Final Report

Expanding The Living Architecture in Australia

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Content

Summary

Green roofs and green walls (GRGW) offer great potential to expand the living architecture in Australia. Our study shows that with increased urbanisation and increased awareness of resilience issues affecting cities, the social, economic, and environmental benefits of GRGW grow. Barriers to adoption do exist, largely around installation and maintenance costs, lack of awareness, professional guidance and direct experience of working on projects involving GRGW. These barriers will diminish over time as more buildings are designed or retrofitted with GRGW. There is increasing popularity of GRGW in Australia and, given past patterns of uptake in other countries, this may mature over the coming decade or two. Availability of adequate water for irrigation will be critical in some areas.

A lack of appropriate policy and consistent policy approach to GRGW exists in Australia. No State has a policy for GRGW, although the City of Sydney and City of Melbourne have policies for their LGAs. New South Wales, Victoria, South Australia and Western Australia have guidelines and policies referring to GRGW. Melbourne and Sydney initiated their GRGW policies in 2015 and 2012. Overall there is a lack of policy to promote living architecture in Australia. The literature review (Milestone Report 1) and international case studies (Milestone Report 2) revealed various incentives in the form of subsidies, grants and guidance. Singapore leads in adoption of GRGW with the greatest variety of voluntary measures. Singapore is proactive, marketing itself as a 'garden' city and is 'green' to attract investment, visitors and commerce. This approach resulted in an 805% increase in GRGW and a flourishing GRGW economy. Toronto has the second largest area of GR, delivered through a mandatory approach, commencing in 2010. Their mandatory program is enhanced with grants for structural assessment and the green roof. London increased its GR area by 360% over 11 years on a voluntary approach and shows this approach can deliver very good outcomes.

Four scenarios for Melbourne and Sydney were modeled; labeled 'Mandatory' based on measures adopted in Toronto; 'Voluntary Light' based on measures adopted in London; 'Voluntary Medium' based on measures adopted in Rotterdam and 'Voluntary Heavy' based on measures adopted in Singapore. Our modeling for Melbourne and Sydney showed growth trajectories are substantial in all cases, but are higher when there are a mix of policies and initiatives in place. A mix of voluntary and mandatory, as in Singapore, lead to the greatest growth. However, adopting a Singapore approach is unlikely in Australia, as there is greater state ownership of buildings in Singapore. The second key finding is that focusing on 'new build' is likely lead to more modest growth rates in the short to medium term relative to alternative approaches such as retrofit. The annual growth rate of new stock is around 1 to 3 per cent, which means that over the long term, policies focusing on new stock will have a substantial impact. However, in the short to medium term a retrofit policy would have greater impact given the numbers of existing buildings suitable for retrofit. Other measures such as green leases and green building rating tools maybe less likely to deliver much additional GRGW in the short term as they rely on owners and tenants being proactive.

In respect to the business case and the four scenarios modeled, we found that there is a substantial business case for GRGW investment, but that in the Australian context there are uncertainties, which need further research to enable a comprehensive business case to be constructed. While there is a substantial business case for GRGW investment, the value created is shared across a range of stakeholders. We also find a mix of voluntary policy initiatives are likely to enable a vibrant and substantial GRGW industry. Finally, a range of recommendations are made to expand the living architecture in Australia through greater adoption of GRGW.

Keywords

Green roofs, green walls, living architecture, mandatory approach, voluntary approach, Australia, retrofit.

Introduction

This is the final milestone report for project GC15001 (the reports for milestone one and two are included in appendices 5 and 6). This project analysed policy in cities outside Australia to ascertain whether, and how far, mandatory and voluntary approaches to increase the number of green roofs and green walls (GRGW) in urban settlements have succeeded. GRGW deliver benefits such as: improved air quality; attenuation of storm-water; reduction of the urban heat island (UHI); space for social interaction and engagement leading to wellbeing; improved thermal performance and reduced building related greenhouse gas emissions; space for urban food production; and improved biodiversity. The built environment contributes between 40-50% of greenhouse gas emissions and offers great potential for mitigation (UNEP 2009). Typically, 1-3% is added to the total stock of buildings each year through new build (Balchin, Kieve and Bull, 1988; Kelly, 2009). Most existing stock will be around for many decades; 87% of the stock we will have in 2050 is already built (Kelly, 2009). With predicted temperature increases, urban centres will become hotter and less comfortable and there is an opportunity to mitigate the temperature increases through wide-scale GRGW retrofit. In this project we have provided policy analyses and considered a range of factors relevant to evaluating the character of what type of policy would likely be suited to Australia to achieve overall policy objectives. We model a number of scenarios, which are indicative of the amount of additional GR retrofit that is likely to arise following adoption of the different approaches considered. The objectives and outcomes of this project are geared to inform policy makers and industry stakeholders with a view to supporting changes in policy, creation of new market opportunities for industry and disseminate best practice guidance information to key stakeholders.

Objective 1 of this research was *to identify and disseminate best practice case studies* and this was achieved in Milestone Report 2; the case studies. These case studies inform our recommendations below with regards to a national policy plan and approach. Objective 2 was *to identify policy frameworks and incentive schemes, which could be implemented in Australia* and these are outlined in the evaluation and discussion and recommendations sections of this report.

This report sets out the rationale and approach for the modeling scenarios. Melbourne and Sydney were selected for the modeling, however the methodology can be applied in other Australian cities, as well as smaller regional cities and, at suburb and precinct scales. Four scenarios are modeled based on a mix of mandatory and voluntary approaches. The three timeframes for the modeling are 5 year intervals; 2022, 2027 and 2032, which sit well with the City of Sydney's 2030 sustainability goals and the City of Melbourne's 2040 sustainability goals. Scenario 1 is labeled 'Mandatory' and is based on measures adopted in Toronto adapted for Sydney and Melbourne. Scenario 2, 'Voluntary Light', is based on measures adopted in London, again adapted to Sydney and Melbourne. 'Voluntary medium' is the title of scenario 3 and is based on measures adopted in Rotterdam. Finally, we consider scenario 4 'Voluntary Heavy', which is based on measures adopted in Singapore. The scenarios are based on growth trajectories observed in each of the cities where the approach was implemented.

Objective 3 is '*to collect data from overseas on the construction and maintenance costs of green roofs and walls to assist in building a value proposition and business case for living architecture*'.

We address this objective by consolidating findings from a broad review of sources where the cost and benefits of green roofs have been estimated. In this process we not only identify and quantify key sources of value, we also identify opportunities for further research and data collection, which is necessary for a reliable estimate of value to enable the development of a generalisable business case for the Australian setting. An outcome of the analysis is that we distinguish between three different ways value is created by GRGW technology, namely (i) displacement (of conventional roof and wall space) value focused, (ii) increase amenity value focused, and (iii) urban food production value focused.

The evaluation and discussion of the modeling and our key findings from the overall project follow. The report concludes with evaluation and discussions and our recommendations as to the next steps.

Methodology

In Milestone Report 1 the literature review, a desktop study of multiple secondary sources was undertaken, including research reports, peer reviewed journal and conference papers, local government policy papers and frameworks and website information. In Milestone Report 2, the Case Studies, data was collected from a number sources including face to face and telephone interviews and site visits.

In this final report, the methodology for the scenario modeling was to extrapolate possible growth trajectories for four policy scenarios which were selected from the case studies to gain insight into the potential increases that could be achieved if Australian cities were to adopt similar policies and incentive measures. The scenarios are labeled: 'Mandatory' based on measures adopted in Toronto; 'Voluntary Light' based on measures adopted in London; 'Voluntary Medium' based on measures adopted in Rotterdam and 'Voluntary Heavy' based on measures adopted in Singapore. We estimated the growth trajectory experienced in each city for the period coinciding and following the policy implementation. Using these estimates, we then modeled for a subset of Australia's most populous cities, namely the City of Sydney and the City of Melbourne, and our findings are reported in the Outputs section of this report under Output 3 Modeled growth trajectories for four scenarios. In the absence of reliable data of sufficient quantity and quality, and the absence of a well-specified forecasting model, we utilise the observed growth trajectories in each of the four scenario benchmark cities. Despite the inherent limitations of this method, the observed growth trajectory in each case is informative about the possible evolution of the GRGW market in for each policy set. Further, to avoid trajectories that are too optimistic, we condition the terminal market size by capping it using an estimate of green roof market potential.

The cost benefit summary and evaluation comprised data collected from additional literature including published papers and industry reports, Milestone Reports 1 and 2, Australian local government and commercial property databases. In order to identify and quantify key sources of value, we conducted a search for published studies and reports where the costs and benefits of green roofs have been conducted, both in Australia and overseas. While we found a large number of reports and studies, only a few of them provide the necessary detail to extract reliable estimated of the cost and benefits. The variation in costs from one build to another is one reason why it is very hard to get average values for the purpose of modelling. From these studies we identified six, which were the most comprehensive, and we report the high level findings from them and summarise the key sources of value in terms of cost and benefits. The advantage of this approach is we are able to identify that substantial data is missing for the Australian context and provide suggestions for future work. Appendix 2 contains a more comprehensive list of sources of information about cost and benefits to assist industry stakeholders to build a value proposition and business case for living architecture.

Outputs

The outputs can be subdivided into three sections;

Output 1 - Literature Review.

A holistic literature review summarising the key findings and patterns emerging from literature around;

- Drivers for and barriers against green roofs and walls,
- The concept of resilience and resilient cities,
- International and Australian policy approaches to green roofs and walls,
- A critical review of factors affecting adoption of mandatory and/or voluntary approaches, and finally;
- A review of the components of, and arguments for and against the business case for GRGW.

There are many drivers for living architecture (GRGW) in our cities. As cities grow, there are increases in greenhouse gas emissions, air pollution, impervious surfaces urban temperatures, loss of tree canopy cover, loss of green open space, natural soils, biomass and biodiversity and land for food production. Living architecture can mitigate the negative aspects of these issues. GRGW have social, economic, health and environmental benefits.

Barriers are social, economic, technological and environmental. Costs are a significant barrier and lack of construction industry experience. Industry and built environment professional capacity is in a developing phase and not fully ready to implement on a larger scale in buildings, precincts and at city scale. Training and skill development is needed. There is significant potential to retrofit existing buildings, feasibility is determined partly by structural capacity of the buildings to sustain additional loads and; this needs to be more fully understood by stakeholders. There is a lack of appropriate policy and regulations to integrate living architecture practices in new building design and also retrofit.

No consistent policy approach to GRGW was found in Australia. No states have a policy for GRGW, however the City of Sydney and City of Melbourne councils have policies. NSW, Victoria, South Australia and Western Australia have guidelines and policies referring to GRGW. Overall there is a lack of policy to promote living architecture.

US Cost Benefit Analysis (CBA) found a viable case for large-scale retrofit of GR (GSA, 2011). Increases in residential property value with good amounts of green infrastructure was between 6 to 15%, and AECOM reported in 2017 a typical premium of $50,000 to Australian residential property value (AECOM, 2017). It is held that wide-scale adoption of GR in Toronto could attenuate the urban heat island there by 0.5 to 5^{o} Celcius, and as heat wave is a resilience issue for Sydney, Melbourne and Adelaide, wide-scale adoption could be beneficial in attenuating excess heat.

Output 2 - Cases studies and interviews.

A holistic review summarising mandatory and voluntary approaches to GRGW in five international cities London, Rotterdam, Singapore, Stockholm and Toronto;

- In Australia policies and guidelines in Melbourne, Victoria and Sydney, New South Wales were reviewed.
- Our study found Singapore leads in adoption of GRGW with the greatest variety of voluntary measures, as well as having mandatory measures. The city is proactive, marketing itself as a 'garden' city; seeing great advantage in being 'green' to attract investment, visitors and commerce. This lead to an 805% increase in GRGW and a flourishing GRGW economy. Toronto has the second largest recorded area of green roofs in our study, delivered through a mandatory approach, which commenced in 2010. They have increased their total green roof area to 346,000 m^2. Their mandatory program is enhanced with financial incentives of grants for structural assessment and the green roof itself. London increased its GR area by 360% over 11 years on a voluntary approach and shows this approach can deliver very good outcomes.
- Melbourne and Sydney have not initiated their GRGW policies until recently, in 2015 and 2012 respectively.

Output 3 – Scenarios modeling and value proposition.

- Based on output 2, four approaches for Melbourne and Sydney are modelled. Scenario 1 is labelled 'Mandatory' and is based on measures successfully adopted in Toronto, adapted for Sydney and Melbourne. Scenario 2, 'Voluntary Light', is based on measures successfully adopted in London, again adapted to Sydney and Melbourne. 'Voluntary medium' is scenario 3 and is based on measures successfully adopted in Rotterdam. Finally, scenario 4 'Voluntary Heavy', is based on measures successfully adopted in Singapore and adapted to Sydney and Melbourne. Additional information is provided in Appendix 1, which complement the reported results.

- We present a summary of key sources of value in terms of specific cost and benefits. We find evidence for a viable business case for retrofitting extant buildings with living architecture. There are three key business models, which drive value. First, displacement of conventional roofs and walls with living architecture results in energy savings in many cases, as well as value uplift for building owners (increased rent and capital values), and increased life of roof membranes. Also, there are broader benefits to a range of stakeholder including stormwater management, increased air quality, attenuation of urban heat island effect, carbon savings and increased biodiversity and habitat. Second, increased amenity from conversion of unused or bland space into usable space, such as creation of accessible rooftop gardens, community gardens, and more pleasant spaces. There is a positive mental health and productivity benefit, which accompanies this sort of retrofit. Third, urban food production, while still in an early more speculative stage of industrial development, has the potential to create value from the production and sale of fresh produce in local markets. Appendix 2 contains a list of key sources of data from Australian and overseas sources which would be useful to assist in building a value proposition and business case for living architecture.

- The shortfalls in regards to the quantification of benefits were found to be a general lack of reliable quantitative data on the costs and benefits of living architecture, which apply to different roof, wall and living architecture configurations. Further, there are few sources of reliable data comparing different living architecture design options. We also found that it is a common challenge internationally to quantify the benefits in a meaningful way. More research or easily accessible data is needed on a range of dimensions, including (i) both the methods of estimating the value uplift in terms of rental and capital value for property owners, and typical estimates of value which can be used as inputs in specific business cases, (ii) estimates of the energy saving potential in the Australian context, and (iii) documentation of the magnitude of the benefits from increased amenity. While urban food production is a potentially valuable model, more work is needed in the Australian context on what type of business model and production technology would deliver the greatest value.

Output 4 – Factsheet on local and national government green roof and wall policy recommendations

The Factsheet has been complied based on our research and is shown in Appendix 3.

Outcomes

1. Summary of cost benefit analyses of living architecture

While there are many reports and papers which list the cost and benefits of GRGW investment, only a few contain comprehensive evaluations which quantify the net benefits of GRGW, taking into consideration the total cost over the life cycle. Appendix 2 contains a list of key reports and data sources, which would assist industry stakeholders to build a value proposition and business case for living architecture.

Table 1 summarises the key benefits and interests in green roof and wall installations. There are numerous stakeholders who benefit, either directly or indirectly, from the installation of green roofs and walls. Starting at the macro level, this includes the wider community or society, building occupants and building owners, building investors, insurers and developers. The benefits can be economic, social and/or environmental, all to varying degrees. Furthermore, the primary driver for an installation inevitably brings environmental, social and economic co-benefits, regardless of the stakeholders' intentions. For example, a green roof installed as an amenity space will also improve air quality, attenuate some stormwater, add to local bio-diversity and provide some level of additional thermal insulation.

Castleton, Stovin, Beck and Davison (2010) evaluate green roofs; building energy savings and the potential for retrofit. They conducted a literature review and analysis to identify which situations are likely to lead to the greatest energy savings from GRs. They estimated that an extensive roof retrofit cost is about £150/ m^2 in 2010 prices, ranging from £50 to £180/ m^2. They found that there is substantial potential for green roof retrofit for older buildings which as they often have ample structural strength but little in the way of insulation; which contrasts to newer buildings tend to have better insulation properties and accordingly do not get such an uplift in energy savings.

Table 1 Stakeholder benefits and interests in green roof and wall installations

Stakeholder	Benefit type (direct / indirect)	Interests	Other stakeholder beneficiaries and type of benefit
Owner	Value uplift / energy consumption reduced / air quality / bio-diversity (direct), health and wellbeing.	Economic	Community – air quality / stormwater attenuation / bio-diversity / UHI (indirect).
Community	Job creation in design, installation and maintenance.	Economic	
Insurers	Reduced stormwater flooding (indirect less claims for flood affected property and infrastructure).	Economic	Policy-holders could have a reduced insurance premium /policy discount when a green roof is installed.
Community	UHI (direct).	Social and economic	Healthcare providers (public and private) benefit as less people affected by heat stress and needing care. Private healthcare policy could offer a reduced premium /policy discount when a green roof is installed.
Tenants/ users	Lower running costs, better environment, UHI (direct).	Social and economic	Community – air quality / stormwater attenuation / bio-diversity / UHI (indirect).
Visitors	UHI (direct), better environment, better air quality, more attractive environment.	Social	Community – air quality / stormwater attenuation / bio-diversity / UHI (indirect). Economic benefit from additional visitors and longer stays.

(Source: Adapted: AECOM, 2017)

Six of the most comprehensive are summarised in Table 2 below.

Table 2 Summary of key comprehensive cost benefit analysis studies of green vs conventional roofs

Source	Data / experiment	Finding
McRae, A.M., 2016. *Case Study: A Conservative Approach To Green Roof Benefit Quantification And Valuation For Public Buildings.* The Engineering Economist, 61(3), pp.190-206.	Feasibility analysis of hypothetical green vs black roof scenario, based on USA data from published studies. McRae provides a detailed description of how to conduct a valuation to compare roof types.	Modest positive net benefit for green versus black roof.
Sproul, J., Wan, M.P., Mandel, B.H. and Rosenfeld, A.H., 2014. *Economic Comparison Of White, Green, And Black Flat Roofs In The United States*. Energy and Buildings, 71, pp.20-27.	50 year life-cycle cost analysis (LCA) comparing conventional black (dark colored) to white and green roofs. Data is based on 22 case studies spread over a range of USA climate zones.	Positive net benefit of US$70.90 per m^2 comparing green to black roofs. Negative net benefit of US$96.30 per m^2 comparing green to white, but the difference is argued to be marginal and not uniform in that 3 of the 22 cases the green was less than an US$8.40 difference and one was US$122.60 in favour of the green.
Beauchamp, P. and Adamowski, J., 2012. *Different Methods To Assess Green Infrastructure Costs And Benefits In Housing Development Projects*. Journal of Sustainable Development, 5(4), p.2.	Feasibility study for a 600 hectares 'green development' in Montrèal, Canada; comparing green infrastructure to conventional infrastructure using three methods.	Neutral or positive net benefit in favour of green infrastructure.
GSA. 2011. *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings. A Report of the United States General Services Administration*. Retrieved on 4th May 2017 from: https://www.gsa.gov/portal/mediaId/158783/fileName/The_Benefits_and_Challenges_of_Gree	The most comprehensive analysis of the costs and benefits of GR infrastructure, drawing from over 200 studies plus original data from contractors and vendors. They model a number of scenarios and isolate the net benefit accruing to	Positive net benefit. Key driver of value for owners is real estate value uplift. Most benefits accrue to the community.

Source	Data / experiment	Finding
n_Roofs_on_Public_and_Commercial_Buildings.action	owners, tenant and community.	
Carter, T. and Keeler, A., 2008. *Life-Cycle Cost–Benefit Analysis Of Extensive Vegetated Roof Systems*. Journal Of Environmental Management, 87(3), pp.350-363.	Data from an experimental extensive green roof plot, compared to a traditional roofing scenario. Analysis is a 60 year feasibility study of replacing all flat roofs in an urban watershed in Athens, GA, USA.	Negative net benefit, with GR 10 to 14% more expensive than conventional. They find that a 20% reduction in green roof construction costs would make the Social NPV positive.
Wong, N.H., Tay, S.F., Wong, R., Ong, C.L. and Sia, A., 2003. *Life Cycle Cost Analysis Of Rooftop Gardens In Singapore*. Building and Environment, 38(3), pp.499-509.	Feasibility study of hypothetical cases. They conduct a simulated life cycle cost analysis, combining hand collected data on pricing with other data when developing the cases.	Extensive green roof has positive net benefit over the life cycle, whereas the others compared have a negative net financial benefit. They find large variability in initial cost, ranging from extensive roof system, intensive GR (shrubs) and intensive GR (trees) as \$89.86, \$178.93 and \$197.16/ m^2, compared to \$49.35 and \$131.60/m^2 for exposed flat roof and built-up roofs.

(Source: Adapted from Brown et al. (2018)).

Tables 3 and 4 summarise the key costs and benefits over the lifecycle of a green roof for a typical building owner. Please note, we have only included estimates of key material items. Some cost benefit analyses include a much wider range of items, with most having only a minor or irrelevant impact on the cost benefit calculation (cf. GSA, 2011). Further, in most of these studies they compare a typical green roof to a typical black roof, and in some cases, a white roof. What is striking about these results is the magnitude of the range in cost / benefit estimations for building owners. While on one hand, this is unsurprising because of the wide range of green roof designs and contextual factors which influence price, on the other hand the range illustrates the need for more work on clarifying the cost benefit equation for this key decision-making group. To that end, the Growing Green Guide has compiled a range of case studies which reflect a range of roof characteristics and design choices, that include cost estimates. They also have some more detailed cost estimates of individual components of green roofs and walls. These are available at: http://www.growinggreenguide.org/technical-guide/design-and-planning/cost/

Table 3 Summary of typical lifecycle costs of a green roof for building owners

Phase	Cost	Value	Frequency	Range	Sources
Installation	Green Roof Installation	$92.46/m^2	Once off	$19.08 - $215.76	(Alumasc sales representative, 2009 in Castleton et al., 2010; Carter and Keeler, 2007; GSA, 2011; McRae, 2016; Sproul et al, 2014; The Green Roof Centre, 2010)
Lifetime	Maintenance	$2.00/m^2	Annually	$0.49 - $2.83	(GSA, 2011; McRae, 2016; Munby, 2005; Sproul et al, 2014)
Replacement	Replacement	$63.91/m^2	Every 40 Years	$55.54 - $72.28	(GSA, 2011; Sproul et al, 2014)
	Disposal	$1.17/m^2	Every 40 Years	$1.06 - $1.27	(GSA, 2011; Sproul et al, 2014)

Note: All data has is in Australian Dollars at 2016 rates based on applying foreign exchange rates for the relevant year and the compound Australian inflation rate. See appendix 2 a more detailed breakdown of costs.
(Source: Adapted from Brown et al. (2018)).

Table four summarises the key savings over the lifecycle of a green roof. Representing the frequency of occurrence, the uncertainty surrounding the value.

Adhikari, Savvas and Dixon (2016) present a detailed simulation study of the possible energy saving benefits of GR for a variety of Australian climates. They find that the key variables driving the energy savings are: shading effects of foliage; plant physiology; growing media moisture content, thermal conductivity and specific heat capacity; and solar absorption, transmittance and reflectance of the leaf surface area and the leaf reflectivity and emissivity (Adhikari, Savvas and Dixon 2016;5). As with the international studies presented in Table 2 and 3 they find substantial variation in savings between climate zones and roof characteristics, reporting potential energy savings ranging from 2 to 37%. Given the paucity of data in the Australian context, they argue that; “further validation of these finds will be required in the form of monitoring data from built green roofs, in benchmarked trials and research projects …..”(Adhikari, Savvas and Dixon, 2016:19).

