayner, unpublished data; Livingston et al., 2004) and may make such species unsuitable for green roofs in the Mediterranean or subtropical climates of Australia's major cities.

Biosecurity issues may also limit the use of plants commonly grown on green roofs elsewhere in the world. A number of species advocated as suitable for green roofs are self-sowing and can spread problematically on a green roof and, more seriously, on the ground below (Snodgrass and Snodgrass, 2006). Because the height of release is an important determinant of the dispersal distance of wind dispersed plants and because green roofs may act as magnets for birds in an otherwise barren urban landscape, the potential for species growing on buildings to spread to surrounding areas should not be underestimated. It is therefore important that green roof designers select species that will not invade nearby natural and anthropogenic habitats. No sedums are native to Australia but eight species have naturalised (Walsh and Entwistle, 1996). *Sedum praealtum* A. DC. and *S. acre* are considered to be a major weed problem at multiple locations (Groves et al., 2003) and *S. acre* threatens an endangered treeless vegetation community in the Australian Alps (McDougall and Walsh, 2007). A number of *Sedum* species are also listed as weeds in New Zealand (Webb et al., 1988).

Extensive plant screening research trials where plants were tested for appearance, cover and other desirable traits were essential in the early development of the green roof industry in Germany (Dunnett and Kingsbury, 2004a). Although climatic similarities allow many European species to be used on temperate North American green roofs, recent research has evaluated the suitability of native species (Hauth and Liptan, 2003; Monterusso et al., 2005; Licht and Lundholm, 2006; Durhman et al., 2007). Reasons for growing native species on green roofs include their adaptation to the prevailing climate (Monterusso et al., 2005), habitat supplementation and biodiversity conservation benefits and aesthetic and cultural reasons (Brenneisen, 2006; Dunnett, 2006a). Habitats identified as supporting plants that may be adapted to the harsh green roof environment include mountains, coastal areas, dry grasslands, cliffs and scree slopes (Lundholm, 2006; Dunnett and Kingsbury, 2008).

Screening trials of native and exotic plants suitable for green roofs have only just begun in Australia. Because of climatic and vegetation differences between Australia and the northern hemisphere, research will be needed to identify taxa suitable for Australian green roof environments and to evaluate their performance. For green roofs to become widely accepted in Australia this research is needed across the different climate zones; Brisbane, for example, has a very different climate to Melbourne.

Fortuitously, the Australian flora has great potential for the green roof environment and is attracting the interest of northern hemisphere green roof plant suppliers. Due to the old and highly

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weathered soils, many Australian plants are adapted to the nutrient-poor conditions found on green roofs. Australia is also the world's driest inhabited continent and has the lowest effective precipitation due to variable and low precipitation and high evapotranspiration rates in the interior (Fox, 1981). Over 70% of its land area is generally classed as arid or semi-arid and consequently the Australian flora contains many drought adapted species (Barker and Greenslade, 1982). However, few have been successfully brought into horticultural production (Blackwell, 1998) and not all plant traits that confer drought tolerance will be useful on green roofs.

Despite the continent's aridity, Australia's flora lacks life forms considered typical of desert biota on other continents. Stem succulence, as found in the Cactaceae and, Euphorbiaceae, leaf succulence (Azioaceae, Liliaceae), succulent rosette plants of the genera *Yucca* L., *Agave* L., *Aloe* L. and deciduous spiny shrubs are almost absent (Beard, 1981). Resurrection plants, which can survive foliage dehydration due to air-dryness and may therefore be suitable for green roofs, are widespread in Australia but not as numerous as in Southern Africa (Gaff and Latz, 1978). Instead Australia's arid zone is dominated by sclerophyllous species with deep tap roots that allow them to access underground aquifers and survive drought, but make them unsuitable for green roofs due to the shallow soil profile. It is only on alkaline and saline soils that have developed over limestone and calcareous clays that communities dominated by succulent chenopods of the genera *Maireana* Moq., *Atriplex* L. and *Sclerolaena* R.Br. are found (Beard, 1981). In these areas there is also an abundance of herbaceous plants with soft or fleshy leaves such as *Carprobrotus* N.E.Br. *Calandrinia* Kunth and *Portulaca* L. species (Kapitany, 2007) that are worth assessment.

Australia's drought adapted herbaceous perennials also have great potential as green roof plants. These plants dominate native grassland and grassy woodland vegetation communities in south-eastern Australia that experience long periods of summer drought. These habitats are similar to the short grass prairies of North America that Dunnett and Kingsbury (2004b) suggest may be a good model for green roofs. The flora is visually attractive and a number of species are already used in horticulture. As in their natural habitat, these species may go dormant during the hot summer months but have a variety of forms and foliage colour and will provide attractive floral displays in spring. Other Australian plants potentially suitable to green roofs include desert annuals that have spectacular natural displays and could add seasonal colour.

Water

One of the major drivers for the implementation of green roofs has been to reduce stormwater flows. In parts of the Northern Hemisphere, combined sewer and stormwater pipes mean that heavy rainfall events can overwhelm sewer capacity leading to the pollution of nearby water ways (Tillinger et al., 2006). In Australian cities, the separation of sewer and stormwater systems has avoided this problem but extensive areas of impervious surfaces generate high quantities of runoff containing elevated levels of nitrogen, phosphorous and other pollutants that increase flooding and erosion and harm stream ecology (Walsh et al., 2005). Consequently, stream ecologists and waterway managers are interested in the potential of green roofs to mitigate the cumulative effects of impervious surfaces which have been termed the 'urban stream syndrome' (Walsh et al., 2005).