Table 4 Key benefits to building owners from green roof installations

Phase	Saving	Value	Frequency	Range	Sources
Lifetime	Energy Saving	$1.69/m^2	Annually	$1.05 - $2.34	(Carter and Keeler, 2007; GSA, 2011; McRae, 2016; Sproul et al, 2014; Wong et al, 2003)
	Property Value	1485.80/m^2	Lifetime Value	$734.7 - $2236.89	(GSA, 2011; Perini and Rosasco, 2013)
	Stormwater Retention	1.27/m^2	Annually	$0.19 - $2.34	(Clark, C., Adriaens., P., and Talbot, F. B., 2008; Sproul et al, 2014)
Replacement	Avoided Membrane Replacement	96.40/m^2	Every 17 Years	$79.17 - $113.63	(Clark et al., 2008; GSA, 2011)

Note: All data has is in Australian Dollars at 2016 rates based on applying foreign exchange rates for the relevant year and the compound Australian inflation rate. See appendix 2 for more detailed breakdown of benefit estimates.
(Source: Adapted from Brown et al. (2018)).

The analysis in this section and our findings in Milestone Report 1 highlight a central challenge to the development of a more vibrant GRGW industry in Australia, that there are substantial uncertainties with respect to quantifying the cost and benefits. The Australian context has a number of characteristics, which would have an effect of the relative values. For example, different weather conditions affecting the relative energy benefits. As the Australian winter is relatively mild compared to the location of many of the extant studies on energy savings (i.e. Canada and Europe), the magnitude of insulation benefits would differ substantially. Other factors include differences in the built environment characteristics, storm water and UHI characteristics, regional differences in storm water charges, the effect of the smaller Australian market on installation and maintenance costs and differences in tax and regulatory costs. Given the overall benefits from GRGW technology, there is a case for (i) collection and collation of information about cost and benefits specifically, and (ii) more research to lower uncertainty of investment in the Australian context; such as on which installations, GRGW designs, and plant selections deliver the most benefits for localised conditions.

2. Three business models to drive uptake of living architecture

Research into the barriers to the adoption of other sustainability focused investments such as energy efficiency initiatives in the built environment finds that, unless there is a substantial value for building owners, take-up is modest (Sorrell et al. 2000). This is consistent with Tayouga and Gagnè (2016) who analysed, which factors lead to the adoption of green infrastructure. They found that financial incentives, education and provision of ecosystem services together, consistently lead to the uptake of green infrastructure. The key ecosystem services from GRGW have been well documented, including carbon sequestration, storm water extenuation among others (e.g. GSA, 2011). Given that building owners are generally the key decision-makers under voluntary schemes, it is necessary to calibrate policy initiatives accordingly so that benefits to them are well understood.

Our analysis of value drivers indicates that there are at least three different business models, each of which creates value in different ways for key stakeholders, and in particular building owners. The three business models are:

- Displacement (of conventional roof and wall space) value focused.
- Increase amenity value focused.
- Urban food production value focused.

There is no doubt that there is overlap between each of these business models. However, as they are focused on different value propositions the design and use of the GWGR is different. Notable differences include plant, medium and irrigation selection and maintenance. Problematically, the focus of much of the research into the business case for GRGW has focused on the displacement value business model (as illustrated by the studies in Table 2). Having noted that, there are a number of detailed resources available to support industry stakeholders who have an interest in the other business models. For example, Daniel Winterbottom and Amy Wagenfeld (2015) have complied a detailed book on 'Therapeutic Gardens: Design for Healing Spaces". Broto (2016) provides insight into different displacement value possibilities, in the book 'Vertical Garden Design Guide and 42 cases'. While we found a number of outstanding resources about how one might design a business model for urban farming (e.g. Ableman 2016; Hedin, 2015; Stone, 2016), we found few studies beyond pilot test (e.g. Wilkinson, Ghosh and Page, 2014). To that end, at present this business model remains largely speculative as a standalone business model. Notwithstanding this, we see potential in urban food production as technology advances, such as the advent of more effective used of robotics, such as the open source FarmBot technology (https://farm.bot/), in urban settings. Further, there are proposals to invest into urban farming, such as the recent announcement from Frasers Property to invest into a 2000 square metre urban farm and retail space in Burwood, Melbourne (Bliszczyk, 2018). See appendix two for a further list of data sources.

Each of the three business models convey benefits to society at large, but also convey benefits to building owners / occupiers albeit in different ways, largely due to the design and use focus of the GRGW being different.
Business model one (displacement value), is the *displacement of conventional roof and wall space,* which primarily drives value for owners via:

- Increased property value.
- Increased rental returns.
- Reduced vacancy rates.
- Direct cost savings from energy saved.
- Direct cost saving from increased roof longevity.

Increase amenity value, business model two, primarily drives value for owners via the same factors as with the displacement of conventional spaces, plus other factors, which are largely site specific:

- Conversion of previously unutilised space into usable space which can be utilised as common areas such as an accessible rooftop garden or rented out such an accessible rooftop garden, bar or restaurant.
- Increase productivity of employees where the building owner is an employer.
- Mental health benefits such as reduced anxiety and increased community, such as GRGW installations at health facilities.

Notably, the increased amenity value will in many cases reduce some of the other benefits, such as less energy savings from less area covered by living architecture. On the other hand, for some sites the mental health and community benefits may be substantial. A good example of this is the installation at the Wayside Chapel in Kings Cross Sydney, where the community garden has a therapeutic influence on the at risk community being supported at the site.

Thirdly, the *Urban Food Production value* business model, is likely to drive value via similar factors as with the displacement of conventional spaces, plus other factors which are idiosyncratic to the specific technology employed to grow and harvest the produce:

- Sale of produce for consumption such as herbs, fruit and vegetables.
- Sale of flowers and other non-edible products.

Notably, while there are examples of urban food production, we found little evidence of well-developed businesses which could compete with extant non-urban farming practices on a cost competitive basis. However, as robotics and other forms of automation come down in price and available land for farming becomes scarcer relative to population, the Urban Food Production value business model will become more viable in a wider range of contexts. Currently our anecdotal evidence suggests that typical urban food production using GRGW technology is about local supply to boutique markets, such as growing food for residents of buildings and local cafes. That is, food grown is often used in affiliated enterprises, rather than being sold on market. Undoubtedly more research is needed to investigate how to design GRGW business models so they may be cost competitive relative to extant markets. We have included the Urban Food Production model due to its potential as a key model to enable wider adoption of GRGW technology.

3. Modelled growth trajectories for the four scenarios

In this section, we report modelling for four scenarios based on mandatory and voluntary approaches and plausible levels of uptake in the case study cities presented in Milestone Report 2, namely Toronto, London, Rotterdam and Singapore.

Mandatory and voluntary approaches were reviewed and quantified in four cities; Toronto, London, Rotterdam and Singapore, in terms of the amounts of increased uptake of GRGW that resulted from the various approaches adopted. This section summarises the four scenarios modelled in this report mandatory (Toronto), voluntary light (London), voluntary medium (Rotterdam) and voluntary heavy (Singapore).

Toronto with it's mandatory approach, coupled with some financial incentives delivered 346,000 square metres of green roof space from 2010 to 2017. In 2011, there was 113,000 square metres of green roof provided and the increase, in those 6 years, has been 306%. This figure indicates that the mandatory approach has lead to reasonable results.

The City of London adopted a light touch set of voluntary measures and achieved an increase of 360% of total green roof space over an 11 year period from 2005 to 2016 and this approach was termed ‘voluntary light’.

Rotterdam has a voluntary approach to increasing the installation of GRGW, through incentives, grants, tax benefits, and demonstration projects. Rotterdam achieved an increase of 120% of green roof area from 2012 to 2017. Similar rates of increase were noted with this London and Rotterdam approaches, however the Dutch scheme has more economic incentives, and this approach was termed ‘voluntary medium’.

In Singapore, most policy instruments are voluntary; however, the culture of integrating skyrise greenery is ingrained in the development sector, and boosted by incentives, grants, awards, certification schemes and government led development. Singapore has seen the greatest uptake of GRGW, some 805% increase over 10 years. For example, all public housing (some 80% of the total stock) is designed with skyrise greenery. The Singapore government acknowledges that the density of the city means that there is little open green space and recognises the need for urban greening. Their vision is of ‘a city in a garden’, and skyrise greenery as means to achieve this. The Singapore government promotes green roofs and walls for their potential to increase livability, providing green space for recreation, relaxation and social gathering. This approach is termed ‘voluntary heavy’.

Using data about the base level of GRGW from the City of Sydney and the City of Melbourne to ascertain the increase in green roofs should a similar trajectory be realised. Each scenario is modelled over three time frames;

- Short term (5 years to 2022),
- Medium term (10 years to 2027) and;
- Long term (15 years to 2032).

The focus of the analysis is on GR retrofit with a focus on extensive roofs, as there is some evidence that this is where there is the largest potential for impact. First, in settings which have achieved greater levels of GRGW uptake, the growth largely comes from retrofit and extensive GR design. For example, Herman (2003, in Castleton et al. 2010, p. 1583) found that about 14% of German flat roofs had a GR installation, with 80% of those extensive roofs. Castleton et al (2010) attributed this to there being less need to invest in improving structural capacity. Second, growth in building stock is relatively slow, at about 1-3% per year (Balchin, Kieve and Bull, 1988; Kelly, 2009), so even if 100% of new stock was fitted with GRGW technology, overall growth would likely be modest compared to a broader retrofit strategy.

The four scenarios are presented in Tables 5 – 8. Appendix 1 contains further information, which has informed this analysis. Given the high growth rate of Scenario 4, it was necessary to estimate an upper bound to represent a level of market saturation, to avoid overstating the potential for this market. We chose a conservative estimate, from an established model to predict the level of market saturation for this situation. We estimate an upper bound of 3,245 green roofs for Sydney LGA and 570 green roofs for City of Melbourne. The approximate Total Roof Area (m²) of Buildings within the City of Sydney LGA is 9,341,483.42m² and comprises 16,233 buildings according to the Buildings' Roof Area and SLEP 2012 Land Use Zones General Overview. Accordingly, the average roof size is about 576m². Applying Ahrestani's (2011) estimate of 20% of Sydney buildings being suited to retrofit, 3,245 of these buildings could be retrofitted with extensive green roofs. The City of Melbourne has 880,000m² of rooftops (COM, 2017). Applying the COM report findings (COM, 2017), 37.27% of Melbourne rooftops are suited to extensive green roof retrofit there is a total potential extensive green roof area of 328,000m². Assuming the average roof size is about 576m², this figure represents 579 roofs. Given the difficulties of estimating the growth in building stock in these relatively saturated locations, we assume the total roof space will be similar in the future (assuming new build displaces extant build).

Table 5 Estimates for total incremental green roof coverage in hectares for each of the four scenarios modelled

Scenario	**Approach**	**Annual growth trajectory from benchmark city**	**Estimated total increment green roof coverage in ha by 2032**	
			Sydney	**Melbourne**
Scenario 1 – Mandatory (Toronto)	Extra light voluntary and mandatory	9.6%	279	64
Scenario 2 – Voluntary light (London)	Voluntary	12.4%	375	85
Scenario 3 – Voluntary medium (Rotterdam)	Voluntary	17.1%	635	145
Scenario 4 – Voluntary heavy (Singapore)	Voluntary and mandatory	29.8%	>1,471	>262

There are two key findings from Table 5. First, growth trajectories are substantial in all cases, but are higher when there are a mix of policies and initiatives in place. In all cases a mechanism existed to enable value to be realised for building owners, such as tax benefits, avenues for accreditation or financial incentives such as grants. Toronto and London have the lowest number of initiatives, which is reflected in less growth. A mix of voluntary and mandatory, as in the case of Singapore, lead to the greatest growth. Notably, both Rotterdam and Singapore combine active planning, ambitious targets, and direct investment in living architecture for public assets – which likely drove the higher growth. While the Singapore scenario is included, it is not likely to be a plausible option in the Australian context to the extent that there is greater state ownership of buildings in Singapore, and accordingly the potential for growth at that level in Australia is unlikely if the same policies were adopted. While there are differences between the Australian and case locations, the growth trajectories experienced in each case are informative about the possible magnitude of similar policy initiatives in other jurisdictions, and the relative magnitude of different levels of policy intensity from Extra light to mandatory. In that if a voluntary medium strategy was adopted there would likely be substantial uptake of somewhere between 12.4 and 29.8% annual growth such as experience by Rotterdam.

The second key finding is that focusing on 'new build' is likely lead to more modest growth rates in the short to medium term relative to other approaches. With respect to Toronto's mandatory policy, the focus is on new build and accordingly is constrained in effectiveness by the rate of new development, which can be contrasted to the some of the more effective policies, which incorporate a focus on retrofit, as well as new build. To put this into context, the growth rate of new stock has been estimated to be between 1 to 3 per cent (Balchin, Kieve and Bull, 1988; Kelly, 2009), which means that over the long term policies focusing on new stock will have a substantial impact. However, according to City of Melbourne (2013) 37.27% of Melbourne rooftops are suited to extensive green roof retrofit, and 26.81% are suited to intensive green roof retrofit. In the case of Sydney, green roof retrofit potential is about 20% (Ahrestani, 2011) for the Sydney CBD. Accordingly, it likely that a retrofit policy is would have a greater impact in the short to medium term. Further, we have assumed that only 75% of a given roof is available for retrofit, which is consistent with earlier studies (e.g. Wilkinson and Reed, 2009).

Table 6 Estimates for total number of green roof projects for each of the four scenarios modeled

Panel A: City of Sydney LGA

Total number of projects at end of period	Annual growth rate	Base level of projects	Short term (5 years to 2022)	Medium term (10 years to 2027)	Long term (15 years to 2032)
Scenario 1 - Mandatory (Toronto)	9.6%	123	194	307	485
Scenario 2 - Voluntary light (London)	12.4%	123	220	395	707
Scenario 3 - Voluntary medium (Rotterdam)	17.1%	123	271	595	1,310
Scenario 4 - Voluntary heavy (Singapore)	29.8%	123	453	1,668	>3,245

Panel B: City of Melbourne

Total number of projects at end of period	Annual growth rate	Base level of projects	Short term (5 years to 2022)	Medium term (10 years to 2027)	Long term (15 years to 2032)
Scenario 1 - Mandatory (Toronto)	9.6%	28	44	70	110
Scenario 2 - Voluntary light (London)	12.4%	28	50	90	161
Scenario 3 - Voluntary medium (Rotterdam)	17.1%	28	62	136	298
Scenario 4 - Voluntary heavy (Singapore)	29.8%	28	103	380	>570

Table 7 Estimates for incremental number of green roof projects in for three time periods for each of the four scenarios modeled

Panel A: City of Sydney LGA

Incremental number of projects in each time period	Annual growth rate	Short term (5 years to 2022)	Medium term (10 years to 2027)	Long term (15 years to 2032)
Scenario 1 - Mandatory (Toronto)	9.6%	71	113	178
Scenario 2 - Voluntary light (London)	12.4%	97	174	312
Scenario 3 - Voluntary medium (Rotterdam)	17.1%	148	325	714
Scenario 4 - Voluntary heavy (Singapore)	29.8%	330	1,215	>1,577

Panel B: City of Melbourne

Incremental number of projects in each time period	Annual growth rate	Short term (5 years to 2022)	Medium term (10 years to 2027)	Long term (15 years to 2032)
Scenario 1 - Mandatory (Toronto)	9.6%	16	26	41
Scenario 2 - Voluntary light (London)	12.4%	22	40	71
Scenario 3 - Voluntary medium (Rotterdam)	17.1%	34	74	163
Scenario 4 - Voluntary heavy (Singapore)	29.8%	75	277	>190

Table 8 Estimates for the coverage of incremental green roof projects in for three time periods for each of the four scenarios modeled

Panel A: City of Sydney LGA

Estimated size of incremental projects (ha)	Annual growth rate	Short term (5 years to 2022)	Medium term (10 years to 2027)	Long term (15 years to 2032)	Total
Scenario 1 - Mandatory (Toronto)	9.6%	31	49	77	279
Scenario 2 - Voluntary light (London)	12.4%	42	75	135	375
Scenario 3 - Voluntary medium (Rotterdam)	17.1%	64	140	309	635
Scenario 4 - Voluntary heavy (Singapore)	29.8%	142	525	>681	>1,471

Panel B: City of Melbourne

Estimated size of incremental projects (ha)	Annual growth rate	Short term (5 years to 2022)	Medium term (10 years to 2027)	Long term (15 years to 2032)	Total
Scenario 1 - Mandatory (Toronto)	9.6%	7	11	18	64
Scenario 2 - Voluntary light (London)	12.4%	10	17	31	85
Scenario 3 - Voluntary medium (Rotterdam)	17.1%	15	32	70	145
Scenario 4 - Voluntary heavy (Singapore)	29.8%	32	119	>82	>262

Evaluation and discussion

Mandatory and Voluntary Approaches to green roofs

Many cities adopt more policy instruments and/or financial incentives, or a combination of the two approaches to incentivise green roofs. Globally, legislation and policies can originate at national level or state or city or local council levels. Toronto and Vancouver have made green roofs mandatory for new developments, with Toronto having financial incentives if certain criteria are met. Chicago combines mandatory and voluntary strategies including the 2005 Green Roof Grant Program, the 2006 Green Roof Improvement Fund, the 2007 Sustainable Development Policy, the 2008 Adding Green to Urban Design Plan, and the 2015 Green Permit Benefit Tier Program. Through these instruments, the city encourages green roofs through both financial and non-financial incentives, with reduced permit fees or priority development review. Additionally, some US and Canadian cities (Vancouver and Los Angeles) mandate that some new buildings are required to meet sustainability standards contained rating tools such as the Leadership in Energy and Environmental Design (LEED), into which green roofs and green walls can be incorporated.

In Switzerland, Basel has mandated green roofs for all new and renovated flat roofs since 2002, through the city's Building and Construction Laws, with subsidies of 20 Swiss francs per metre squared to support the initiative. Basel's total area of green roofs has increased to 100 ha in 2015, the largest area per head of population of green roofs globally. Since 2008 Copenhagen has mandated green roofs as a requirement of its urban development strategy, and green roofs are mandatory for all municipal buildings. Stuttgart, in Germany, mandated green roofs in 1986 and has increased its total area from 6Ha to 30Ha in 2015 (Irga et al, 2017). Stuttgart also provides financial support for green roofs through the German Building Code. In Japan, the Tokyo Green Plan 2012 mandated new private developments greater than 1000 m^2, and public buildings greater than 250 m^2, must have at least 20% greened roof or, face a US $2000 fine. The National Building Law 2005, mandates all new apartment or office buildings in urban areas must provide at least 20% vegetated rooftops. Tokyo increased green roofs from 5.24 ha in 2000 to 10.44 ha in 2001, and from 2007 to 2010 57.2ha of GRGW were installed.

In Hong Kong, high urban density leading to reductions of urban green space, has driven green infrastructure policy and incentives. Detailed guidelines provide guidance on design, plant selection, installation, maintenance, and costing tools for intensive and extensive green roofs. Government policy encourages green roofs on public buildings. Financial incentives include Policies JPN1 and JPN2, which promote green features by exempting communal 'sky' gardens from gross floor area and site coverage taxes. Singapore uses financial incentives to reduce cost barriers with the Skyrise Greenery Incentive Scheme (SGIS) 2009, providing up to 50% of the installation costs of green roofs. London's approach is voluntary and provides guidance and management strategies for green roofs. Some of the City of London's policy instruments with regard to GWGRs overlap, and are incorporated into multiple strategic approaches. For example, it features in the Biodiversity Action Plan 2010–2015, Green Roof Case Studies 2011, Green Roof Map 2013 and most recently, London's Response to Climate Change 2015. Overall, the best outcome has arisen from Singapore's voluntary approach.

Another option is the voluntary green building rating tools, such as LEED, Green Star and BREEAM, all of which measure the level of sustainability in buildings. In the private commercial sector there is considerable evidence of a premium in value as a result of high levels of sustainability (Newell et al, 2011. Fuerst and McAllister, 2011a) and this is a motivation for this sector to adopt more green features, including green roofs, in their stock. Some claim (Miller et al, 2008. Sah et al, 2017) that these tools deliver more sustainability to the built environment.

Existing Levels of Activity: **GRGW Policy and Programs in Australian Cities**

The City of Sydney published a *Green Roofs and Walls Policy* in 2014, a *Green Roofs and Walls Policy Implementation Plan, and Environmental Performance Grants* supported by *Sustainable Sydney 2030.* Information on GRGW benefits, barriers to uptake, and design considerations is available. A comprehensive resource manual for green roofs is provided, as well as leadership through GRGW on council buildings, and establishing advisory committee and a Technical Advisory Panel (TAP) from 2012 to 2014. Subsidies can be provided on a case-by-case basis through environmental performance grants. In summary support includes awareness, guidance, financial incentives, and GRGW monitoring. Since implementation of its green roofs and walls policy in 2014, the City of Sydney has experienced a 23% increase in total GRGW coverage.

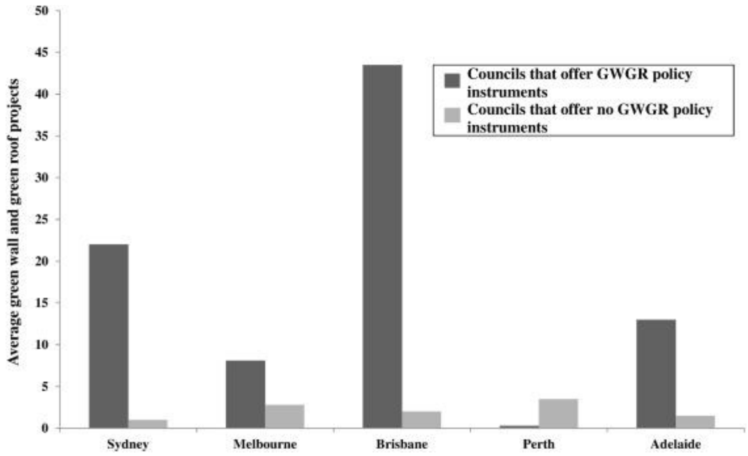
The City of Melbourne and three other councils use the *Growing Green Guide 2014* (State of Victoria, through the VAS Partnership, the Inner Melbourne Action Plan & the University of Melbourne, 2014). The support mechanisms are awareness and guidance. Since the 2014 release of guidance document, the average uptake of GRGW across all Greater Melbourne councils increased though it is not measured and publicly available.

Adelaide City Council provides *Green Infrastructure Guidelines 2014,* which refers to living architecture, green streets, Water Sensitive Urban Design (WSUD) and urban forests. The section on GRGW, provides brief information on GRGW benefits and design. Support has been in the form of awareness and guidance however, there has been a negligible increase in GRGW uptake since release of guidelines. In 2016 the Green City Grant Program was launched with 50% match funding for projects including green roofs and walls, up to a maximum $10,000. Grants are open to residents and businesses in the City of Adelaide. In 2016 seventeen project were funded under the scheme which represents a considerable increase in uptake of GRGW as a result (City of Adelaide, 2018).

Brisbane City Council provides the *Plan for Action on Climate Change 2007* and the *Community Sustainability and Environmental Grants Program.* Mention of GR, as a strategy for climate action, is in the climate change policy, and within strategic land use and planning, and research sections. Support is in the form of awareness and financial incentives. AUD$1000–$10,000 grants are awarded on merit to sustainability projects within Brisbane City Council that reduce energy consumption and greenhouse gas emissions of their facilities. There has been a strong uptake of GRGW in Brisbane City Council, though it is not clear if this uptake is associated with policy (see figure 1).

Finally, Perth has no enacted GRGW policies or guidance notes and has the least number of GRGW projects and the smallest total greened area of all capital cities in Australia. Figure 1 shows these city councils and the numbers of LGAs that offer or do not offer GRGW policy instruments. Table 9 summarises the provision in the five Australian key cities.

Figure 1 Australian Cities councils with and without GRGW policies.



(Source: Irga et al, 2017).

Table 9 GWGR Guidance and Policies in Australian State Capitals

City	Policy	Mechanism	Policy details	Comments
Sydney	City of Sydney provides *Green Roofs and Walls Policy 2014*, *Green Roofs and Walls Policy Implementation Plan Environmental Performance Grants* supported by *Sustainable Sydney 2030*	Awareness, guidance, financial incentives, GRGW monitoring	Information on GRGW benefits, barriers to uptake, design considerations. Comprehensive resource manual for GR. Leadership through GRGW on council buildings, establishing advisory committee. Subsidies provided case-by-case through environmental performance grants.	Since implementation of green roofs and walls policy in 2014, City of Sydney has experienced 23% increase in total GRGW coverage
Melbourne	City of Melbourne and four other councils endorse the *Growing Green Guide 2014* (State of Victoria, through the VAS Partnership, the Inner Melbourne	Awareness, guidance	Comprehensive information on GRGW benefits; technical design, installation, maintenance considerations; detailed best practice case studies in Victoria. Leadership through GRGW on council buildings.	Since 2014 release of guidance document, average uptake of GRGW across all Greater Melbourne councils increased

City	Policy	Mechanism	Policy details	Comments
	Action Plan & the University of Melbourne, 2014).			
Adelaide	Adelaide City Council provides *Green Infrastructure Guidelines 2014* *Green City Grant Program 2016*	Awareness, guidance Financial incentives	Document refers to living architecture, green streets, WSUD, urban forests. Section on GRGW, providing brief information on GRGW benefits, design. Grants meeting up to 50 per cent of the cost of eligible greening projects start at $500 for residents and $1,000 for businesses and property owners, up to a maximum grant of $10,000.	Negligible increase in GRGW uptake between 2014 release of guidelines and 2016. 2016 Green City Grant Program resulted in 17 projects funded to a value of $80,000.
Brisbane	Brisbane City Council provides *Plan for Action on Climate Change 2007*, and *Community Sustainability and Environmental Grants Program*	Awareness, financial incentives	Mention of GR as a strategy for climate action in climate change policy, within strategic land use and planning, and research sections. AUD$1000–$10,000 grants awarded on merit to sustainability projects within Brisbane City Council that reduce energy consumption and greenhouse gas emissions of their facilities.	Strong uptake of GRGW in Brisbane City Council. Unclear if uptake is associated with policy.
Perth	No enacted GRGW policies or guidance notes.	N/A	N/A	Perth hosts the least number of GRGW projects and the smallest total greened area of all Australian capital cities.

(Source: Adapted from Irga et al 2017).

Other Voluntary Measures

Green leases

Another option for increasing the living architecture considered was the adoption of green leases in the commercial sector (Heaton, 2017). This is a voluntary mechanism whereby landlords and tenants can agree to ‘green lease’ clauses, which aim to improve environmental performance of commercial office buildings. The clauses can be either enforceable or not, therefore, if the clause is unenforceable and the tenant or landlord does not undertake the commitment outlined, there is nothing the other party can do in effect. A 2015/2016 study of green leases in Sydney and Australia (Bright et al, 2016) concluded that different types of green lease exist, so called light green, mid green and dark green; depending on the scope of clauses and amount of enforcement permissible. Furthermore, green infrastructure provision would be one of many possible environmental performance or improvement options for landlords and tenants to consider. Thus one has to consider the cost benefit equation and how likely tenants, on 5-year terms, would be to pay for GI measures, as they would be highly unlikely to recoup economic payback for the investment during this short term. Currently most Australian green leases are light, with limited enforceability of clauses (Bright et al, 2016) and thus the amount of green infrastructure that could be realistically delivered with this approach is not substantial.

Green Building Rating Tools

A final option to increase the living architecture is through voluntary sustainability rating tools. In Australia, Green Star is a rating tool adopted by a small proportion of commercial owners, as a means of differentiating their buildings, and to attract premium tenants (Wilkinson et al, 2015). Research shows these Green Star rated buildings have had fewer vacancies, greater absorption rates, higher capital values and higher rental values (Newell and Lin Lee, 2012. Newell et al, 2011. Fuerst and McAllister, 2011a. Fuerst and McAllister, 2011b); which might encourage some owners to expand provision. There is an option to gain credit through the specification of a green roof in Green Star. The total amount of office buildings rated by these sustainability tools is tiny, compared to the total stock of buildings. Again reliance is on the market to decide to use the tool, and then to decide the green roof or wall option in worthwhile on their building. A newer tool gaining popularity in the Australian commercial property sector is the WELL Building Standard (Meagher, 2017), which emphasises the well-being features of buildings; as such more green infrastructure or living architecture is likely to feature in WELL accredited buildings. A 2015 study (Wilkinson et al, 2015), examined the commercial property sector and uptake of sustainable measures, and whether mandatory approaches to sustainability as contained with the Building Code of Australia (BCA) were delivering more sustainability than voluntary approaches such as Green Star. The conclusion was that mandatory measures, though lower in the amount of sustainability delivered on a per building basis, were resulting in more sustainability because all new buildings had to comply with the BCA, and also many alterations and adaptations to existing buildings triggered BCA requirements (Wilkinson et al, 2017). Again, the WELL Standard includes GRGW as an option in a suite of measures, but it is an option only, and owners are free to select other measures. Whilst some increases in living architecture are likely as the WELL Standard is adopted by a greater number of owners, it will be variable and is unlikely to be significant across the whole market.

Discussion and findings

Williams et al (2010) concluded there was a more limited uptake of GWGRs in Australia compared to many other countries. Irga's et al's study (2017) quantified the number and distribution of GWGRs across Australian capital cities and found the distribution of projects was highly variable (see figure 1). In each capital city, the council encompassing the CBD had the highest number of GWGR projects, with Irga et al (2017) concluding the distribution of GWGR projects is related to

the density of development within an LGA. The trend was apparent when GWGR project density was assessed on a per capita basis (Irga et al, 2017). As urbanised areas have the smallest amounts of existing greenspace, and the highest population density, this is not unexpected.
The most worthwhile and practical means of increasing and improving urban greening is through its incorporation onto existing or newly built infrastructure; green roofs and green walls (Wilkinson and Dixon, 2016). Furthermore green roofs and green walls can be positive visual symbols of an institutions prestige, status and commitment to a more sustainable, resilience and liveable city. This driver may contribute to their greater presence in inner city locations.

There is increasing popularity in GWGR technology in Australia however it is in its initial stages of development, compared to other countries such as Basel, where legislation was enacted in 1996 (Irga et al, 2017). Consequently, the numerous ecological and environmental services the technology can provide are not widely comprehended by all stakeholders. It is necessary to identify, articulate and; where possible, quantify these benefits such as increasing bio-diversity, improving air quality, attenuating stormwater, improving building energy efficiency. In this way perceptions that high profile projects may be costly showcase designs, and merely 'eco bling' will be discounted (Wilkinson and Dixon, 2016). Irga et al (2017) concluded the GWGR drivers in Australia may vary compared to Europe and North America, where environmental benefits may be stronger drivers. The drivers of GWGR in Switzerland are aimed explicitly at increasing biodiversity, replacing lost habitat, saving energy in building operation and providing stormwater retention (Brenneisen, 2006. Irga et al, 2017). In Australia a wider range, and more generous, incentives are required to stimulate more environmentally targeted investment in green roofs and walls to deliver the associated environmental benefits in a shorter timeframe. Reliance on the attraction of aesthetic benefits alone is deemed insufficient (Irga et al, 2017).

There has been a large variation across Australia's state capitals in the uptake of green roofs and walls (see figure 1). Some claim this is due to a lack of evidence of suitability in Australia (Williams et al, 2010). With many guides from northern hemisphere and international sources, there has been a lack of local information on plant suitability (Perkins and Joyce, 2012). This is changing with the guides in Sydney and Melbourne (City of Sydney, 2014. State of Victoria, through the VAS Partnership, the Inner Melbourne Action Plan & the University of Melbourne, 2014a).

Internationally there is increasing awareness in the general public of the value of GWGR projects (Pérez-Urrestarazu et al., 2015), which is occurring also in Australia. The examples now installed, demonstrate to stakeholders both what is possible and successful to a somewhat risk-averse industry (Perkins and Joyce, 2012). However Irga et al (2017) concluded, this does not explain the variation in adoption across the capital cities and it may be the lack of effective examples in climates with hot dry summers (Adelaide and Perth) and the lack of water storage capacity in shallow substrates affected uptake in some areas, although this may be changing with the uptake of grants from 2016 onwards through Adelaide's Green City Grant Program (City of Adelaide, 2018). Sustainable irrigation is a pre-requisite to successful adoption and longevity in these locations (Irga et al, 2017).

Many Australian cities experience periodic water shortages, especially during times of drought. Water supply also has to accommodate rapid population growth (estimated to be 23.55% for the

City of Sydney LGA from 2015 to 2031 and Melbourne predicted to grow by 9.63% between 2016 and 2018). Using scarce water resources to water plants in times of shortage is socially, environmentally and economically unsustainable. It follows that buildings with green roofs or walls should have on site rainwater harvesting and/or use of greywater for watering purposes wherever possible. Specification of drought tolerant planting is also recommended. However, in Brisbane, greater amounts of rainfall, and climatic conditions similar to some south-east Asian locations such as Singapore might allow stakeholder there to adopt research and development from those countries (Irga et al, 2017).

Irga et al (2017) concluded that population size did not correlate with the number of GRGW. Brisbane had the most GRGW projects per capita, though not the highest number of GRGW projects. They speculated that it may be due to a greater level of corporate social responsibility in the area, but it could also be that green roofs play a positive role in attenuating rainwater runoff, which is valued here (Lamond et al, 2014).

Carter and Fowler (2008) found that policy instruments and mechanisms related to GWGRs were a major driver globally in affecting the amount of GWGR projects. In Australia local government is responsible for land management, land-use planning, policy development, and developmental control. Irga et al (2017) found, across all capital cities, existence of GWGR policy strategies and documents at council level correlated with higher average numbers of GWGR projects per council than for those without (see figure 5). From the analysis of uptake of GRGW in cities with policies (Wilkinson et al, 2017b. Irga et al, 2017), it is apparent that in all cases the outcomes were positive and the numbers of GRGW projects increased. Support can come on the form of the council adopting the technology, as with Melbourne and CH2 in 2006, as an exemplar demonstrating longevity. The City of Sydney's policy with the detailed technical, research based guides, an introduction of standards, and financial incentives were seen as very effective in the Australian context. No Melbourne council has a GRGW policy, however a partnership of the State of Victoria, four Melbourne councils and the University of Melbourne, produced the comprehensive Growing Green Guide (State of Victoria, through the VAS Partnership, the Inner Melbourne Action Plan & the University of Melbourne, 2014a). This resource is available to the Greater Melbourne councils to overcome the barriers limiting uptake outlined by Williams et al. (2010) and may have contributed to increasing uptake in these councils. The Policy Options Background Paper (State of Victoria, through the VAS Partnership, the Inner Melbourne Action Plan & the University of Melbourne, 2014b) investigated current policies in place globally, to ascertain what opportunities existed for policy in Victorian legislation and what the next steps could be to realise how green roofs, walls and facades can be best supported by government policy. The Policy Options Background paper is written for Victorian local councils, interested groups in the building industry, the Victorian Government's Department of Transport, Planning and Local Infrastructure, and anyone interested in how to support a significant increase in the number of green roofs, walls and facades being installed and maintained in Melbourne and Victoria. This formed part of the Growing Green Guide for Melbourne project, with support from a Policy Reference Group, including representatives from the Cities of Melbourne, Port Phillip, Yarra and Stonnington, as well as a planning representative from the Department of Transport, Planning and Local Infrastructure. Building on from this Policy Options paper, the City of Melbourne intends to develop a green infrastructure specific policy in 2018 (pers comm, 2017). Adelaide City Council has offered more limited guidance on the installation and maintenance in their 'Green Infrastructure Guidelines (Adelaide City Council, 2014) and had experienced less adoption. This document discusses the benefits, design considerations and maintenance considerations very briefly and lacks local case study examples (Adelaide City Council 2014). However, the uptake in Green Roofs and Walls increased in 2016 with the launch of the Green City Grant Program (City of Adelaide, 2018) whereby 17 projects received partial funding by the City of Adelaide. The grants are open to residents and businesses and allow a maximum grant of $10,000. Overall this evidence suggests that an inspiring and practical policy, and increased local government support are successful ways to promote GWGR.

Some cities, such as Singapore and Seattle, use direct financial incentives, subsidies, and rebates to incentivise GRGW. In Singapore, the Skyrise Greenery Incentive Scheme funds up to 50% the costs of installation of green roofs, and the scheme lead to an increase of 110 projects in 2015 and by 2017; 80 ha of green roofs (Wilkinson et al, 2017b) Seattle adopts a Floor Area Ratio (FAR) bonus that gives developers incentives for GRs in all new developments. The outcome of this incentive delivered 62 green roofs in covering 33387.03 square metres as of December 2009. San Francisco, on the other hand, uses the financial incentive of a rates discount for properties with GRs, with over 10% of 78 development projects having green roofs in 2013. New York uses a tax abatement of US$4.50 per square foot of building-integrated green space to encourage uptake in green roofs (Irga et al, 2017). These international examples illustrate that supportive policy has a positive effect in the uptake of GWGRs. To be effective, the policy instrument needs to be developed specifically for the area (Carter and Fowler, 2008). Some direct approaches may not be feasible economically or politically, particularly in fiscally conservative cities and that indirect incentives may be more appropriate here. The City of London provides an example, where GRs are encouraged through various policy instruments, including the city's Biodiversity Action Plan 2010–2015 wherein green roofs, walls and balconies can be used to maximise wildlife habitat. This indirect incentive has had a marked effect, by 2013, 678 green roofs were provided in the City of London.

Where the green roof industry is well established, voluntary associations certify the construction of green roofs such as LEED in the USA. In Vancouver all new building re-zonings must achieve a Gold LEED rating and thus the city relies on the knowledge and expertise of these voluntary organisations. The City of Los Angeles public works Green Building Program mandates all non-residential buildings over 10,000 ft^2 and large-scale residential buildings must meet LEED certifications. The City of Melbourne (COM, 2013) posited that the Building Code of Australia (BCA), the Green Building Council of Australia (GBCA) Green Star, or National Australian Built Environment Rating System (NABERS) could drive development of guidelines, codes and standards for green roofs and walls. In this way, Australian LGA policy could focus on making new and existing developments meet these mandatory and/or voluntary standards. Irga et al. (2017) concluded such policy implementation in Australia could increase the uptake of GWGR.

Australian capital cities are at various stages of the development of their GWGR sectors. Sydney appears to be the most advanced, with Melbourne and Brisbane following. Carter and Fowler (2008) concluded that the success of the policy in increasing GWGRs may be lengthy in the realisation of the benefits. Evidence above from Singapore and other cities, and also in Wilkinson et al (2017b) is that rapid uptake is possible in certain conditions, and that these benefits include; employment opportunities in installation and maintenance, added capital and rental values to property, as well as air quality, improved bio-diversity, stormwater attenuation, lower energy consumption and associated GHG emissions. On a mass scale over time there is also attenuation of the urban heat island, which is a major issue in Australian capital cities and one we must address urgently if we are to achieve sustainable, resilient and liveable urban settlements.

In respect to the business case and the four scenarios modeled, we found that there is a substantial business case for GRGW investment, but that in the Australian context there are uncertainties, which need further research in order to enable a comprehensive business case to be constructed. While there is a substantial business case for GRGW investment, the value created is shared across a range of stakeholders. We also find that a mix of voluntary policy initiatives is likely to enable vibrant and substantial GRGW industry. Our analysis suggests that mandatory approaches, which target new build, are limited by the growth of the sector, whereas the majority of growth is likely to come from GRGW retrofit supported by voluntary initiatives. Appendix 4 contains a summary of financial and other incentives which have been trialed in a variety of jurisdictions.

While in this study we have been able to model some plausible scenarios for the Sydney and Melbourne, more work is need. We primarily focus on the Sydney LGA, so further work on the other growth areas such as Brisbane, Adelaide and Perth, as well as residential, regional and other areas. We have incorporated our recommendations into the next section.

Recommendations

In investigating ways to expand the living architecture in Australia, this project analysed whether mandatory or voluntary approaches to green roofs and green walls would deliver more living architecture over the short, medium and long term. Based on our analysis, we would recommend a range of strategies:

1. The policy package should reflect a mix of elements, which focus on the key elements which have been shown to influence the adoption of green infrastructure in a wide range of settings (Tayouga and Gagne, 2016), namely:
    a. Education to enhance '*awareness, knowledge, and understanding of the types and uses of green infrastructure, including the ecosystem services it provides, by the general public, stakeholders, and policy- and decision-makers*' (p. 9).
    b. Provision of ecosystem services, where the GRGW infrastructure performs equally or better than traditional infrastructure.
    c. Financial incentives, including '*both directs, such as grants and subsidies, and indirect, such as energy cost savings, incentives*' (p. 9).

2. Our analysis would also suggest mix of voluntary and mandatory policy, with:
    a. predominantly voluntary approach for retrofit which includes mix of initiatives to enable value to be realised for building owners, such as tax benefits, avenues for accreditation or financial incentives such as grants, and
    b. mandatory approach for new build and renovations (as enforcement can be tied to approval process).

No consistent policy approach to GRGW was found in Australia, and whilst no states have a policy for GRGW, within Sydney only the City of Sydney has a policy, three LGAs have guidelines and two LGAs incorporated GRGW into other policies, however 14 LGAs have no policies, support or guidance. In Melbourne five councils have guidelines and four councils incorporate GRGW into other policies, however 23 councils have no policies, support or guidance. Overall there is a lack of coherent policy to promote living architecture throughout the States and Territories.

There is a viable case for large-scale retrofit of GR, with increases in residential property value with green infrastructure between 6 to 15%, with a typical premium of $50,000 (AECOM, 2017). With wide-scale adoption of GR the UHI in Toronto could be attenuated by 0.5 to 5^{o} Celcius, and as heatwave is a resilience issue for Sydney, Melbourne and Adelaide, wide-scale adoption could be beneficial in attenuating excess heat resulting in fewer adverse health impacts, heat related fatalities and costs to the healthcare system. The costs to the healthcare system need to be modeled based on predicted increased temperatures and our ageing populations, who are more vulnerable to heat stress.

Based on our analysis of existing policy and provision of GRGW in Sydney and Melbourne and our modeling of Sydney data we make the following nine additional recommendations with respect to future research and critical education / information infrastructure:

Improve the quality of information to better inform policy makers, building owners and other key stakeholders

1. Further evaluation of GRGW potential for LGAs outside Sydney and Melbourne (Perth, Brisbane and Adelaide).
2. Develop a comprehensive cost benefit analysis of GRGW value potential for key cities to better inform policy makers and stakeholders who at present must rely on imprecise estimates of value. This would include a thorough GIS based modelling, extending the work of Ahrestani (2011).
3. Further quantification of the CO_2 emissions, UHI attenuation, stormwater attenuation and building energy savings with a view to identifying which GRGW designs lead to the greatest effect in the Australian context, and to quantify what level of value could be realised for each factor and also as an integrated measure.
4. Establish a clear data management and access mechanism whereby data is collected, stored and made available about the cost and benefits of GRGW installations to reduce the cost of information search for key stakeholders. This information can be interpreted and incorporated into publications and reports such as Rawlinson's Australian Construction Handbooks, in the same way as other infrastructure costs are.

Investment into research and development to enable better business models and GRGW design

5. Research program on developing GRGW robotics and automation technology in Australia as these could reduce labour and other costs, reduce OHS issues related to maintenance and costs substantially especially for higher rise building stock and roofs without perimeter walls, and provide an opportunity to grow export markets for Australian technology.
6. Establish a sufficient number of experimental sites in key cities to evaluate the relative merits of various GRGW configurations, such as the one established at The Hills BARK BLOWERTM landscape yard at Kenthurst, Sydney (see: http://www.barkblower.com.au/greenroofs.php; Morris, 2011). This critical infrastructure would enable the emergence and identification of better designed GRGW instillations. For example, it would enable streams of research targeting the evaluation of plant, growing medium and irrigation for various business models, which would have the effect of reducing the risk to industry participants to invest in value adding enterprises and start-ups, which are also more likely to succeed if armed with reliable information.
7. Investigation of the potential for targeted commercial focused investment in R&D to support Start-Ups in GRGW industry, with a focus on developing GRGW technology for both the domestic and international markets. There is an opportunity for GRGW technology to be an alternative market for some Australian manufacturing firms to service both the domestic and international markets.

Built Environment innovation and information needs

8. Evaluation of structural characteristics of the built environment to enable emergence of more cost effective ways of installing GRGW. This evaluation would include physical, institutional and legal aspects which currently manifest as barriers the GRGW uptake.
9. Analyse the extent to which emerging and existing accreditation systems, such as Green Star, could support a vibrant GRGW industry.

Scientific refereed publications

We plan to progress two papers from this project. Their tentative titles are:

- Sara Wilkinson, Paul James Brown and Sumita Ghosh 2018. *Green Roof Green Wall Expansion: An Evaluation of Different City Level Policy Options.*
- Paul James Brown, Sara Wilkinson, Stephen Soco, Isaac Buckton and Jasper Ryan, 2018, *Green Roof Retrofit Potential: An Evaluation of the Business Case*, Working paper, University of Technology Sydney.

We plan to submit two articles to professional practitioner journals in Australia and internationally as follows:

- *Green Roofs, and Mandatory or Voluntary approaches for More Resilient and Liveable Australian Cities?*
- *Green Roofs and Mandatory or Voluntary Approaches for Smarter, More Resilient and Liveable Australian Cities.*

Intellectual property/commercialisation

No commercial IP generated

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Appendices

Appendix 1 – Additional information informing the modeled growth trajectories for Sydney and Melbourne

This appendix describes the size and predicted growth rates for Sydney and Melbourne and the areas modeled and summarises existing policy in the LGA is also provided.

Sydney

The City of Sydney local area is one of the largest and fastest growing local government areas in Australia. Between June 2014 and June 2015, the local area was the largest and third fastest growing local government area in NSW. It is now the fourth largest local government area in the state.

The LGA covers approximately 26.15 square kilometres (see figure A1.1) and comprises a diverse range of suburbs and localities (see table A1.1). In June 2015, the estimated resident population in the local area was 205,339 people, representing around 4.2% of Greater Sydney's total population. Between 2005 and 2015, the local area population increased by nearly 30%, or 46,505 people. Greater Sydney grew by 16.7% and NSW grew by 13.8% over the same period. By 2031, the local population is projected to increase to more than 269,000. The population density in the local area is 7,683 per square kilometre as at June 2015.

Being the economic and cultural centre of the Sydney metropolitan area, the city is highly urbanised. The City of Sydney LGA has over 35 million square metres of internal floor space. In 2012, around 47% of internal floor space was devoted to businesses in key industries including finance, professional and business services and tourism. Just over a quarter (26.6%) was dedicated to residential uses.

Figure A1.1 The City of Sydney (COS) Local Government Area (LGA).