Because substrate and plant roots absorb and retain water, green roofs reduce the area of impermeable surface by acting like a sponge on building roofs. Consequently, runoff from small rainfall events may be eliminated, while during larger rainfall events green roofs act to slow the initial flow and can improve water quality (Mentens et al., 2006; Carter and Jackson, 2007). However, the hydrological performance of green roofs is dependent on many abiotic and biotic variables (Simmons et al., 2008). Roof slope (VanWoert et al., 2005; Getter et al., 2007), drainage layer design (Simmons et al., 2008), substrate depth and composition (Monterusso et al., 2004; VanWoert et al., 2005) and the lifeform of plants (Dunnett et al., 2008) have all been shown to influence the quantity and quality of roof runoff. It is also likely that cover and planting density of species will be important.

Hydrological models have been developed that predict the reduction of runoff achieved by implementing green roofs on an individual roof and city scale (Mentens et al., 2006; Tillinger et al., 2006; Carter and Jackson, 2007; Hilten et al., 2008). Adapting these models for the Australian context or constructing local models will provide technical information that will help the uptake of green roofs. For example, developing a green roof module for MUSIC (MUSIC Development team, 2005), the most widely used urban stormwater model in Australia, would make green roofs an attractive water sensitive design tool for engineers, developers and planners. Ideally the models would be parameterised with the abiotic and biotic variables listed above and their potential interactions. This would require testing of locally constructed substrates for water holding capacity and evapotranspiration rates of the plants utilised.

Although urban areas have excess water runoff, Australian cities also have water scarcity problems. Expanding populations and prolonged drought has led to significant restrictions on the use of potable water in most of Australia's major cities over the last decade (Hensher et al., 2006; Mulley et al., 2007). Consequently, the use of large amounts of potable water to keep plants alive on green roofs is unlikely to be feasible on political or sustainability grounds and will necessitate the selection of hardy drought tolerant species that can tolerate periods of elevated temperatures and significant water deficit. However, if green roofs are to be used to effectively counter the urban heat island effect through evapotranspiration, during hot weather they will need some irrigation. This creates an inherent contradiction between one of the objectives of establishing green roofs in Australian cities and the realities of doing so. Integrated design solutions that incorporate grey water harvesting and/or stormwater capture and reuse for irrigation are likely to be one solution if Australian green roofs are to mitigate the urban heat island effect and reduce summer air conditioning use on a neighbourhood scale (Table 1).

Conclusions

Although they are a proven technology in temperate northern hemisphere countries there are many barriers to the implementation of extensive green roofs in Australia and other areas with year round or seasonal hot, dry climates. At this stage of the industry's development, research is required to determine substrate parameters and plants that can survive periods of hot weather with minimal irrigation. Extensive green roofs with substrate depths less than 100 mm, such as those constructed with *Sedum* mats, are unlikely to be successful in Australia, while green roofs with substrate depths between 100 and 200 mm depth may require supplementary irrigation using captured rainwater or recycled water. This will be particularly true if a diversity of species, other than succulents, is desired. However, many of the difficulties currently preventing wide-scale

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Table 1
Barriers to the implementation of green roofs in Australia and corresponding opportunities.

Barriers	Opportunities
Lack of established local green roof industry	• New Australian companies can establish • International companies can expand market opportunities
Little scientific data available to evaluate applicability to local conditions	• New fields of collaborative research for scientists, potentially attractive to industry • Application of research findings to similar climate zones
Green roofs have minimal inclusion in building green star rating schemes and other planning policies	• Addition of higher values in green star rating schemes can act as incentives • Development of city or state specific policies and incentives to increase uptake
Few demonstration projects to inspire and give confidence to developers of green roofs	• Opportunity to establish 'best practice' from the beginning of the Australian industry • Projects have increased profile and publicity • Projects can attract government support
Many plants commonly used in northern hemisphere unsuitable or prohibited by quarantine	• Australian flora is drought adapted and some species should be suitable for green roofs • Development of local nursery opportunities in new plant products • Development of flora export markets
Northern hemisphere substrate components and mixes unavailable	• New market development of local horticultural substrates • Increased use and application of waste and recycled materials in substrates
Lack of an Australian standard or industry guidelines	• Production of guidelines for Australian green roof industry • Interpretation of guidelines applicable to countries with similar climates
Lack of experience, knowledge and connection among green roof industries	• Encourages collaboration between industry, governments and researchers • New business opportunities identified and exploited
Likely inability to use potable water for irrigation	• Encouragement of innovative design solutions using stormwater or grey water that are increasingly needed in cities worldwide

construction of green roofs in Australia are also opportunities (Table 1). Areas with constant or seasonal hot, dry climates have the most to gain from implementing green roofs as a climate change adaptation measure (Alexandri and Jones, 2008), which suggests Australia has a lot to gain if the technology can be adapted. Similarly, the risk of typical northern hemisphere green roof plant species failing could spur the identification of suitable Australian native species and develop an export market for them. Once the substrate and plants required for successful Australian green roofs are identified and developed, the environmental benefits of green roofs in Australian conditions can be evaluated and policy incentives developed to increase uptake.

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