(Source: COS, 2017)

Table A1.1 Suburbs and localities within the City of Sydney LGA

Panel A: Suburbs

• Alexandria	• Erskineville	• Redfern
• Annandale	• Eveleigh	• Rosebery
• Barangaroo	• Forest Lodge	• Rushcutters Bay
• Beaconsfield	• Glebe	• St Peters
• Camperdown	• Haymarket	• Surry Hills
• Centennial Park	• Millers Point	• Sydney
• Chippendale	• Moore Park	• The Rocks
• Darlinghurst	• Newtown	• Ultimo
• Darlington	• Paddington	• Waterloo
• Dawes Point	• Potts Point	• Woolloomooloo
• Elizabeth Bay	• Pyrmont	• Zetland

Panel B: Localities

• Brickfield Hill	• Glebe Point	• Sydney CBD
• Broadway	• Green Square	• University of Sydney
• Central	• Hyde Park	• The Domain
• Chinatown	• Kings Cross	• The Hungry Mile
• Circular Quay	• Martin Place	• Three Saints Square
• Darling Harbour	• Railway Square	• Town Hall
• East Sydney	• Royal Botanic Garden	• Wynyard
• Garden Island	• Strawberry Hills	

The COS LGA has a number of large public parks and good proportion of the LGA has water front location (see figure A1.1). Table A1.2 shows the Sydney Metropolitan Councils and the total numbers of green roof and green wall (GWGR) projects, as well as the types of policy instruments in place. In the Table under policy instruments, 1 specifies that the council had a GWGR specific policy. Number 2 indicates that there were guidelines or guidance offered by the local council but no specific policy in place. Number 3 specifies GWGR ventures were incorporated into other policies, such as green infrastructure policy, storm water management or ecologically sustainable development policy. Final number 4 indicates no policies, support or guidance are offered. It is clear from the table that Sydney, or the City of Sydney has the most projects and also a policy. Conversely few councils without a policy have any GWGR projects.

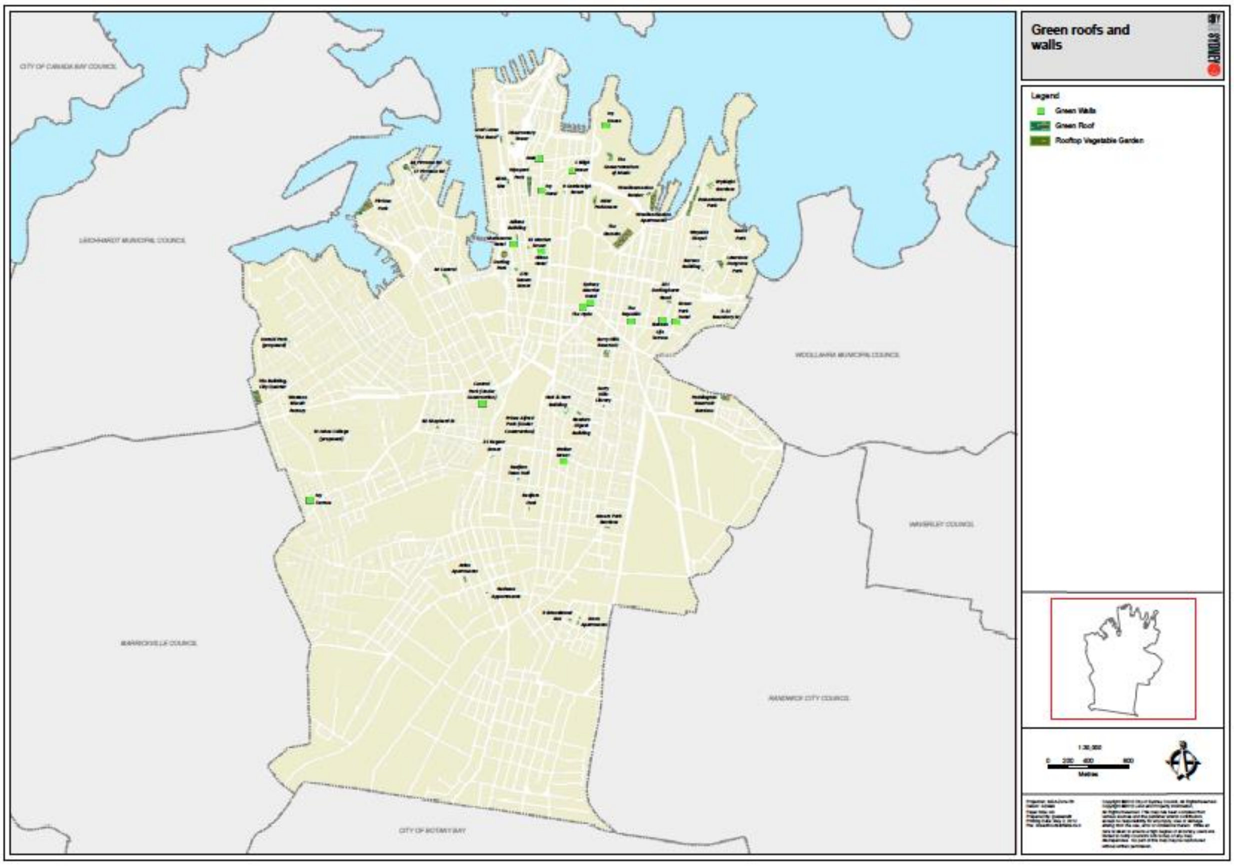
Table A1.2. Sydney metropolitan councils and total number of GWGR projects and policy instrument type.

Local government area	Total GWGR projects	Policy present[a]
Sydney	123	1
Ku-ring-gai	2	3
Lane Cove	1	2
Bankstown	1	4
Blacktown	1	4
Hurstville	1	4
Kogarah	1	4
Holroyd	0	2
Hornsby	0	2
The Hills	0	3
Ashfield	0	4
Auburn	0	4
Botany Bay	0	4
Burwood	0	4
Camden	0	4
Campbelltown	0	4
Canada Bay	0	4
Canterbury	0	4
Fairfield	0	4
Hunter's Hill	0	4

1 specifies that the council had a GWGR specific policy. 2 indicates that there were guidelines or guidance offered by the local council but no specific policy in place. 3 specifies GWGR ventures were incorporated into other policies, such as green infrastructure policy, storm water management or ecologically sustainable development policy. 4 specifies no policies, support or guidance offered.
(Source: Irga et al, 2017).

Focusing on the City of Sydney, as the only LGA with a policy, figure A1.3 shows where all 123 current green roofs in the LGA are located. Currently the wealthier, the harbour side and the CBD areas have higher proportions of green roofs. There is a clear correlation between the LGA's with a policy and those without in terms of uptake of green roofs and walls.

Figure A1.3 shows a map of all the existing Green roofs in the City of Sydney LGA.

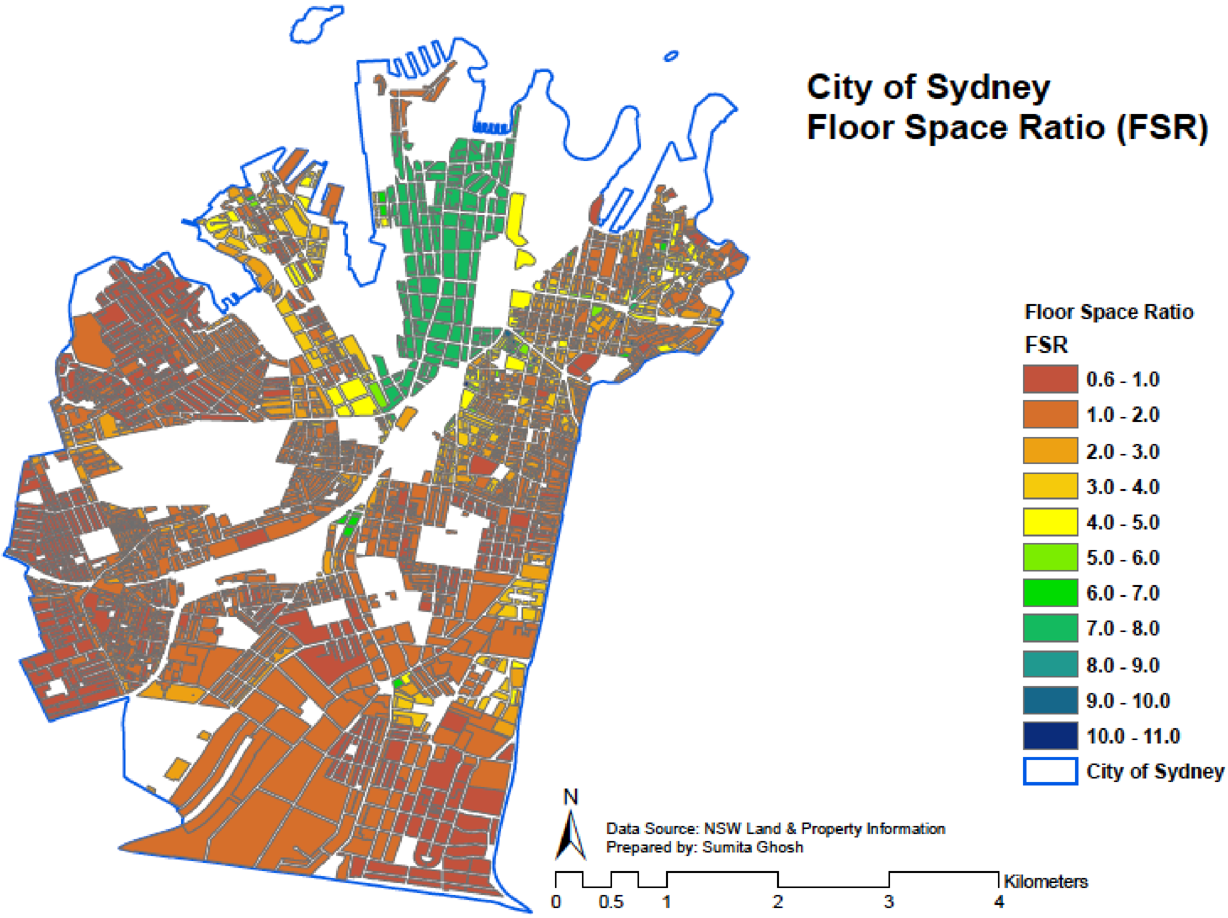


(Source: City of Sydney, 2017)

Current levels of development activity in the COS LGA, as of July 15th 2017, show 127 Development Applications submitted to the COS LGA dating from 31st October 2016. Of these 44, or 34.64% include works to roofs which could be suited to green roofs. Given this level of applications, 127 over 9 months – there are approximately 14 DA's per month of which just under 5 are suited to green roof applications.

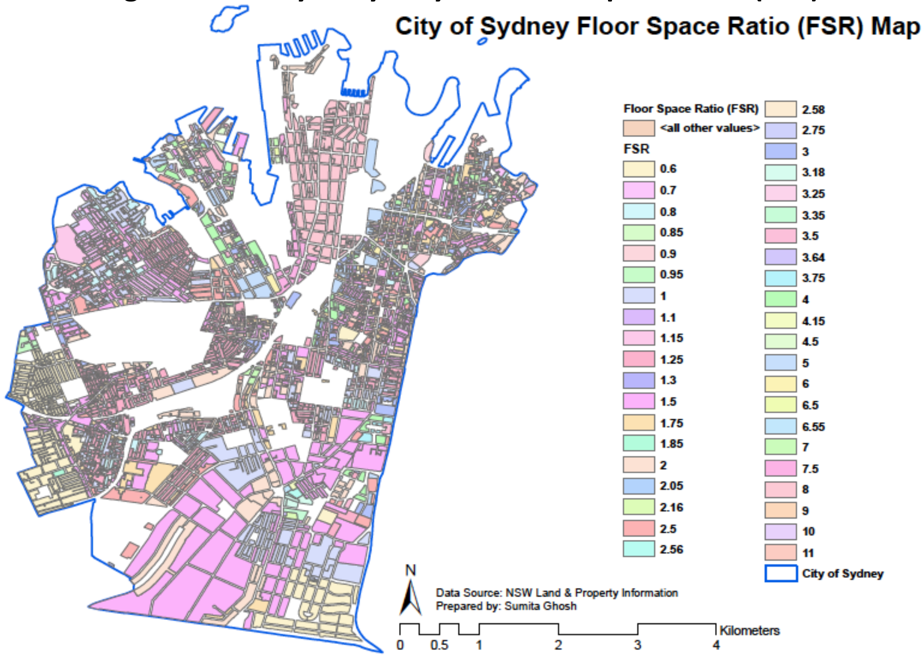
The City of Sydney floor space ratio (FSR) as per City of Sydney Local Environmental Plan shown in figures A1.4 and A1.5 shows the variability across the LGA, with lower FSR to the south and west where low-density residential and industrial land uses predominate. The CBD has the highest FSR for the LGA and is where the high-density residential and premium commercial property land uses dominate.

Figure A1.4 City of Sydney LGA Floor Space Ratio (FSR).



(Source: City of Sydney, 2017)

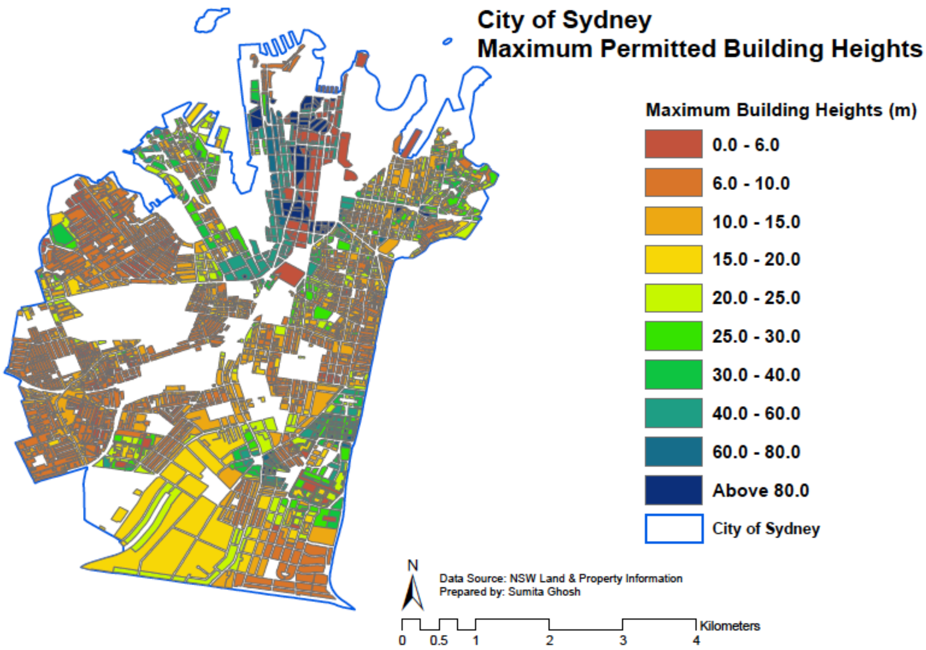
Figure A1.5 City of Sydney LGA Floor Space Ratio (FSR).



(Source: City of Sydney, 2017)

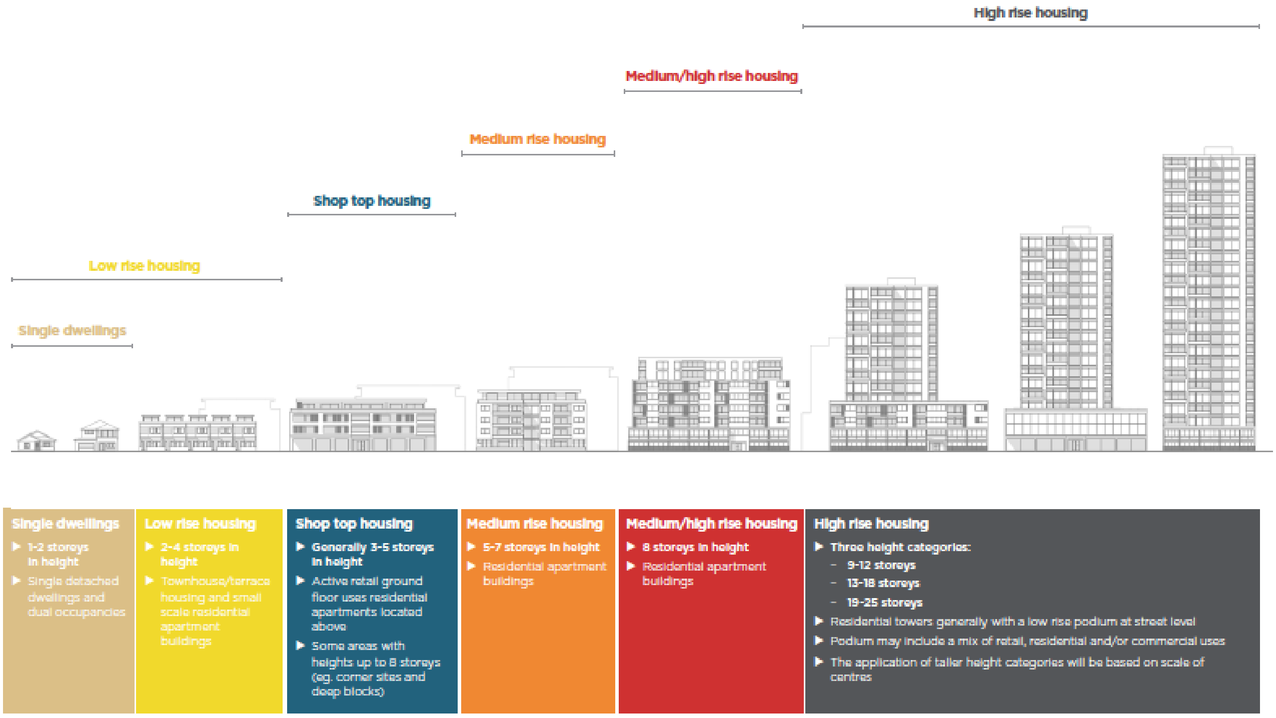
Figure A1.6 shows the maximum permitted building heights in the COS LGA. Currently highest permissible building heights are found in the CBD area. This restriction affects the type of GRGW provision and also the amounts of overshadowing.

Figure A1.6 City of Sydney LGA Floor Space Ratio (FSR).



(Source: City of Sydney, 2017)

Figure A1.7 Contemporary Housing Typologies Used In Sydney



(Source: Planning NSW 2017).

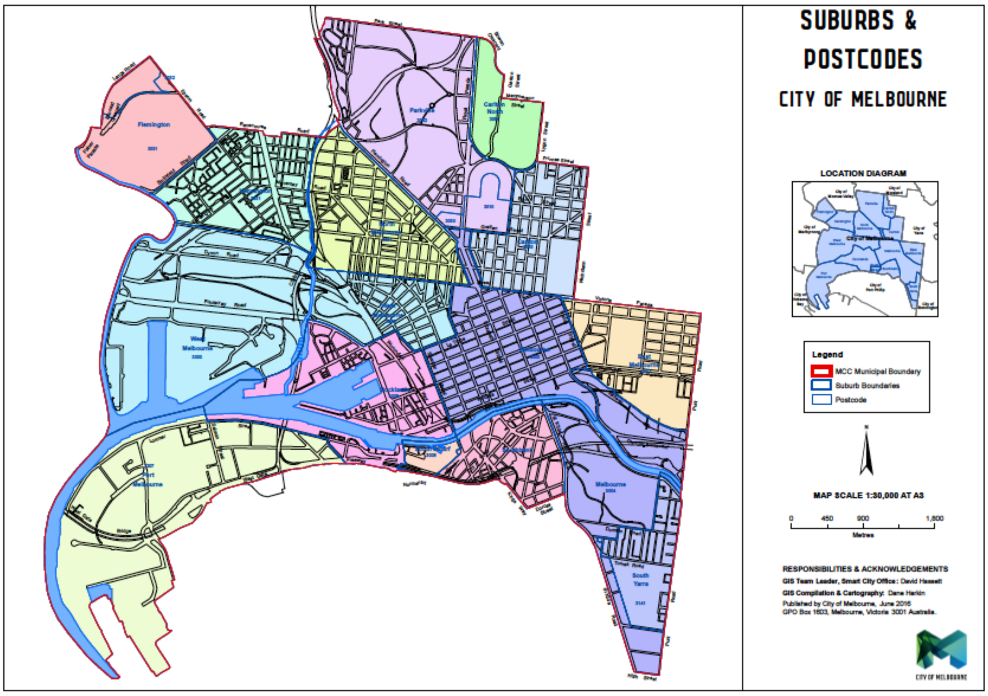
Melbourne

Melbourne is Victoria's capital city and the business, administrative, cultural and recreational hub. Metropolitan Melbourne covers 9990.5 km^2, and in 2011, has a population of around 4.5 million and 1,572,171 dwellings. The City of Melbourne municipality covers 37.7 km^2 and has a residential population of 136,336 (as of 2016), which is forecast to grow to 150,874 in 2018. It is made up of the city centre and a number of inner suburbs, with distinctive characters and with different businesses, dwellings and communities living and working there. The City of Melbourne's population is made up of many groups of people of all ages and from many cultures. Residents include young professionals, international students and older couples. On a typical weekday around 909,000 people use the city, and annually Melbourne hosts over a million international visitors.

Gross Local Product (GLP) measures the size of the City of Melbourne economy. In 2016 it measured $92.12 billion, and as such, the City of Melbourne makes a major contribution to the Victorian and Australian economies. It accounts for 25% of Victoria's Gross State Product and 6% of Australian Gross Domestic Product. There are 455,753 jobs in the municipality. The biggest industry is the professional, scientific and technical services sector. 7.95 Million metres squared of office space and 1.55 Million metres squared of retail space are provided.

The City of Melbourne as a council (Melbourne City Council) oversees the municipal area that includes Melbourne's city centre and several inner suburbs. As a capital-city council, it speaks on behalf of Melbourne in local, national and international forums. The City of Melbourne works with other local councils and the Victorian Government to ensure the city is safe, healthy and clean. It supports Melbourne's position as Australia's pre-eminent centre for arts and culture, education, dining and shopping. The City of Melbourne's seven neighbouring councils are Hobsons Bay, Port Phillip, Stonnington, Yarra, Moreland, Moonee Valley and Maribyrnong (see figure A1.8).

Figure A1.8 Map of City of Melbourne

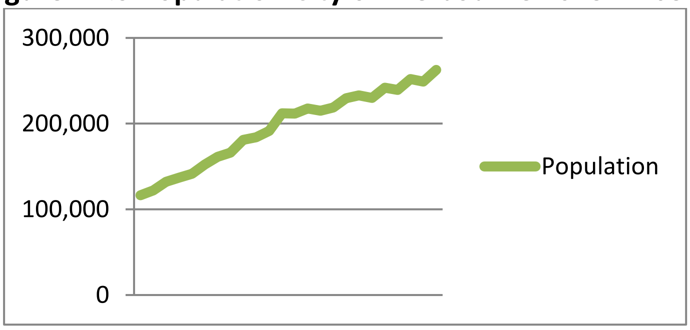


(Source: City of Melbourne, 2017).

The city's current population is estimated at 137,542 residents, however by 2036 this figures is predicted to reach 262,700, some 92% higher than the 2016 population figure (City of Melbourne, 2017). See figure A1.9.

There are 75,543 private dwellings in the City of Melbourne in 2017 and by 2036 this figure is predicted to increase to 166,573 – some 45.35%. The current household size is 1.95 and this is expected to decrease to 1.77 in the long term, making social amenity spaces such as green roofs even more important as spaces for social interaction and engagement. Total built space in 2015 was 31,985,00 m^2 and there were some 16,300 business locations (City of Melbourne, 2017).

Figure A1.9 Population City of Melbourne 2013 – 2036.



(Source: City of Melbourne, 2017).

The City of Melbourne is located at latitude 37 degrees 49 minutes south and longitude 144 degrees 58 minutes east on the south-east edge of Australia. Focused around a central business district, metropolitan Melbourne's suburbs spread more than 40 km to the south, and to the Dandenong ranges 30 km in the east. They extend up to 20 km to the north and sprawl across flat basalt plains to the west. Melbourne has a temperate climate influenced by its location at the apex of one of the world's largest bays, Port Phillip Bay.

City of Melbourne LGA

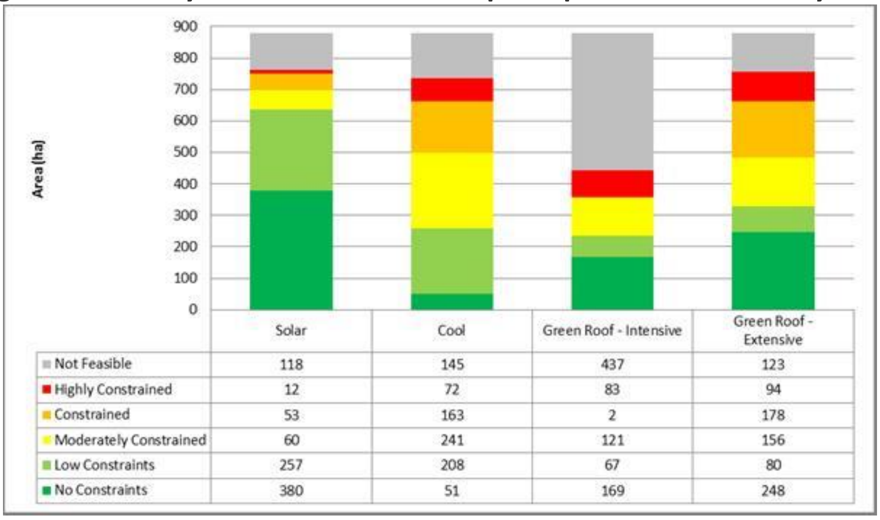
The total area of rooftops in the City of Melbourne is 880,000 m^2 of 880 hectares (COM, 2017). As only a small proportion of these areas are used for building services equipment, the potential for green roof retrofit to benefit building owners, the community and the environment is significant (COM, 2017). In a COM project to identify rooftops that have low or no constraints for retrofit, the adaptation potential by Area (ha) whole city are:

- 637 ha for solar panels
- 259 ha for cool roofs,
- 236 ha for intensive green roofs and
- 328 ha for extensive green roofs.

The rooftop adaptation 'potential' across the whole city is presented in the figure A1.10, which shows that solar panels provide the largest potential for rooftop retrofit. The reason being, there are less limiting or constraining factors that apply to more complex adaptations such as green roofs. Intensive green roofs provide the least potential for rooftop adaptation, reflecting the complexity of retrofitting intensive green roofs on existing buildings.

Cool, or white roofs have a similar amount of properties identified as having 'No Constraints' as both intensive and extensive green roofs. When the total areas for these categories are compared however, green roofs have far larger "No Constraints" potential when compared to cool roofs, as much as three times the potential for intensive green roofs and five times for extensive green roofs. Therefore green roof implementation will have a larger impact per property adapted than cool roofs.

Figure A1.10 City of Melbourne Rooftop Adaptation Potential by Area.



(Source: COM, 2017)

Results were analysed to ascertain which suburbs showed potential for different roof adaptation types. For green roofs, the greatest area of opportunity, in terms of total area and the proportion of roof area within the suburb, is within Melbourne, Port Melbourne and Docklands. The smallest area is in the suburbs of Carlton North, South Yarra, Kensington and Flemington. The suburb of Melbourne, incorporating the Hoddle Grid has a higher proportion of sites deemed unfeasible for solar adaptation than other suburbs, due to the increased variability in building height and overshadowing.

Table A1.3. Melbourne metropolitan councils and total GWGR projects and policy instrument types.

Local government area	Total GWGR projects	Policy present[a]
Melbourne	28	2
Stonnington	13	2
Port Phillip	12	2
Yarra	7	2
Boroondara	6	3
Monash	5	3
Manningham	4	4
Greater Geelong	4	4
Frankston	3	4
Yarra Ranges	3	4

Local government area	Total GWGR projects	Policy present[a]
Casey	2	4
Greater Dandenong	2	4
Moonee Valley	2	4
Banyule	2	4
Mornington Peninsula	1	3
Glen Eira	1	3
Cardinia	1	4
Whitehorse	1	4
Bayside	1	4
Hobsons Bay	1	4
Maroondah	0	2
Knox	0	4
Kingston	0	4
Wyndham	0	4
Melton	0	4
Brimbank	0	4
Hume	0	4
Maribyrnong	0	4
Moreland	0	4
Darebin	0	4
Whittlesea	0	4
Nillumbik	0	4

1 specifies that the council had a GWGR specific policy. 2 indicates that there were guidelines or guidance offered by the local council but no specific policy in place. 3 specifies GWGR ventures were incorporated into other policies, such as green infrastructure policy, storm water management or ecologically sustainable development policy. 4 specifies no policies, support or guidance offered.

(Source: Irga et al, 2017).

Appendix 2 – Key sources of data from Australian and overseas which would be useful to assist in building a value proposition and business case for living architecture

In this appendix we list of key sources of data from Australian and overseas which would be useful to assist in building a value proposition and business case for living architecture. The main sources of data are published studies and reports, as well as primary data collection, which are usually reported in aggregate.

There are a range of information sources tailored to the Australian context which have useful quantitative data to build a business case, with some of the key ones being:

- Green Roofs Australasia. URL: https://greenroofsaustralasia.com.au/
- Growing Green Guide:
    - State of Victoria, through the VAS Partnership, the Inner Melbourne Action Plan & the University of Melbourne, 2014. Growing Green Guide: A Guide to Green Roofs, Walls and Facades in Melbourne and Victoria, Australia. *Australia: State of Victoria*. http://www.growinggreenguide.org/
- Jones, R., Symons, J. and Young, C., 2015. Assessing the Economic Value of Green Infrastructure: Green Paper. URL: https://www.vu.edu.au/sites/default/files/cses/pdfs/assessing-economics-gi-green-paper-visesccwp24.pdf
- RICS, 2016. Green Roofs and Walls: RICS Professional Guidance, Australia, 1st edition, Royal Institution of Chartered Surveyors (RICS), London. pp. 28. IBSN 9781783211456. URL: http://www.rics.org/Global/Green_roofs_and_walls_1st_edition_PGguidance_2016.pdf
- Wilkinson, S. J. and Dixon, T. 2016. Green Roof Retrofit Building Urban Resilience John Wiley and Sons. ISBN: 978-1-119-05557-0.
- Wilkinson, S. J., Ghosh, S. and Page, L., 2014. Urban food production on Sydney CBD rooftops, Final report for City of Sydney Environment Grant Ref 2013 / 110462. pp. 62.

The Growing Green Guide (State of Victoria, through the VAS Partnership, the Inner Melbourne Action Plan & the University of Melbourne, 2014c) does contain a section on Cost Considerations and acknowledges that each roof, wall or facade will vary significantly in terms of cost, depending on the design site, the system installed and the construction materials used. The Guide contains a range of indicative costs for installation, materials and fees from 2014 which need to be adjusted for inflation and changes that have occurred since the publication date.

Problematically, only a few studies contain comprehensive evaluations, which quantify the net benefits of GRGW, taking into consideration the total cost over the life cycle. An example is Kosareo and Ries (2007) who do a life cycle assessment of green versus conventional roofs and find that energy cost savings and longer roof life lead to green roofs having greater environmental benefits; and are hence preferred. Problematically, they do not model the financial cost and benefits for each option. We identified six studies which contain comprehensive cost benefit analysis and are reported in Table 2 above and repeated here:

- Beauchamp, P. and Adamowski, J., 2012. Different methods to assess green infrastructure costs and benefits in housing development projects. *Journal of Sustainable Development*, 5(4).
- Carter, T. and Keeler, A., 2007. Life-cycle cost–benefit analysis of extensive vegetated roof systems, *Journal of Environmental Management*, 87, pp 350-363
- GSA, 2011. *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings*. A Report of the United States General Services Administration. Retrieved on 4th May 2017 from: https://www.gsa.gov/portal/mediaId/158783/fileName/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.action
- McRae, A., 2016. Case study: A conservative approach to green roof benefit quantification and valuation for public buildings, *The Engineering Economist*, 61(3), pp 190-206.
- Sproul, J. et al., 2014. Economic comparison of white, green, and black flat roofs in the United States, *Energy and Buildings*, 71, pp 20-27.
- Wong, N. et al., 2003. The effects of rooftop garden on energy consumption of a commercial building in Singapore, *Energy and Building*, 35, pp 353-364.

Table A2.1 and A2.2 provided additional information to support the result reported in Table 2.

Table A2.1 - Costs associated with phases of green roof life cycle

Phase	Cost	Value	Source
Installation	Green Roof Installation	$106.93/m^2	McRae 2016
		$159.45/m^2	Sproul et al 2014
		$93.32/m^2	Carter and Keeler 2007
		$26.36 - 61.50/m^2	http://www.thegreenroofcentre.co.uk/green_roofs/faq - 2010
		$19.08 - 57.25/m^2	Alumasc sales representative, 2009 2009 in Castleton et al., 2010.
		$215.76/m^2	GSA 2011
Lifetime	Maintenance	$1.73 - 2.55/m^2	McRae 2016
		$2.83/m^2	Sproul et al 2014
		$2.38/m^2	GSA 2011
		$0.49/m^2	Munby, 2005
Replacement	Replacement	$55.54/m^2	Sproul et al 2014
		$72.28/m^2	GSA 2011
	Disposal	$1.27/m^2	Sproul et al 2014
		$1.06/m^2	GSA 2011

(Source: Adapted from Brown et al. (2018)).

Table A2.2 Savings associated with phases of green roof life cycle

Phase	Saving	Value	Source
Lifetime	Energy Saving	$2.34/m^2	Carter and Keeler 2007
		$1.46/m^2	GSA 2011
		$2.14/m^2	Sproul et al 2014
		$1.48/m^2	Wong et al, 2003
		$1.05/m^2	McRae 2016
	Property Value	$2236.89/m^2	GSA 2011
		$734.70/m^2	Perini and Rosasco 2013
	Stormwater Retention	$2.34/m^2	Sproul et al 2014
		$0.19/m^2	Clark et al., 2008
Replacement	Membrane Renewal	$79.17/m^2	GSA 2011
		$113.63/m^2	Clark et al., 2008

(Source: Adapted from Brown et al. (2018))

The two most comprehensive studies, which compile a range of data estimates are, Ahrestani (2011) and GSA (2011). We report here the source references here to illustrate the different and fragmented nature of GRGW date sources that can be used to build a reliable business case from.

Stormwater

From Ahrestani (2011):

- Arnell, N.W., 1999. The effect of climate change on hydrological regimes in Europe: a continental perspective. *Global Environmental Change* 9, 5–23.
- Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P. (Eds.), 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. *IPCC Secretariat, Geneva*, p. 210.
- Berndtsson, J.C., 2010. Green roof performance towards management of runoff water quality and quality: A review. *Ecological Engineering*, 36, 225-231.
- Berndtsson, J.C., Bengtsson, L., Jinno, K., 2009. Runoff water quality from intensive and extensive vegetated roofs. *Ecological Engineering*, 35, 369-380.

- Carter, T. and Jackson, C.R., 2007. Vegetated roofs for stormwater management at multiple spatial scales. *Landscape Urban Planning*, 80, 84–94.
- Fioretti, R., Palla, A., Lanza, L.G., Principi, P., 2010. Green roof energy and water related performance in the Mediterranean climate. *Building and Environment,* 45, 1890-1904.
- Getter, K.L., Rowe, D.B., Andresen, J.A., 2007. Quantifying the effect of slope on extensive green roof stormwater retention. *Ecological Engineering,* 31, 225–231.
- Hilten, R. N., Lawrence, T. M., Tollner, E. W., 2008. Modeling stormwater runoff from green roofs with HYDRUS-1D. *Journal of Hydrology, 358*, 288–293.
- Mentens, J., Raes, D., Hermy, M., 2006. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landscape Urban Planning*, 77, 217–226.
- Olguin, H.F., Salibian, A., Puig, A., 2000. Comparative sensitivity of *Scenedesmus acutus* and *Chlorella pyrenoidosa* as sentinel organisms for aquatic ecotoxicity assessment: studies on a highly polluted urban river. *Environmental Toxicology,* 15, 14–22.
- Sutherland, A.B., Meyer, J.L., Gardiner, E.P., 2002. Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. *Freshwater Biology*. 47, 1791–1805.
- Wolman, M.G., 1976. A cycle of sedimentation and erosion in urban river channels. *Geografiska Annaler*, 49, 385-395.

From GSA (2011):

- Roofmeadow
- Lawrence Berkeley National Laboratory (LBNL) studies
- District Department of Environment (DDOE)
- District of Columbia Water and Sewer Authority
- Berghage, R.D., C. Miller, B. Bass, D. Moseley, and K. Weeks., 2010. Stormwater runoff from a large commercial roof in Chicago. In Proceeding of the Cities Alive Conference, Vancouver, BC.
- NC State University, An Evaluation of Cost and Benefits of Structural Stormwater Best Management Practices in North Carolina
- Davis., G., Use of Green Roofs to Meet New Development Runoff Requirements. Nov. 2007
- DC WASA Long Term Control Plan. District of Columbia Water and Sewer Authority, Combined Sewer System Long Term Control Plan, July 2002
- Philadelphia Combined Sewer Overflow Long Term Control Plan Update, Volume 3, Basis of Cost Opinions, September 2009
- ECONorthwest, 2007. The Economics of Low-Impact Development: A Literature Review. Eugene, Oregon.
- NYCDEP. Rapid assessment of the cost-effectiveness of low impact development for CSO control

Insulation and other energy related benefits

From Ahrestani (2011):

- Akbari, H. and Konopacki, S., 2005. Calculating energy-saving potentials of heat island reduction strategies. *Energy Policy*, 33(6), 721–56.
- Christian, J.E. and Petrie, T.W., 1996. Sustainable Roofs with Real Energy Savings. *Proceedings of the Sustainable Low-Slope Roofing Workshop*, ed. Desjarlais, A., Oak Ridge National Laboratory, Oak Ridge, Tennessee, p99.
- Fang, C.-F., 2008. Evaluating the thermal reduction effect of plant layers on rooftops. *Energy and Buildings,* 40, 1048–1052.
- Martens, R., Bass, B., Alcazar, S.S., 2008. Roof-envelope ratio impact on green roof energy performance. *Urban Ecosystems,* 11, 399-408.
- Niachou, A., Papakostantinou, K., Santamouris, M, Tsangrassoulis, A., Mihalakakou, G., 2001. Analysis of the green roof thermal properties and investigation of its energy performance. *Energy and Buildings,* 33, 719-729.
- Sailor, D. J., 2008. A green roof model for building energy simulation programs. *Energy and Buildings*, 40, 1466–1478.
- Saiz, S., Kennedy, C., Bass, B., Pressnail, K., 2006. Comparative Life Cycle Assessment of Standard and Green Roofs. *Environmental Science and Technology*, 40, 4312-4316.

- Santamouris, M., Pavlou, C, Doukas, P., Mihalakakou, G., Synnefa, A., Hatzibiros, A., Patargias, P., 2007. Investigation and analysing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece. *Energy*, 32, 1781-1788.
- Spala, A., Bagiorgas, H.S., Assimakopoulos, M.N., Kalavrouziotis, J., Matthopoulos, D., Mihalakakou, G., 2008. On the green roof system. Selection, state of the art and energy potential investigation of a system installed in an office building in Athens, Greece, *Renewable Energy*, 33, 173-177.
- Takebayashi, H. and Moriyama, M., 2007. Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. *Building and Environment,* 42, 2971–2979.
- Ülo Mander, A. T., 2010. Temperature regime of planted roofs compared with conventional systems. *Ecological Engineering,* 36, 91-95.
- Wong, N.H., Cheong, D.K.W., Yan, H., Soh, J., Ong, C.L., Sia, A., 2003. The effects of rooftop garden on energy consumption of a commercial building in Singapore. *Energy and Buildings,* 35, 353-364.

From GSA (2011):

- Lawrence Berkeley National Laboratory (LBNL) studies
- Miller, C. Bass, B. Weeks, K. Berghage, R., and Berg, S., 2010. Stormwater policy as a green roof (dis) incentive for retail developers. In Proceedings: The Cities Alive Conference, Vancouver, BC
- Gaffin, S. R., Rosenzweig, C., Eichenbaum-Pikser, J., Khanbilvardi, R. and Susca, T., 2010. A Temperature and Seasonal Energy Analysis of Green, White, and Black Roofs. Columbia University, Center for Climate Systems Research. New York. 19 pages.
- Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2010. NISTIR 85-3273-25. Annual Supplement to NIST Handbook 135 and NBS Special Publication 709, pp. 43
- ASHRAE 90.1-2004 energy model of 275,000 gfa (25,000 sf roof) office building in Washington DC
- University of Toronto Green roof Energy analysis
- Clark, C., Adriaens, P., and Talbot, F.B., 2008. Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits. *Environmental Science and Technology 42 (6)*: 2155-2161

Carbon Sequestration Capabilities

From Ahrestani (2011):

- Energy Wise Hotels Toolkit, 2007. Melbourne City Council. The Available Online:http://www.melbourne.vic.gov.au/enterprisemelbourne/environment/Documents/EnergyWiseHotels.pdf [26/4/2010]
- Getter, K.L., Rowe, D.B., Robertson, G.P., Cregg, B. M., Andersen, J.A., 2009. Carbon sequestration potential of extensive green roofs. *Environmental Science and Technology,* 43, 7564-7570.
- Energy Efficiency Fact Sheet, Origin Energy. Available Online: http://www.originenergy.com.au/files/SMEfs_HeatingAirCon.pdf [25/4/2010]
- Myors, P., O'Leary, R., Helstroom, R., 2005. Multi unit residential buildings energy peak demand Study. *Energy Australia and NSW Department of Infrastructure, Planning and Natural Resources.* Available Online: http://www.energyaustralia.com.au/Common/Network-Supply-and-Services/Demand-Management/~/media/Files/ETT/Demand%20Management/Related%20projects/Networks_multi_unit_sumrep_Oct08.ashx [25/4/2010]
- Mandatory Disclosure of Commercial Office Building Energy Efficiency-Regulation Document, 2009, *National Framework for Energy Efficiency,* Department of the Environment, Water, Heritage and the Arts. Available Online: http://www.climatechange.gov.au/en/what-you-need-toknow/buildings/commercial/~/media/publications/energyefficiency/buildings/disclosure-regulation.ashx [24/4/2010]
- Pears, A., 1998. A Report for Environment Australia. *Sustainable Solutions Pty. Ltd*. Available Online: http://www.energyrating.gov.au/library/pubs/pearsago1998.pdf [25/4/2010]
- Shixiao, X., Xinquan, Z., Yingnian, L., Liang, Z., Guirui, Y., Xiaomin, S., Guangmin, C., 2005. Diurnal and monthly variations of carbon dioxide flux in an alpine shrub on the Qinghai-Tibet Plateau. *Chinese Science Bulletin,* 50 (6), 539-543.

- Williams, N.S.G., Rayner, J.P., Raynor, K.J., 2010. Green roofs for a wide brown land: Opportunities and barriers for rooftop greening in Australia. *Urban Forestry and Urban Greening,* doi:10.1016/j.ufug.2010.01.005
- Zanki, V., Martinac, I.M., Curko, T., 2002. Environmental Aspects of Energy use in HVAC Systems in Hotel Facilities. *American Metrological Society,* 16th International Conference on Biometeorology. Available Online: http://ams.confex.com/ams/15BioAero/techprogram/paper_50089.htm [25/4/2010]

Air Pollution Mitigation Benefits

From Ahrestani (2011):

- Baldocchi, D.D., Hicks, B.B., Camara, P., 1987. A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. *Atmospheric Environment*, 21, 91-101.
- Bidwell, R.G.S., Fraser, D.E., 1972. Carbon monoxide uptake and metabolism by leaves. *Canadian Journal of Botany,* 50, 1435-1439.
- Currie, B.A. and Bass, B., 2008. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. *Urban Ecosystems,* 11, 409–422.
- Deutsch, B., Whitlow, H., Sullivan, M., Savineau, 2005. Re-greening Washington, DC: A Green Roof Vision Based on Quantifying Storm Water and Air Quality Benefits. Available Online: http://www.greenroofs.org/resources/greenroofvisionfordc.pdf [22/4/2010]
- Tan, P.Y. and Sia, A., 2009. A pilot green roof research project in Singapore. *Centre for Urban Greenery and Ecology, Singapore*. Available Online:
- http://research.cuge.com.sg/images/stories/Papers/a_pilot_green_roof_project_in_singapore.pdf [20/4/2010]
- Yang, J., Yu, Q., Gong, P., 2008. Quantifying air pollution removal by green roofs in Chicago. *Atmosphere and Environment,* 42, 7266–7273.

From GSA (2011):

- Getter, K.L., Rowe, D.B., Robertson, G.P., Cregg, B.M., Andresen, J.A., 2009b. Carbon sequestration potential of extensive green roofs. *Environmental Science and Technology 43 (19),* 7564-7570.
- Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2010. NISTIR 85-3273-25. Annual Supplement to NIST Handbook 135 and NBS Special Publication 709, pp. 46-47

Increases in Urban Biodiversity

From Ahrestani (2011):

- Baumann, N., 2006. Ground-Nesting Birds on Green Roofs in Switzerland: Preliminary Observations. *Urban Habitats*, 4 (1) 37–50.
- Brenneisen, S., 2006. Space for Urban Wildlife: Designing Green Roofs as Habitats in Switzerland. *Urban Habitats*, 4 (1) 27–36.
- Grant, G., 2006. Extensive Green Roofs in London. *Urban Habitat,* 4 (1), 51-65.
- Kadas, G., 2006. Rare Invertebrates Colonizing Green Roofs in London. *Urban Habitat,* 4 (1), 66-86.
- Köhler, M., 2006. Long-Term Vegetation Research on Two Extensive Green Roofs in Berlin. *Urban Habitat,* 4 (1), 3-26.

From GSA (2011):

- Australia's BushBroker scheme

Aesthetic and Therapeutic Values

From Ahrestani (2011):

- Dunnett, N., Kingsbury, N., 2004. Planting green roofs and living walls. Timber Press, Portland, Origan.
- Ulrich, R., 1983. View Through a Window May Influence Recovery from Surgery. *Science,* 224, 420-421.

Heat island:

From GSA (2011):

- Acks, K. (2006). *A Framework for Cost-Benefit Analysis of Green Roofs*: Initial Estimates. in Green
- Roofs in the Metropolitan Region: Research Report. C. Rosenzweig, S. Gaffin, and L.
- Parshall (Eds.) Columbia Center for Climate Systems Research and NASA Goddard Institute for Space Studies

Air quality:

From GSA (2011):

- Clark, C. Adriaens, P., and Talbot, F.B. *Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits.* University of Michigan
- Niu, H., Clark, C., Zhou, J., and Adriaens, P. (2010) Scaling of Economic Benefits from Green Roof Implementation in Washington, DC. *Environmental Science Technology*
- Casey Trees Study (DC) Based on the cost on installing selective catalytic reduction on a 10MW natural gas turbine
- A.H. Rosenfeld, H. Akbari, J.J. Romm and M. Pomerantz. (1998). Cool communities: strategies for heat island mitigation and smog reduction. *Energy and Buildings 28*:51-62

Real estate:

From GSA (2011):

- Real Capital Analytics Midyear Review, July 22, 2010
- TIAA-CREF Q32010
- Reed Construction Data®. (2010, February 17). "Construction Forecasts: RSMeans' dollars-per-square-foot construction costs: four office building types of structure nnovations". Retrieved November 2010, from Reed Construction Data®.: http://www.reedconstructiondata.com/construction-forecast/news/2010/02/rsmeans-dollars-per-square-foot-construction-costs-four-office-building-typ
- Davis Langdon Adamson. (2004) Costing Green: A Comprehensive Cost Database and Budgeting Methodology.
- Climate Progress (2010, September 24). "Costs and benefits of green buildings". Retrieved December 2010, from Climate Progress. http://climateprogress.org/2010/09/24/costs-and-benefits-of-green-buildings/ (took green roof cost and divided it by average green cost premium of construction (4%) per sf of roof)
- Delta Associates. "Cap Rate Study: District of Columbia." Prepared for Office of Tax and Revenue Real Property Tax Administration. January 2010. http://aoba-metro.org/uploads/FINAL%2029275%20Cap%20Rate%20Study%20DC.PDF
- Cassidy Turley: Commercial Real Estate Services. (2010, October 13). " DC Overtakes NYC for Highest Office Rents". Retrieved November 2010, from Cassidy Turley: Commercial Real Estate Services. http://www.cassidyturley.com/News/PressReleases/Entry.aspx?topic=Cassidy_Turley_eports_U_S_Office_Sector_Continuing_to_Rebound_

Appendix 3 – Factsheet GWGR policies for each Australian major city compared to some of the most successful international policies

This factsheet summarises key Green Roof and Green Wall Policies for each Australian major city and is adapted from Irga et al., (2017).

City	Policy name	Mechanism	Policy details and comments
Sydney	City of Sydney provides *Green Roofs and Walls Policy 2014*, *Green Roofs and Walls Policy Implementation Plan Environmental Performance Grants* supported by *Sustainable Sydney 2030*	Awareness, guidance, financial incentives, GRGW monitoring	Information on GRGW benefits, barriers to uptake, design considerations. Comprehensive resource manual for GR. Leadership through GRGW on council buildings, establishing advisory committee. Subsidies provided case-by-case through environmental performance grants. Since implementation of green roofs and walls policy in 2014, City of Sydney has experienced 23% increase in total GRGW coverage.
Melbourne	City of Melbourne and 3 other councils endorse the *Growing Green Guide 2014* (State of Victoria, through the VAS Partnership, the Inner Melbourne Action Plan & the University of Melbourne, 2014) City of Melbourne have launched a $1.2 million Urban Forest fund.	Awareness, guidance	Comprehensive information on GRGW benefits; technical design, installation, maintenance considerations; detailed best practice case studies in Victoria. Leadership through GRGW on council buildings. Since 2014 release of guidance document, average uptake of GRGW across all Greater Melbourne councils increased. Applications for 2017 are under review.
Adelaide	Adelaide City Council provides *Green Infrastructure Guidelines 2014*	Awareness, guidance	Document refers to living architecture, green streets, WSUD, urban forests. Section on GRGW, providing brief information on GRGW benefits, design. Negligible increase in GRGW uptake since release of guidelines
	Green City Grant Program 2016	Financial incentives	17 projects funded in 2016.
Brisbane	Brisbane City Council provides *Plan for Action on Climate Change 2007*, and *Community Sustainability and Environmental Grants Program*	Awareness, financial incentives	Mention of GR as strategy for climate action in climate change policy, within strategic land use and planning, and research sections. AUD$1000–$10,000 grants awarded on merit to sustainability projects within Brisbane City Council that reduce energy consumption and greenhouse gas emissions of their facilities. Strong uptake of GRGW in Brisbane City Council. Unclear if uptake is associated with policy.
Perth	No enacted GRGW policies or guidance notes	N/A	N/A Perth hosts the least number of GRGW projects and the smallest total greened area of all capital cities sampled in Australia.

(Source: Adapted from Irga et al., 2017).

Appendix 4 - List of key incentives used by cities that have mandated Green roofs and walls

City	Policy name	Incentives	Policy details	Comments
Basel, Switzerland	*Building and Construction Law* (BCL) 1996–1997 and 2005–2006, BCL 2002	Financial incentives	BCL 1996–1967 and 2005–2006 provided subsidies of 20 Swiss francs per m^2 of GR. BCL 2002 mandated GR on all new and renovated flat roofs.	In 1998, 10% of flat roofs in Basel had GR. By 2015, over 100 ha GR in Basel, constituting the largest area of GR per capita in world.
Chicago, USA	City of Chicago provides *Adding Green to Urban Design Plan 2008, Green Permit Benefit Tier Program* and *Green Permit Program 2015, Sustainable Development Policy 2007, Green Roof Improvement Fund 2006, Green Roof Grant Program 2005*	Financial incentives	Various GR projects eligible for reduced permit fees, priority development review, financial, non-financial incentives under different policies. Guidance on GR best practices.	In 2008, 400 GR covering 37 ha. By 2010, 509 GR measuring 52 ha.
Hong Kong SAR	HK Government Policy Address 2006–2007, 2004 Green and Innovative Buildings (JPN1) and 2006 Second Package of Incentive to Promote Green and Innovative Buildings (JPN2), Amenity Features in PNAP116, provision of public and private open space in HKPSG, Town Planning Conditions, and Lease Conditions, Design and Technical Guidelines, HK Building Environmental Assessment Method, Comprehensive Environmental Performance Assessment Scheme, Architectural Services Department Green Roof Application in HK	Financial incentives	Comprehensive guidelines on benefits, design, plant selection, installation, maintenance, and costs of intensive and extensive green roofs in Hong Kong. Government policy encourages green roofs on public buildings, JPN1 and JPN2 promote green features by exempting communal sky gardens and podium gardens from gross floor area and site coverage taxes thus providing economic benefit to the developer.	Abundance of intensive green roofs due to dense urban environment, lack of recreation space at ground level, market-driven desire for attractive landscaping, building and development requirements
New York City, USA	The NYC Green Infrastructure Plan 2008 Green Roof and Solar Tax Abatement Program	Financial incentives	Property tax abatements or tax relief of \$4.50 per ft^2 (up to \$100,000 or the building's tax liability, to property owners that green roofs	
Portland, OR, USA	Portland Green Building Policy (2001) Clean River Rewards (2005) Stormwater Management Manual (1999)	Incentives density bonus, grants for retrofits, mandatory	Eco-roof floor area ratio (FAR) bonus allows developers an extra 3 ft^2per ft^2 of green roof without additional permits. All city owned buildings are required to have 70% green roof. Additional stormwater reduction discount programs	
San Francisco, USA	City and County of San Francisco 2030 Sewer System Master Plan San Francisco's Property Assessed Clean Energy (PACE) Program	Financial incentives	Properties with green roofs are eligible for lower rate financing programs	In 2013, 8 of 78 projects submitted for review included a green roof, with a total 139,000 ft^2 of

				green roof construction
Seattle, Washington	Incentives density bonus, public building rules The Seattle Stormwater Code Seattle's Green Factor Policy	Financial incentives	Floor area ratio (FAR) bonuses determined on a case-by-case basis The Seattle Stormwater Code requires storm-water filtration and retention of run-off that can be achieved through the installation of green roofs. Seattle's Green Factor requirements for new developments which can be achieved with green roofs and green walls	
Singapore, Republic of Singapore	Skyrise Greenery Incentive Scheme (SGIS) 2009, SGIS 2.0 2015, Landscaping for Urban Spaces and High-Rises (LUSH) 2009, LUSH 2.0 2014	Financial incentives	SGIS provides funding of up to 50% GRGW installation costs. LUSH provides development exemptions and incentives for building greening, including GRGW.	SGIS 2009 assisted GRGW retrofit to over 110 buildings. LUSH 2009 added over 40 ha building greening. Singapore has 163 GRGW, covering 72 ha (Sept 2016).
Stuttgart, Germany	City of Stuttgart *1986* regulations, *Climate Atlas 2008* Stuttgart, German Building Code (GBC), FLL Green Roof Guidelines 2008	Financial incentives	All new development plans require flat or pitch roofs (to 12 degrees) to be green. City of Stuttgart provides financial support for GR. Subsidies are only for existing buildings or new buildings when the construction plan does not already require a green roof. From 1986 – 2009, 430 projects and 66,000 m² of green roofs received funding. The subsidy was 17.90 Euro / m² (50 % of the installation and material costs, requirement 12 cm substrate height). Owners must maintain the GR for at least 10 years. In 2014 a relaunch of the incentive programme took place. Reduced stormwater fee: 50% reduction for green roofs	Since 1986, City of Stuttgart provided financial support for 6 ha GR. By 2015, Stuttgart had 30 ha GR.
Toronto, Canada	City of Toronto provides Green Roof Bylaw 2009, Eco-Roof Incentive Program 2009, Guidelines for Biodiverse Green Roofs 2013	Financial incentives	2010 Bylaw mandates GR on all new commercial, institutional, residential developments of 2000 m^2 + GFA. From 2012, bylaw applies to industrial developments. Eligible GR receive CAD \$75/m^2up to \$100,000 through incentive program	From 2010 to 2015, 260 GR projects measuring 19.6 ha created, adding to a total of 444 GR in Toronto.
Tokyo, Japan	Tokyo Green Plan 2012; Tokyo Metropolitan Government Environmental White Paper 2006 and Nature Conservation Ordinance; Tokyo 2020; The Green Building Program 2002 and Tokyo	Financial incentives	All new private buildings greater than 1000 $m^2$and public buildings greater than 250 m^2mandated to have at least 20% greened roof or incur US\$2000 fine. The Green Building Program assesses and	From 2000 to 2001, total area of green roofs in Tokyo increased from 5.24 ha to 10.44 ha.

Metropolitan Condominium Environmental Performance Labelling System; 10 Year Project for Green Tokyo 2006; Japanese national building law 2005	publishes efforts made by developers to promote green architecture. Project for Green Tokyo provides tax incentives. Government leadership aiming to create 400 ha of green roofs and walls on offices, schools, hospitals, and in areas adjacent to roads, railroads and parking lots between 2006–2016, making use of green fundraising schemes. National law requires all new apartment or office buildings in urban areas to have at least 20% vegetated rooftop	57.2 ha of green roofs and walls installed between 2007 and 2010.

Appendix 5 – Milestone report 1: Green walls and roofs: A mandatory or voluntary approach for Australia? Literature Review

LITERATURE REVIEW

Green roofs and walls: A mandatory or voluntary approach for Australia?

Green Cities: Expanding the living architecture industry in Australia (GC 15001)

Prepared by University of Technology Sydney
on behalf of Horticulture Innovation Australia

6 June 2017

This project has been funded by Horticulture Innovation Australia Limited with co-investment from the University of Technology Sydney, Elmich, Junglefy, Aspect Studios, Fytogreen and funds from the Australian Government.

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Cover image: Green wall on One Central Park, Chippendale (P. Osmond, n.d.)

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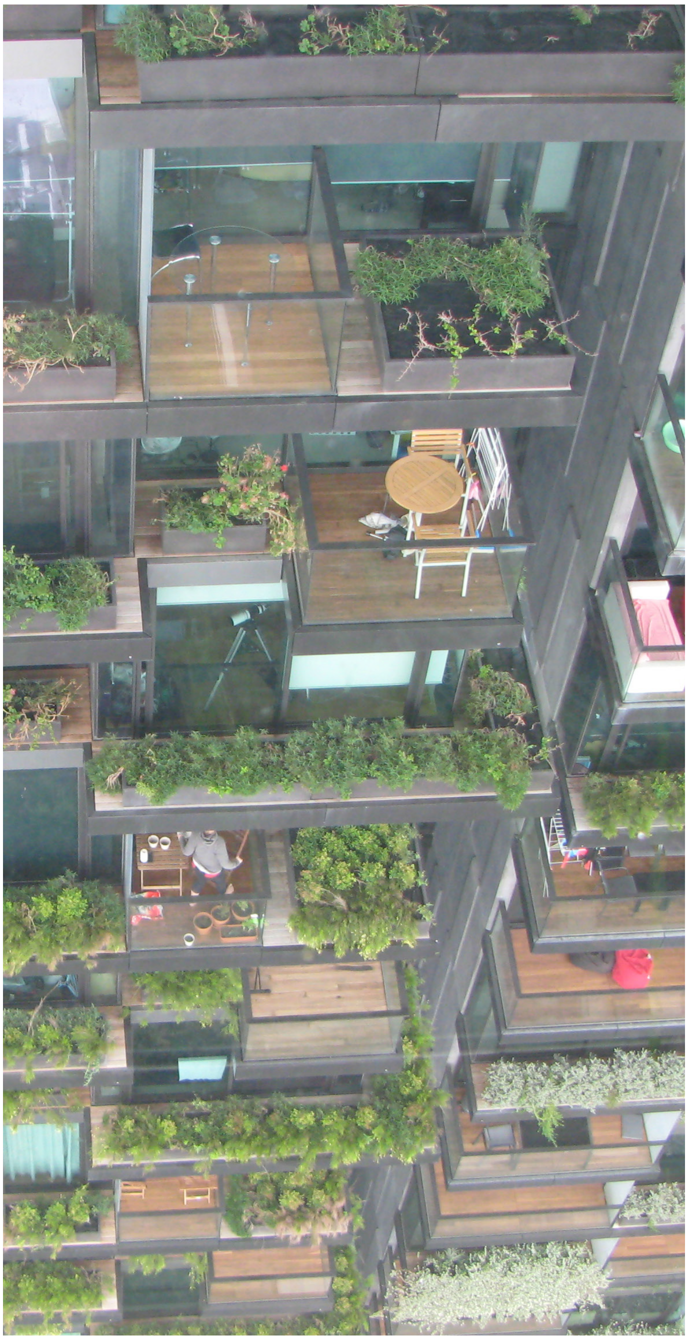


Vertical greening on One Central Park, Chippendale (Source: P. Osmond, n.d.)

EXECUTIVE SUMMARY

This study used a desk-top review of secondary sources to determine the drivers and barriers to the establishment of the living architecture. The review also covered the concept of resilience and resilient cities as there is a strong case for increasing living architecture to mitigate some of the acute and chronic resilience issues. The next stage of the review explored international policy approaches in key cities and then examined Australian State policy. A critical review of factors affecting adoption of mandatory and/or voluntary approaches to green roofs and walls was undertaken, before finishing with a review of the component of, and arguments for and against, the business case for green roofs and walls.

The study concludes there are numerous drivers for the establishment of a living architecture (green roofs, walls and facades) in our cities. As populations grow and cities become bigger, there are corresponding increases in greenhouse gas emissions, air pollution, impervious surfaces urban temperatures as well as loss of tree canopy cover and land for food production. Living architecture can mitigate the negative aspects of these issues. As such green roofs, walls and facades have multiple social, economic, ecological, environmental and health benefits.

Barriers exist and are social, economic, technological and environmental. Costs are a significant barrier, as well as lack of experience in the industry, especially in terms of construction and management. Construction industry and built environment professional capacity for green-roofs is in a developing phase and not fully ready to implement on a wider scale in buildings, precincts, and city scales. Further training and skill development is needed. There is significant potential to retrofit existing buildings, feasibility being determined partly by the structural capacity of the buildings to sustain the additional loads and; this needs to be more fully understood by stakeholders. There is also a lack of appropriate policy and regulations to integrate living architecture practices at the design phase of new buildings and also to retrofit buildings.

Resilience and resilient cities is a concept that will increase in importance. Action at building level is vital and filters up to city, regional and national scales. For example, retrofit of all structurally adequate roofs and walls in Sydney and Melbourne would lead to mitigation of the urban heat island, which impacts on health and livability. Similarly, improvement in storm-water attenuation as a result of mass green roof and wall retrofit decreases the impacts of flash flooding. We looked at case study cities to identify resilience issues and approaches to green roof and walls. Resilience issues in Sydney, Melbourne, Toronto, Singapore, London and Rotterdam are similar and can be mitigated through living architecture. Two resilience issues, heatwave and rainfall flooding, can be alleviated through green roofs and walls.

The review of international policy in Singapore, London, Stockholm, Toronto and Rotterdam demonstrated various approaches taken by policy makers, and a mix of mandatory and voluntary policy mechanisms increase installation of green roofs and walls. The drivers differ, though most are related to issues of increasing resilience and livability. The approaches adopted in these cities are expanded and critiqued in the Case Study report accompanying this report.

No consistent policy approach to green roofs and walls was found in Australian states. No states have a policy for green roofs and green walls, however the City of Sydney and City of Melbourne councils have created policies for each of their LGAs. NSW, Victoria, South Australia and Western Australia have varying numbers of documents, including guidelines and policies, which refer to green roofs and walls. Overall there is a lack of policy to promote living architecture in Australia.

Mandatory or voluntary approaches are key policy mechanisms for increasing green roofs and walls. Four types of policy instruments can be used: information and advocacy; incentives; government demonstration and provision, and regulation. Mandatory approaches fall into the regulation category, while voluntary approaches can be information and advocacy, incentives, or government demonstration and provision. International case studies demonstrate a range of approaches, although our research reveals that there are more voluntary approaches in place than mandatory.

Cost Benefit Analyses undertaken in the US indicated a viable case for large-scale retrofit of green roofs. Increases in residential property value with more green infrastructure in Canada of between 6 and 15% is recorded, and it is recommended a study is undertaken to model the percentage of uplift in value in various Australian cities and suburbs. Furthermore at city scale, modelling in Toronto, Canada showed the UHI could be attenuated by 0.5°C to 2°C through green roof retrofit. If green walls and living walls are added to this calculation, reductions would be greater. Liveability of both Melbourne and Sydney will be affected by predicted temperature increases and we need empirical data for both cities.

The questions that remain unanswered in Australia are; how much green infrastructure do we need to retrofit to achieve resilience? What is the cost benefit analysis for this? And what does the business case look like? Finally, is this more likely to be delivered through a market lead approach, a mandatory approach, or a hybrid of the two approaches? The final report presents different scenarios and modelling to demonstrate the case for mandatory or voluntary approaches and their respective strengths and weaknesses in Australia.

Green roof on One40William, Perth (source: Deep Green Landscaping, 2015)

1. Introduction

This literature review has been prepared by the University of Technology Sydney (UTS) for Horticulture Innovation Australia (Hort Innovation), as part of the research project 'Green Cities: Expanding the living architecture industry in Australia' (GC15001). This research was commissioned by HIA to analyse policy internationally and nationally to ascertain whether, and how far, mandatory and/or voluntary approaches to increase green roofs and green walls, have succeeded, and to provide recommendations for the Australian context.

Green infrastructure offers significant, wide-ranging benefits across economic, social and environmental aspects. As part of green infrastructure, green roofs and walls contribute to these benefits, particularly in dense urban areas. Green roofs improve air quality, provide space for social interaction and relaxation, help manage urban stormwater, reduce the urban heat island effect, provide space for urban food production and improve urban biodiversity. This range of economic, social and environmental benefits has led to the uptake of green roofs and green walls nationally and internationally.

As Australia's population grows, our towns and cities will continue to expand and become more dense, leaving less space for open green space and vegetation. Increasing urbanisation will have significant effects on the natural environment and the health and well-being of human and non-human populations. Green roofs and green walls can help mitigate some of these impacts.

This literature review summarises the key literature about green roofs and green walls. We start with a review of the drivers and barriers for the establishment of a living architecture. This is followed by a discussion of resilience and resilient cities, with reference to issues relating to Sydney, Melbourne, Singapore, London and Rotterdam. We then summarise international policy approaches in Singapore, London, Stockholm, Toronto and Rotterdam and state policy in Australia. These international cities have been selected for their innovative and proactive approaches to green walls and roofs. This is followed by a discussion of mandatory or voluntary approaches to green roofs and green walls. We finish with a review of approaches to creating a business case for green roofs and walls.

We conducted this research through a desktop review of literature, including academic and 'grey' literature (such as government reports, newspaper articles etc). We reviewed a wide range of sources such as academic journal articles, books, industry publications, government policies and guidelines and websites. This literature review represents key findings which will inform the next stage of the project, the research report.

2. Drivers and barriers for the establishment of a living architecture

Drivers for Living Architecture

Cities are becoming more dense and compact as two-thirds of the world population is likely to live in urban areas by 2030 (Population Reference Bureau, 2011). Rising greenhouse gas emissions, increase in air pollution, loss of land for food production due to rapid urbanisation, decreasing tree canopy cover, urban heat island effects, greater imperviousness and building high-density cities to accommodate ever-expanding population are some of the critical challenges faced by many of the world cities (UN-Habitat. 2011; 100 Resilient Cities 2016). Australian cities also experience similar issues. The Australian Climate Change Science Programme projections for Australian cities predict increased average temperature with more extreme heat events, increase in rainfall, drought, fire weather and warmer oceans and sea level rise at a high confidence level (CSIRO and Bureau of Meteorology 2016). Sydney, Melbourne, and Adelaide are already getting warmer up to 4°C when compared to surrounding areas and summer heat in outdoor public spaces in Sydney is increasing beyond human's thermal comfort (Sharfi and Lehmann 2015). Increased heat wave events in Australian cities could lead to higher heat related mortality rate. The contributing factors to urban heat island effects or heat stress in cities include urban landscape composition (e.g. urban greenery ratio), urban geometry, surface cover and materials and anthropogenic consumption and related emissions (Oke 2006 as quoted in Sharfi and Lehmann 2015). Water flow in streams supplying water to Melbourne is likely to decline by 7 to 20 percent by 2050, compared to 1990 averages due to drought conditions (UN-Habitat. 2011). Adelaide, Canberra, Perth, Brisbane, and Sydney would also face drought and water shortage problems (UN-Habitat. 2011). Living architecture is viewed as 'a powerful inspirational model' for achieving curative environmental solutions that can restore and enhance amenity, quality of lived experience of people, wellbeing, and productivity (Peck 2012). It is an important pathway to build resilience in cities and communities to deal with the climate change challenges.

Imagining high-density cities integrated with nature is becoming common as pioneering green cities have become exemplars of collective and positive experiences. An important emerging driver for living architecture is people's changing ideas of a city (Klinkenborg 2009) and how a city and its components should be designed and planned as places of social and human-nature interactions. Re-imagining the structures and appearances of current and future cities are going through an innovative phase as the cities are no more thought as an 'antithesis of nature' (Klinkenborg 2009). Through these transformative and regenerative processes, the cities are evolving as naturalised or biophilic human habitats where nature manifests itself in newly urbanised forms such as green roofs, walls, and facades.

People are starting to comprehend the immense value of incorporating green infrastructure or living architectural practices within built environments. Bringing back lost nature in the cities recreates the ground space utilising unused roof and wall spaces of buildings. Practical applications of these practices generate improved thermal performance and sound insulation of buildings, better storm water management, and air quality, increased property prices, the creation of useful places for social interactions and community engagement, cooler cities, and reduction in energy consumption and greenhouse gas emissions. Aesthetic qualities of cities and urban development projects are improved enhancing urban design characteristics of cities. Green roofs also contribute to urban ecology or biodiversity protection and urban food production at commercial scales as rooftop urban farms. Two extensive green roofs in the inner city Berlin covering 650 square metres supported 110 species over a time frame of twenty years (1985-2005) (Köhler 2006). Brooklyn Grange Rooftop Farm in New York includes two rooftop organic vegetable farms with a land area of one hectare and produces over 22,680 kilograms of food annually (Miller 2014). Urban farms open up opportunities for new job creation and local economic development. A perception study conducted in City of Sydney (2017) on green roofs and walls before developing Green Roofs and Walls Strategy for the city. Green Roofs and Walls Strategy for the City of Sydney was adopted in April 2014. This study indicates that associated social amenity values are a primary driver for the acceptance of accessible green roofs installation in buildings (City of Sydney 2017). A higher level of community awareness on green roof and walls was established through this research (City of Sydney 2017).

Increasing numbers of media articles on the green roof topics play important roles in creating public awareness. For example, a Sydney Morning Herald article published in 2008 reported findings that green roofs could lower summer temperature of roofs ranging from 75°C to 120°C to mid to high 30°C in Australian conditions. Technological capacity is also a guiding factor to implement green roofs walls and facades.

Living architecture such as green roofs are multifunctional green infrastructure (Dixon and Wilkinson 2016) and have multiple social, economic, ecological, environmental, and public health benefits. Hopkins and Goodwin (2011) categorised these benefits into two types: public benefits, shared at wider community and government levels and private benefits, received by building owners and occupants. These public and private benefits provide meaningful economic returns. These benefits are the key drivers and central to the uptake of living architecture practices (Hopkins and Goodwin 2011) at various urban spatial scales. Appropriate policy, initiatives, and incentives of federal, state and local governments and key national priorities have significant influences on the processes and guide the progress in implementing green roofs, green walls, and façades at local and city scales. The drivers would also vary with the implementation of green roofs, walls, and facades in different land use zones such as residential, commercial and industrial (City of Sydney 2017) and various locations and at different densities with the city.

With regards to green roofs whether new installation or retrofit stakeholders may make their decision based on one or more the following reasons;

1. Thermal performance – improve insulation and reduce energy consumption
2. Urban Heat Island
3. Storm-water – attenuation of pluvial flooding
4. Biodiversity enhancement
5. Conservation of endangered flora and fauna
6. Urban food production
7. Provision of social space (Wilkinson & Dixon, 2016).

The majority of stakeholders will be concerned primarily with

88 Angel Street, Newtown (source: O. Steele, 2016) the building level rather than the city level. In table 1 the primary and secondary benefits are identified for each type of green roof, similar primary and co-benefits will accrue for green walls and facades to greater or lesser degrees.

More specific research on Australian cities is essential to determine the existing drivers that could continue to influence and new drivers that could arise over the time to impact the green roofs, walls and facades uptake.

Barriers to living architecture

There are significant challenges, barriers, and issues associated with the establishment of living architecture practices (green roofs, walls, and facades) in current and future cities. Retrofitting existing buildings is important as estimates suggest 87% of all buildings we will have in 2050 have been already built. Potential to retrofit existing buildings are determined by the ability of the buildings to sustain structural loads of green roofs (Feitosa and Wilkinson 2016; GSA 2011). Intensive green roofs require supporting heavier weights of deeper soil than the extensive green roofs on the buildings (Downton 2013). In addition the technological capacity and reliability to install green roofs on buildings without the possibilities of leakages and structural damage is an issue of huge importance (GSA 2011). In spite of technological advancements, the reliability of green roof systems and associated risks of leaks are obstacles

Table 1 Green roof type primary and co benefits

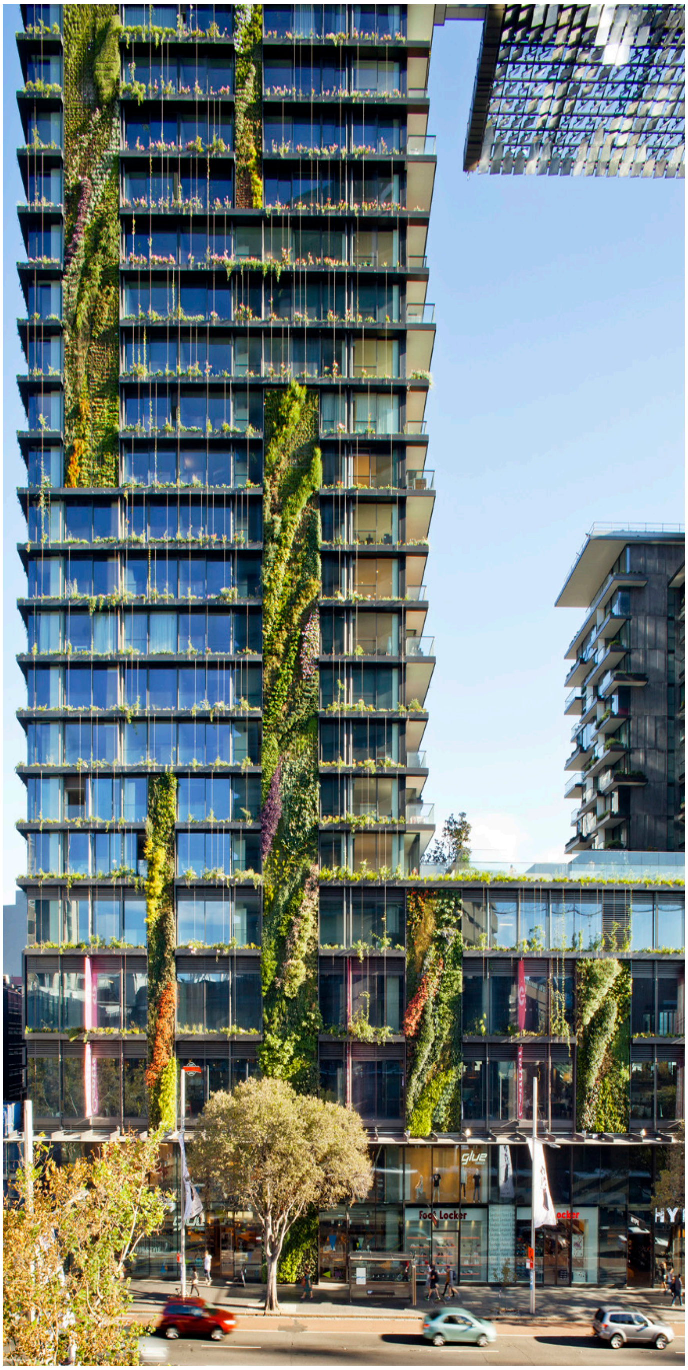
GREEN ROOF TYPE	PRIMARY REASON	CO-BENEFITS
1. Thermal	Improve insulation and reduce energy consumption	• Storm-water attenuation • Urban heat island • Bio-diversity • Air quality
2. Storm-water	Attenuate pluvial flooding	• Thermal improvement • Urban heat island • Bio-diversity • Air quality
3. Biodiversity enhancement	Increase local bio-diversity	• Air quality • Urban heat island • Thermal improvement • Storm-water attenuation
4. Conservation of endangered flora and fauna	Provide environment for endangered species	• Air quality • Urban heat island • Thermal improvement • Storm-water attenuation
5. Urban food production	Local food production	• Reduce carbon food miles • Air quality • Urban heat island • Thermal improvement • Increase bio diversity • Storm-water attenuation
6. Provision of social space	Amenity space	• Thermal improvement • Air quality • Urban heat island • Thermal improvement • Storm-water attenuation • Food production

(Source: Wilkinson & Dixon, 2016)

for implementation (City of Sydney 2017).

Stormwater management, dynamics, and monitoring are some of the critical challenges for green roofs. For example Sydney is predicted to get more intense rainfall in future which may lead to greater likelihood of flash flooding. Further training and skill development across the built environment stakeholders with regards to retrofitting green roofs for effective stormwater management is essential (Wilkinson et al. 2015). When assessing green roof retrofit potential, existing structural load bearing capacity, access to green roofs, power and water supply, orientation to sunlight, and occupational health and safety are determinants of suitability to retrofit, and of the type of green roof to install (Feitosa and Wilkinson 2016). The University of Melbourne and the Inner Melbourne Action Plan (IMAP) councils (2014) have jointly formulated 'Growing Green Guide' for plant selection for Melbourne and surroundings. A planting guide for plant selection considering climatic conditions, sunlight access and growing conditions and purposes of the green roofs, walls and facades such as storm water management, aesthetics, edible or non-edible planting and drought tolerance etc. are absolutely important for effectiveness and long-term survival of plants (University of Melbourne and IMAP 2014). An accurate evaluation method or tool for retrofitting considering climatic conditions, nature of building stocks, plant selection and other relevant factors for Australia needs to be developed. Sustainable adaptive practices are to be formulated for different categories of buildings such as residential, commercial and industrial and others. Limited understanding on and availability of these practices and tools pose significant challenges for the green roof industry.

One of the key concerns of the stakeholders and professionals is the high costs of the green roofs walls and facades installation and maintenance (Downton 2013; City of Sydney 2017; GSA 2011). Specialised knowledge and skills are needed for maintenance and care when these green roofs, walls and facades installed in high-rise buildings, such as One Central Park in Sydney. Easy accessibility for maintenance of green roofs, walls, and facades in indoor and outdoor environments should be considered for retrofitting existing and at the



One Central Park, Chippendale (source: S. Wood, n.d.)

design stage for new buildings. While assessing positive environmental contributions of green roofs in economic returns, these living architecture practices are subject to competition with other more established sustainable technologies and practices in the market such as alternative opportunities for solar water heating, solar PV installation (City of Sydney 2017) and energy efficient fixtures and appliances in the buildings.

Hopkins and Goodwin (2011) identified lack of structured methods and absence of data on material covers and environmental performance of green roofs is a problem for establishing quantitatively positive contributions of the green roofs. For example, the local economic potential of rooftop agriculture could be immense but has not been explored to a sufficient extent (Wilkinson & Page, 2015. GSA 2011). Developers often intend to consider other technologies as more feasible and likely to provide better economic values compared to green roofs, walls and façade technologies. Applications for green roofs have become limited to only to handful of best practice urban development projects (City of Sydney 2017). Continuing maintenance of plants is an added cost, and overall, the extensive cost of installing green roof is a major barrier to the uptake of green roofs. It essential to determine holistically short term and long term multiple performance benefits and associated economic and environmental values to establish the efficiency of green roofs, walls and façades. AECOM (2017) have estimated the value uplift of green infrastructure in the typical Sydney home to be in the order of $50,000 and Newell et al (2011) estimate the price premium in top quality commercial property for sustainability features to be around 9%. Further hedonic modelling of property prices and the amounts of green infrastructure would give more detailed knowledge of the value uplift and stimulate the market to invest in more green infrastructure.

The capacity of the construction industry with regards to green roofs is in a developing phase and not fully ready to roll out green roof or wall installation on a wider scale at building, precinct and city scales. The industry should be able to supply skilled workmanship and withstand the demand for green roofs. Community awareness for green roofs has developed to a reasonable extent, and people recognise the importance green roofs installation in Sydney (City of Sydney 2017). To date green roof policy approaches have been implemented in limited local governments in Australia. There is a lack of appropriate policy and regulations to integrate living architecture practices (green roofs, walls, and facades) at the design phase of new buildings and also to retrofit existing buildings. In 2016 an RICS Best Practice Guidance Note on Green Roofs and Wall (2016) was launched to provide guidance to surveyors (including valuers, quantity surveyors, building surveyors, property managers and facility managers) when advising clients on green roofs and walls.

Overall these are the challenges for implementation of living architecture practices and further work is necessary to address this substantial gap and formulate suitable planning policies, building standards and guidelines integrating green roofs, walls and facades. The barriers are summarised in table 2.

Table 2 Barriers to living architecture

TYPE OF BARRIER	DESCRIPTION
Economic	Perceptions about high installation and maintenance costs. Lack of knowledge regarding value uplift of green infrastructure to property capital and rental values
Environmental	Plant lifecycle and replacement rates Additional water consumption Additional energy consumption Competition with other sustainable technologies e.g., rooftop solar PV
Social	Occupational Health and Safety during installation and maintenance
Technological	Structural capacity for retrofit Leaks Reliability of systems – durability Reliability of systems – maintenance Access to roof for installation and maintenance Orientation (access to sunlight) Lack of guides for building owners and property managers / facility managers Construction industry capacity

(Source: authors)

3. Resilience and resilient cities

As the 21st century progresses, we are evolving collective thinking and responses to the challenges we face. This includes living with a changing climate, increasing global population and changing demographics, mass urbanisation, issues of inequality, instability, food security and increasing scarcity of resources, as well as an increased need for sustainability in the built environment (UN 2015. RICS 2015).

Climate change is one of the greatest challenges of our time. The World Bank Group Report (2015) on Building Regulation for Resilience: Managing Risks for Safer Cities noted in the last two decades natural disasters have claimed 1.3 million lives, affected 4.4 billion people and have created US$2 trillion of economic losses. High-income countries, with advanced building code systems experienced 47% of disasters, yet only 7% of fatalities, and thus a prima facie case exists for rigorous regulation (The World Bank Group, 2015). The World Bank Group called for a fundamental shift from managing disasters to reducing underlying risks. Increases in global temperature, sea level rise, ocean acidification and other climate change impacts are some of the 'chronic' stresses that seriously affect coastal areas and low-lying coastal countries. The survival of many societies and the planet's biological support systems, are at risk.

By way of response, the UN 'Transforming Our World: The 2030 Agenda For Sustainable Development' report (2015) stated that 17 Sustainable Development Goals and 169 targets demonstrate the scale and ambition of a universal Agenda (see figure 1). The goals and targets are integrated, indivisible and balance the economic, social and environmental dimensions of sustainable development. They will stimulate action to 2030 in areas of critical importance for humanity and the planet (UN 2015:1). Goal 11 relates most directly to the built environment and green infrastructure; to 'make cities and human settlements inclusive, safe, resilient and sustainable' (UN 2015). 'Inclusive, safe, resilient and sustainable' settlements and cities provide the setting for the delivery of many sustainable development goals. Goal 3 'Ensure healthy lives and promote well being for all at all ages', is clearly related, in part, to the quality of the buildings in which people live and work, as well as access to green space. Our role as built environment stakeholders is crucial and cannot be under-estimated.

Against this background, the focus is the role of green roofs and walls in contributing to these goals. Resilience is defined and explained and then related to green roofs and walls. The section is structured so that city scale solutions and research is covered firstly followed by individual building scale solutions.

Scale of the problem from city to building scale

It took hundreds of thousands of years for global population to grow to 1 billion, and in another 200 years it grew seven times (UN 2015). In 2011 world population was 7 billion, in 2015 it reached 7.3 billion, and is predicted to be 8.5 billion in 2030, 9.7 billion in 2050 and 11.2 billion in 2100 (UN DESA 2015). Growth is driven by greater numbers surviving to reproductive age, combined with changes in fertility rates, increasing urbanisation and accelerating migration. Such trends have far-reaching implications for the generations to come (UNPF, 2015).

The world is undergoing the largest wave of urban growth in history. More than half the world's population now live in towns and cities, and by 2030; this number will be circa 5 billion (UNFPA, 2015). By 2050, an estimated 66% of global population will be urbanised (RICS, 2015). Though much of this urbanisation will unfold in Asia and Africa, bringing huge social, economic and environmental transformations; all countries and cities will be affected.

Whilst urbanisation could usher a new era of well-being, resource efficiency and economic growth, cities house high concentrations of poverty and inequality. In some cities, wealthy communities coexist alongside, less advantaged ones. As our cities grow, in many cases, faster than ever before we need planning and governance to deliver transition from one level, scale and type of development to others at the city scale, ensuring infrastructure, including green infrastructure, can support growing populations and changing land uses. Within this adaptation of existing areas to accommodate greater numbers of people, and as the predominant land uses undergo change, we need to consider optimum levels of sustainable

Figure 1. UN Sustainable Development Goals

Sustainable Development Goals

Goal 1. End poverty in all its forms everywhere

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3. Ensure healthy lives and promote well-being for all at all ages

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 5. Achieve gender equality and empower all women and girls

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 10. Reduce inequality within and among countries

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

Goal 12. Ensure sustainable consumption and production patterns

Goal 13. Take urgent action to combat climate change and its impacts[*]

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

[*] Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.

(Source: UN Sustainable Development Goals, 2015).

development that includes, at the building level, different degrees of green infrastructure to new and existing buildings.

City Level Challenges

The 100 Resilient Cities (100RC), initiated by the Rockefeller Foundation (100RC, 2016) aims to assist global cities to meet the physical, social and economic challenges faced now, and in the future. Many cities are developing resilience plans, Sydney published its' preliminary assessment in 2016, whereas New York published its' strategy in 2013. The 100RC supports the adoption and incorporation of acute and chronic manifestations of resilience. Acute or shock events include bushfire, earthquakes and floods, whereas chronic stresses undermine and weaken the fabric of a city on a daily or cyclical basis. High unemployment levels; inefficient public transport systems and endemic violence are examples. By addressing shocks and the stresses, a city is more able to respond to adverse events, and better placed to deliver basic functions in good and bad times, to all populations. Melbourne was among the first wave of 32 cities to join the 100RC network and published its resilience strategy in May 2016.

The 100RC has identified and collated the challenges facing a number of global cities. Table 3 illustrates the two Australian cities, Melbourne and Sydney as well as the selected case study cities of London, Rotterdam, Singapore and Toronto, to highlight their challenges and the similarities and differences that exist. The issues range from social to environmental and economical, some are chronic where others are acute. Clearly adoption of green infrastructure including green walls and roofs sits within these circumstances. It follows that different solutions suit different cities and different locations and have different degrees of importance.

Many issues are shared, for example terrorism, whilst others are distinct such as Toronto with its over taxed, under developed, unreliable transportation system. Some cities have multiple issues such as Melbourne listing 14 whereas London lists four. Table 3 shows the resilience issues in the case study cities to illustrate the shared and distinct issues faced. Stockholm is not one of the 100RC and is not included in tables 3 and 4. These criteria may be significant in terms of those

Table 3 Resilience challenges faced in selected Australian and project case study cities

CITY	RESILIENCE CHALLENGES (100 RESILIENT CITIES)
Melbourne	1. Aging infrastructure 2. Coastal flooding 3. Declining or ageing population 4. Disease outbreak 5. Drought 6. Economic shifts 7. Heatwave 8. Lack of affordable housing 9. Rainfall flooding 10. Rapid growth 11. Rising sea level and coastal erosion 12. Social inequity 13. Terrorism 14. Wildfires
Sydney	1. Aging infrastructure 2. Heat wave 3. Infrastructure failure 4. Lack of affordable housing 5. Overtaxed/ under developed/unreliable transportation system 6. Rapid growth 7. Rising sea level and coastal erosion 8. Social inequity 9. Terrorism 10. Wildfires 11. Rooftop solar PV
London	1. Endemic crime and violence 2. Infrastructure failure 3. Lack of Affordable housing 4. Terrorism
Rotterdam	1. Coastal flooding 2. Drought 3. Hazardous materials accident 4. Heat wave 5. Rainfall flooding 6. Refugees

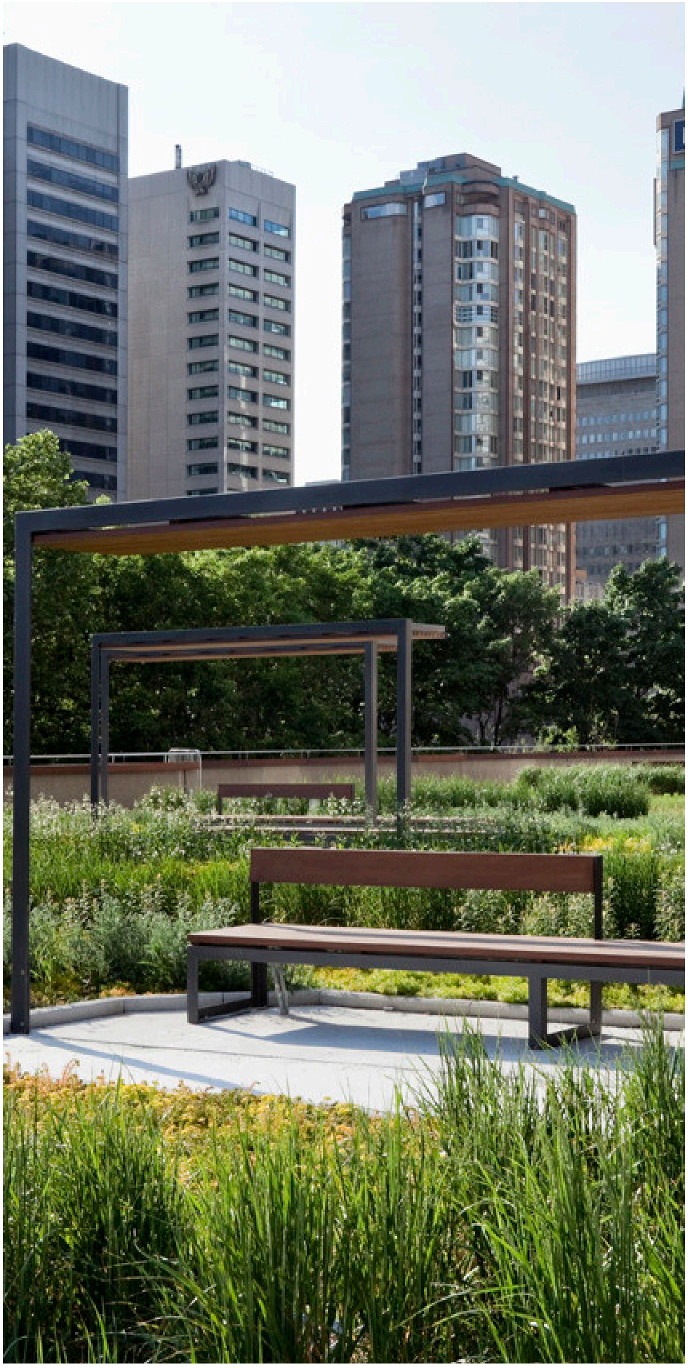
table continued on following page

CITY	RESILIENCE CHALLENGES (100 RESILIENT CITIES)
Singapore	1. Coastal flooding 2. Heat wave 3. Pollution or Environmental degradation 4. Rainfall flooding 5. Raising sea levels and coastal erosion 6. Terrorism
Toronto	1. Aging infrastructure 2. Blizzard 3. Economic inequality 4. Infrastructure failure 5. Lack of Affordable housing 6. Over taxed / under developed / unreliable transportation system 7. Rainfall flooding

(Source: 100 Resilient Cities, 2016)

cities who have or have not adopted mandatory or voluntary approaches to green roofs and walls.

Resilience scales refers to the different levels at which resilience issues impact and can be tackled. The smallest scale is building, followed by precinct or district, city, metropolitan area, country, region and finally the world. This shows how action taken at building levels is effective up the chain to global level. Figure 2 shows this model incorporated into the Rotterdam resilience strategy.



Nathan Phillips Square Podium green roof, Toronto (source: Evans, S.and Pommer, C.2011)

Table 4 Resilience issues and case study cities compared

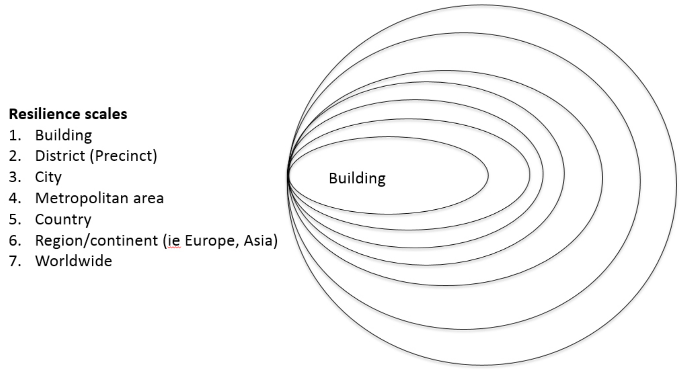
ISSUE	MELBOURNE	SYDNEY	LONDON	ROTTERDAM	SINGAPORE	TORONTO
Ageing infrastructure	●	●				●
Blizzard						●
Coastal flooding	●				●	
Declining or ageing population	●					
Disease outbreak	●					
Drought	●			●		
Economic Inequality						●
Endemic crime & violence			●			
Economic shifts	●					
Endemic crime & violence						
Heatwave	●	●		●	●	
Infra-structure failure			●			●
Lack of affordable housing	●	●	●			●
Overtaxed, underdeveloped unreliable transportation system						●
Rainfall flooding	●				●	●
Raising sea levels & coastal erosion	●	●			●	
Social inequality		●				
Refugees	●					
Terrorism	●	●	●		●	
Wildfires	●	●				

(Source: 100 Resilient Cities, 2016)

The notion of urban resilience

The notion of urban resilience has evolved in recent years and is used in policy and academic discourse (Urban Green Council, 2013; NSW Government Planning and Environment, 2014). The theory of resilience explains complex socio-ecological systems and their sustainable management; here urban settlements, cites and buildings. Theorists claim that systems change continuously in non-linear ways, and that resilience offers a framework for dealing with future uncertainties.

Figure 2 Model of Resilience Scales



(Source: Rotterdam Resilience Strategy, 2017)

Resilience is perceived as positive; taking action to make us less vulnerable to climate change, natural disasters and/or man-made disasters such as economic downturns or collapse. Resilience is an attractive perspective with regards to cities, which are complex adaptive systems (Batty, 2008). Urban settlements with over 50,000 people, account for 71% of global carbon emissions; yet cover only 3% of the area. In accommodating growth and expansion, cities and the buildings within them, need to possess resilience. Resilience is derived from the Latin word 'resilio'; which means to bounce back. In the 19th century, the term evolved to embrace adversity (Alexander 2013). The term is used by many disciplines, which each understand and interpret the notion differently. Meerow et al, (2016) found five themes as shared qualities of resilience, which are;

1. equilibrium versus non equilibrium,
2. positive versus negative conceptualisations of resilience,
3. mechanisms of system change (from persistence, transitional or transformative change),
4. adaptation versus general adaptability, and;
5. timescales of action.

Meerow et al (2016) posited a definition of urban resilience as; The ability of an urban system - and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales - to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity. The 100 Resilient Cities (100RC, 2016) defines urban resilience as 'the capacity of individuals, institutions, businesses and systems within a city to adapt, survive and thrive no matter what kind of chronic stresses and acute shocks they experience'. Both definitions view urban resilience as dynamic and changing.

In defining urban and the characteristics of urban settlement, many definitions posit that cities and urban systems are complex, networked systems (Desouza & Flanery 2013:91) and conglomerations of ecological, social and technical components. Ernstson et al (2010) claim cities are complex socio-ecological systems composed of socio-ecological and socio-technical networks. Cities and their hinterlands are highly inter-dependent with delineation of boundaries problematic, as some systems extend beyond the physical city limits such as water or food supply.

Equilibrium

Scholars debate issues of single state, multiple-state and dynamic non-equilibrium (Davoudi et al, 2012). Single state equilibrium is the ability to return to a previous state of equilibrium post disturbance and prevails in disaster management, for example, where an area and buildings are reinstated post flood. Multiple-state equilibrium acknowledges that there can be numerous states of equilibrium in any system. It has been accepted that systems exist in a state of dynamic non-equilibrium, that is no constant state can exist and there is a continuous state of flux and change. This leads to the rejection of the notion of resilience as 'bouncing back'. In this understanding of the term; systems are 'safe to fail' as opposed to fail safe, and acknowledge that post disturbance, cities and their buildings may not return to a previous state. Further a return to 'normal' may not be desirable and appropriate as the original state was vulnerable. A co-ordinated proactive approach to risk mitigation and adaptation within the urban planning and built environment is recommended (Sanchez et al, 2016).

Positive versus Negative notions
Resilience was perceived as positive in all 25 definitions analysed by Meerow et al (2016), where resilient systems maintained basic functions, prospered and improved. Other studies note some existing states are undesirable (Cote and Nightingale 2011), such as areas with inadequate, poor quality housing.

Mechanism of Change
There are three mechanisms of change or ways to resilience. Firstly 'persistence'; where efforts are made to return or maintain the built environment and its systems in an existing state, e.g., after a storm buildings are reinstated (Chelleri, 2012). Retrofit is an example of persistence. The second mechanism is 'transitional', which implies some adaptation to a new state or incremental change, e.g; change of use from a former land use of warehouse to residential as an area transitions post industrialisation. The third, most extensive change is 'transformative', e.g; where significant adaptive reuse occurs and areas are completely transformed.

Adaptation
Adaptation refers to the differences between high adaptedness compared to more generic adaptability (Elmquist, 2014). Wu and Wu (2013) argued too much emphasis on specified resilience undermines system flexibility and ability to adapt to unexpected threats. Others perceive adaptability as synonymous with adaptive capacity and note the importance of maintaining general resilience to unforeseen threats in addition to specified resilience to known risks. With known risks of pluvial flooding affecting a city, it involves taking measures in the design, construction and adaptation of buildings to reduce the risk of water damage, such as specifying a green roof and ensuring faster recovery when pluvial flooding occurs. Equally adopting flexible design and construction in buildings might accommodate a greater variety of alternate uses over time, thereby having adaptive capacity. Warehouse buildings are an example of a building design with good adaptive capacity; globally they are used as residential buildings, hotels, art galleries and retail centres.

Timescale
Some studies perceive immediacy and rapidity of recovery as essential characteristics, however it is dependent on whether the focus is on rapid onset events such as storms and floods or more long term gradual states such as changing climate (Wardekker et al, 2010). Second, the timeframe is unclear and can be hours, months or years. So reinstatement of energy supply following a storm would be delivered preferably within hours, whereas reinstatement of flood damaged buildings might take months. Further there is the question of reinstatement being a return to the 'prior state', or an improved and different state that would be more resilient to the same type of event. Sanchez et al (2016) note urban transformation requires active engagement in setting long term goals at city or state level, however flexibility is a pre-requisite to adapt to changes that occur otherwise unintended adverse consequences may result. Although these issues are dealt with at city or state level, it is at building level where many interventions and adaptations will occur.

Resilience is complex, with many attributes and levels of interpretation. Meerow et al (2016) stated it was vital to consider the who, what, when, where and why. In considering resilience be aware 'who' is determining what is desirable for an urban system, whose resilience is prioritised and, who is included or excluded from the urban systems? In respect of 'what'; what should the system be resilient to, what networks /sectors are included in the urban system, and this the focus on generic or specific resilience? The question of 'when'; is the focus on rapid or slow onset disturbances, on short or long term resilience, and finally on the resilience of current or future generations? The fourth W covers 'where'; in respect of the boundaries of the urban system, and whether resilience of some areas prioritised over others, and whether building resilience in some areas affects the resilience of other areas. Finally 'why'; what is the goal, what are underlying motivations and is the focus on process or outcome (Meerow et al, 2016).

Built environment resilience refers to the physical built environment that accommodates human activities, whereas community resilience refers to the resilience of individuals or a group of inhabitants and their social constructs. Here the literature is focused on notions of well-being, governance and economy. Sanchez et al (2016) give the example of built environment resilience different stakeholders having a different focus, with built environment resilience, engineers are focused on engineering infrastructure and restoration to operation as soon as possible after a disaster, whereas a community engineering resilience will focus on social and economic outcomes.

Green roof, MONA, Hobart (source: P. Osmond, n.d.)

4. International policy approaches

In this section of the literature review, we summarise international planning policy frameworks related to living architecture, at national and city levels. Our review shows that different international cities have different approaches to implement green roofs and walls. These approaches vary depending on a range of factors including governance structure, climate, location, proposed impacts from climate change and density of the urban form. The following five cities were selected for review:

- London, England;
- Rotterdam, The Netherlands;
- Singapore;
- Stockholm; Sweden
- and Toronto, Canada.

Below, we briefly discuss the different policy approaches taken by each city, and how they are framed. Detailed case studies are presented separately in the separate case studies document. A review of the policy framework and policies for Australian states is outlined separately in Section 5.

London, England

In London, there are three levels of governance: national, regional (Greater London Authority) and local (33 boroughs). While national Planning Policy Statements (PPS) and the Greater London Authority's provide policy guidance from higher governments, boroughs are responsible for planning within their local area. The Local Plan prepared by the City of London (2015) encourages green roofs and walls in its Core Strategic Policy CS19: Open Space and Recreation. The City of London encourages architects and developers to install green walls on buildings for environmental benefits (City of London, 2014). The City has also provided funding for green roofs and rain gardens (Greater London Authority 2017). One of the key drivers for implementing green roofs and green walls in London (as well as green infrastructure more broadly), is urban storm-water management. Managing overland flows during peak rainfall events, as well as water levels in the tidal River Thames, is critical to ensure the resilience of the city.

Rotterdam, The Netherlands

In Rotterdam, there are three levels of government: national, provincial and municipal. Planning for the city of Rotterdam is undertaken by the Municipality of Rotterdam. The key document for sustainable development in Rotterdam is 'Making sustainability a way of life for Rotterdam: Rotterdam Programme on Sustainability and Climate Change 2015-2018' (City of Rotterdam, 2016). This document was endorsed by the municipality in March 2016 and outlines the goal for implementation of green walls throughout the city. To achieve this goal, City of Rotterdam has implemented a series of tools including a grant / subsidy scheme, tax benefits, campaign periods, demonstration projects, information days and personal advice. In Rotterdam, there is a focus on green roofs more than green walls. This is because of their potential to manage urban stormwater, a key issue in the city, which sits an average of 5m below sea level. The government considers green roofs (and other green infrastructure elements) an important way of increasing the resilience of the city.

Singapore

Urban greening has been a key part of the government's plan for the city-state since 1968, when the country's founding Prime Minister, Lee Kuan Yew, announced his vision for Singapore, which centred around the idea of a 'garden city', to attract foreign investment and increase liveability. Singapore has established a comprehensive program to promote rooftop greening in order to reach its goal of 200 hectares of Skyrise Greenery by the year 2030 as outlined in the Sustainable Singapore Blueprint 2015 (Ministry of the Environment and Water Resources and Ministry of National Development, 2014). Singapore encourages green roofs through a wide variety of incentives, guidelines, policies and grants. These include the Skyrise Greenery Incentive Scheme (implemented by the National Parks Board), the Landscaping for Urban Spaces and High-Rises (LUSH) program (implemented by the Urban Redevelopment Authority), as well as the Landscape Excellence Assessment Framework (LEAF) certification program and the Skyrise Greenery Awards (implemented by the National Parks Board).

Stockholm

Stockholm is a metropolitan area housing over a fifth of Sweden's population. There are three tiers of governance at national, municipal and county levels. The municipality is responsible for regulations affecting planning and building and this is delivered through the Planning and Building Act. There are 26 municipalities within Stockholm, which is focussing on increasing densities and redeveloping land to accommodate a growing population. The city aims to be fossil free by 2050. The city acknowledges the role of the built environment to attenuate and mitigate the impacts of climate change and this is manifest in initiatives such as the Green Space Factor (GSF). The GSF and Green Points system, which originates in the GRaBS (Green and Blue Space Adaptation for Urban Areas and Eco Towns) project is applied in urban regeneration schemes such as Hammarby Sjöstad and the Royal Seaport project. GRaBS is a network of pan-European organisations involved in integrating climate change adaptation into regional planning and development.

Toronto, Canada

Toronto has three levels of government: federal, provincial and municipal. The City of Toronto has responsibility for planning in the city. It is a large city with a very high-density downtown (CBD) area. As with many high-density cities, officials are mindful of the climate change and resilience issues that relate to their region and how they must be managed to ensure the city remains a viable functioning centre of government and commerce, as well as being a safe, desirable place for its inhabitants. Toronto acknowledged the need to increase green infrastructure in the early 2000s and enacted a bylaw in 2010 to require owners to install green roofs where certain conditions exist. This Bylaw requires green roofs on new commercial, institutional and residential development with a minimum Gross Floor Area (GFA) of 2,000m² as of January 31, 2010. It was extended from April 30th 2012, to require compliance with the Bylaw for new industrial development. A green roof screening form is a tool to determine whether an owner is required to build a green roof. Numerous tools (checklists, declaration forms and templates) and support is available to owners including financial grants and incentives.

Augustenborg Botanical Roof Garden, Malmo (source: L. Lundberg, n.d.)

As a result a high number of green roofs have been installed in the City. Table 5 provides a summary of the support instruments provided in the case study cities reviewed above.

Table 5 Green roof and wall support instruments in the international case study cities

SUPPORT INSTRUMENT	**CITY**				
	LONDON	ROTTERDAM	SINGAPORE	STOCKHOLM	TORONTO
PLANNING POLICY	●	●	●	●	●
GUIDELINES			●	●	●
GRANT SCHEME		●	●		●
TAX BENEFIT		●	●		
DENSITY BONUS			●		
DEMONSTRATION PROJECTS		●		●	●
PERSONAL ADVICE		●		●	●
PUBLIC AWARENESS CAMPAIGNS AND INFORMATION DAYS		●	●	●	●
AWARDS			●		
RESEARCH		●	●		

(Source: authors)

5. State policy in Australia

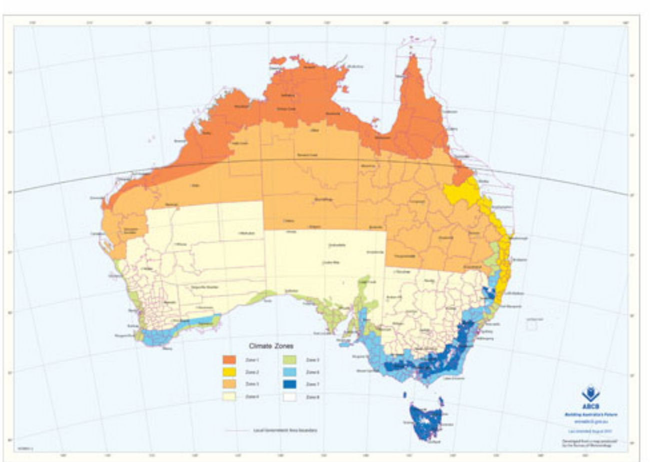
In this section, we discuss green roof and wall policy throughout a number of Australia's states. We review policy and other government documents from New South Wales, Victoria, South Australia, Western Australia and Queensland, that relate to green roofs and walls.

Australia has a three-tiered system of government: federal, state and local. There is no federal government policy on green roofs and green walls. Key documents relating to green roofs and walls produced by the federal government include the Living Wall and Green Roof Plants for Australia (Rural Industries Research Development Corporation, 2012) report and the Your Home: Australia's guide to environmentally sustainable homes guide (Department of Environment and Energy, 2013).

Each state in Australia has a different approach to policy for green roofs and green walls. Each state also has unique characteristics, including size, population, urban density and climate. At the state level, few specific green roof or green wall policies or planning instruments have been developed. However, recognition and support of green roofs and walls is underway, particularly in South Australia, Victoria and New South Wales.

Each state has also has a series of local governments which are responsible for planning across each local government area. While a review of local government policy is not the focus of this section, we do draw out key examples of green roof and wall policies implemented by the local governments of Australia's biggest cities – the City of Sydney and the City of Melbourne. Figure 3 illustrates the different climate zones across Australia and an indication that varying green roof and wall solutions are affected by location.

Figure 3. Climate zones across Australia



(Source: Australian Building Codes Board, 2015)

New South Wales

In New South Wales, the Department of Planning and Environment is the main agency responsible for developing policy which effects living architecture such as green roofs and green walls. There are no mandatory requirements for green roofs or walls on buildings in NSW. The NSW Department of Planning and Environment supports the implementation of green walls and roofs in its Draft Medium Density Design Guide (2016). Part 2C of the guidelines, Landscaped Area, advocates for building designs which incorporate opportunities for planting on structures, including green walls, green roofs and planter boxes. The State Environmental Planning Policy No. 65 – Design Quality of Residential Flat Development (SEPP 65) and its accompanying Residential Flat Design Code was introduced in 2002 by the department. In 2015, the Apartment Design Guide (NSW Department of Planning and Environment) replaced the Residential Flat Design Code. Two sections refer to green roofs and walls:

- Section 4.O 'Landscape Design' of the guide supports the use of green roofs and walls as part of environmentally sustainable landscape design and enhance environmental

performance.
- Section 4.P 'Planting on Structures' encourages plants on structures such as basement car parks, podiums, roofs and walls.

The New South Wales Office of Environment and Heritage (OEH) has taken a leading role in the development of guidelines around green roofs and green walls. The Urban Green Cover in NSW Technical Guidelines (OEH, 2015) advocates for the use of a range of green cover techniques (including green roofs and walls) to help ameliorate the urban heat island effect. These guidelines were produced to encourage industry and government to implement green cover in urban areas by increasing education and awareness. The NSW Environmental Trust, which sits within OEH, is currently finalising a blueprint for urban ecology in major cities across the state. Intensive green roofs and green walls are encouraged for their contribution to increasing urban biodiversity.

The Greater Sydney Commission (GSC) was established in 2015 by the Minister for Planning, to lead metropolitan planning in Sydney to improve productivity, liveability and sustainability. Two of the Commissions principal objectives are to encourage development that is resilient and takes into account natural hazards; and to support ongoing improvement in productivity, liveability and environmental quality. Living architecture can help achieve these objectives. Draft District Plans released by the GSC in November 2016 have no specific reference to green roofs or walls, although they do refer to the Urban Green Cover in NSW Technical Guidelines (OEH, 2015).

The Building Sustainability Index (BASIX) scheme was developed by the Department of Planning to help improve sustainability outcomes of residential properties in NSW. It sets energy and water use targets for single and multi-unit dwellings. Green roofs and green walls can contribute to thermal comfort and energy savings in residential buildings however they are not included in the assessment criteria. Figure 4 illustrates some NSW government documents which refer to green roofs and walls.

At the local government level, the City of Sydney leads the way in establishing a green roofs and walls policy for its local government area (LGA). It published the Green Roofs and Walls Strategy 2012 (City of Sydney 2012) to support the increase in the installation of green roofs and green walls in the LGA.

Figure 4. Some NSW government documents which refer to green roofs and walls

Living wall, Barangaroo, Sydney (source: Urban Developer, 2016)

Victoria

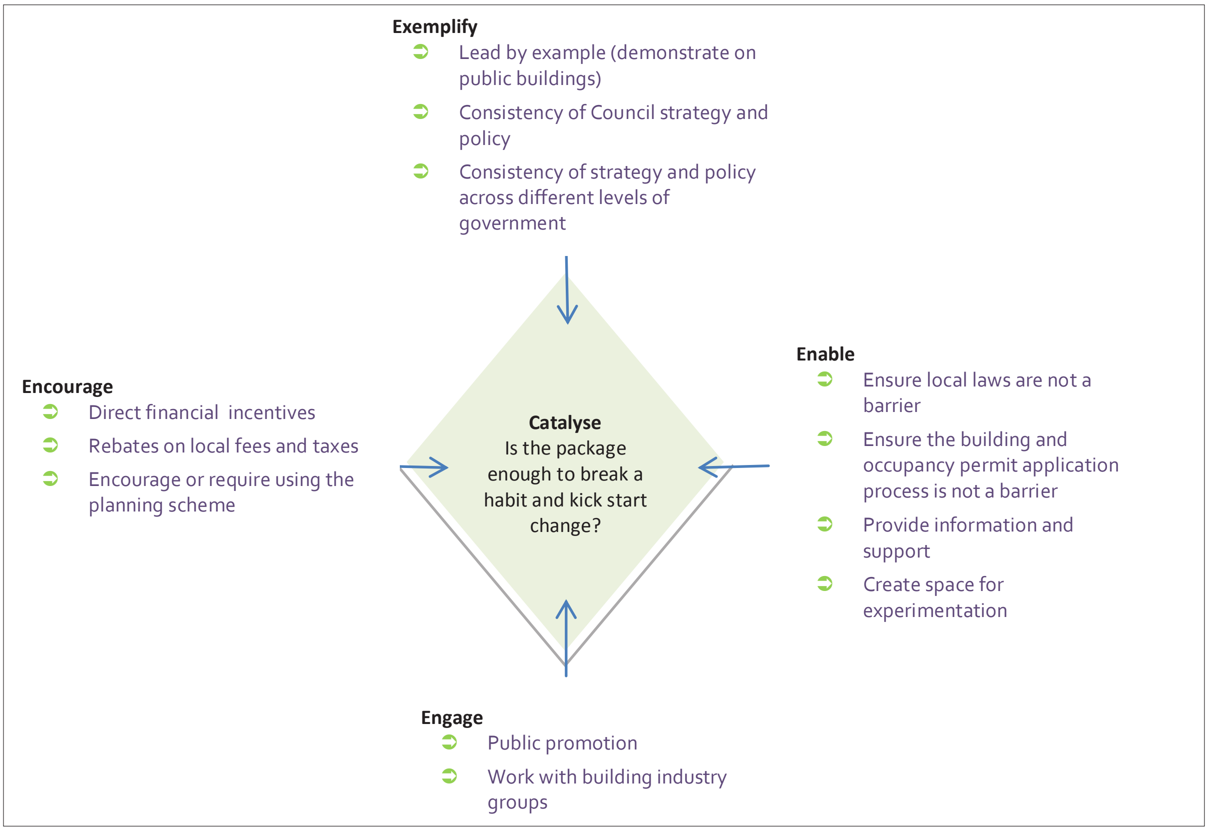
In Victoria, the Department of Environment, Land, Water and Planning is responsible for creating liveable, inclusive and sustainable communities. There are no mandatory requirements for green roofs or walls on buildings in Victoria. The Victorian State Planning Policy Framework currently does not include references to green roofs or walls. However, opportunities to integrate green roofs and walls have been identified in the Policy Options Paper, prepared as part of the Growing Green Guide for Melbourne project in 2013 (see figure 6).

The Better Apartment Design Standards (Department of Environment, Land, Water & Planning, 2016) came into effect in March 2017 when they were implemented through the Victoria Planning Provisions and all planning schemes. The design standards do encourage the use of green walls and greens roofs in apartment design. The landscape section of the standard states that:

- 'the landscape layout and design should … consider landscaping opportunities such as green walls, green roofs and roof top gardens to reduce heat absorption and improve storm water management' (p.17).
- 'If the development cannot achieve the deep soil areas specified in Table 1, an equivalent canopy cover should be achieved by providing either canopy trees or climbers (over a pergola) with planter pits sized appropriately for the mature tree soil volume requirements, or vegetated planters, green roofs or green facades' (p.18).

The Growing Green Guide for Melbourne project was funded by the Department of Sustainability and Environment under the Victorian Local Sustainability Accord. The Growing Green Guide (2014) is product of a collaborative partnership between four Inner Melbourne Action Plan councils - City of Melbourne, City of Port Phillip, City of Stonnington, City of Yarra - and The University of Melbourne. The document was produced for local and state government and industry to help increase the uptake of green roofs and walls throughout the state. It was developed for the design, construction and maintenance of green roofs and walls in Melbourne and Victoria more broadly. The project also explored policy options to support green roof,

Figure 5. Principles to support policy options green roofs, walls and facades



(source: Growing Green Guide Green Roofs, Walls & Facades Policy Options Background Paper, 2013)

Figure 6. Victorian Government green roofs and wall policy and reports

wall and façade development across Victoria, as mentioned above. The Growing Green Guide Green Roofs, Walls & Facades Policy Options Background Paper (2013) advocates the four "E"s of exemplify, enable, encourage and engage as principles to support policy for green roofs, walls and facades (see figure 5).

In terms of government funded research, the Victorian government funded the Victorian Centre for Climate Change Adaptation Research (VCCCAR) from 2009 – 2014. Funding was provided for research projects including green infrastructure and urban heat island mitigation.

At the local government level, the inner city councils in Melbourne lead the way in promoting green roofs and walls, as evidenced by the Growing Green Guide project.

Queensland

There are no mandatory requirements for green roofs or walls on buildings in Queensland. In Queensland, the Department of Infrastructure, Local Government and Planning is responsible for planning policy making. There is no policy for green walls and green walls for the state, or reference to green walls or green roofs in state planning policy.

Western Australia

There are no mandatory requirements for green roofs or walls on buildings in Western Australia. There is no policy for green walls and green walls for the state, however the draft Apartment Design: Volume Two of State Planning Policy No. 7.3 Residential Design Codes: Guidance for multiple-dwelling and mixed-use developments (Western Australian Department of Planning, 2016) contains a number of references to green roofs and green walls and facades. These include:

- Section 4.13 Roof Design. Objective 4.13.3 'Roof design incorporates sustainability features' encourages the design of roofs which feature green roofs for improved sustainability outcomes. (p.118)
- Section 4.14 Landscape Design. Objective 4.14.1 'Landscape design is viable and sustainable' also encourages the use of green roofs or green walls/facades and other vertical greening strategies. (p.120)
- Section 4.15 Planting on structures. Objective 4.15.3 'Planting on structures contributes to the quality and amenity of communal and public open spaces' encourages green roofs and walls for the social and aesthetic benefits that they provide. (p.122)

South Australia

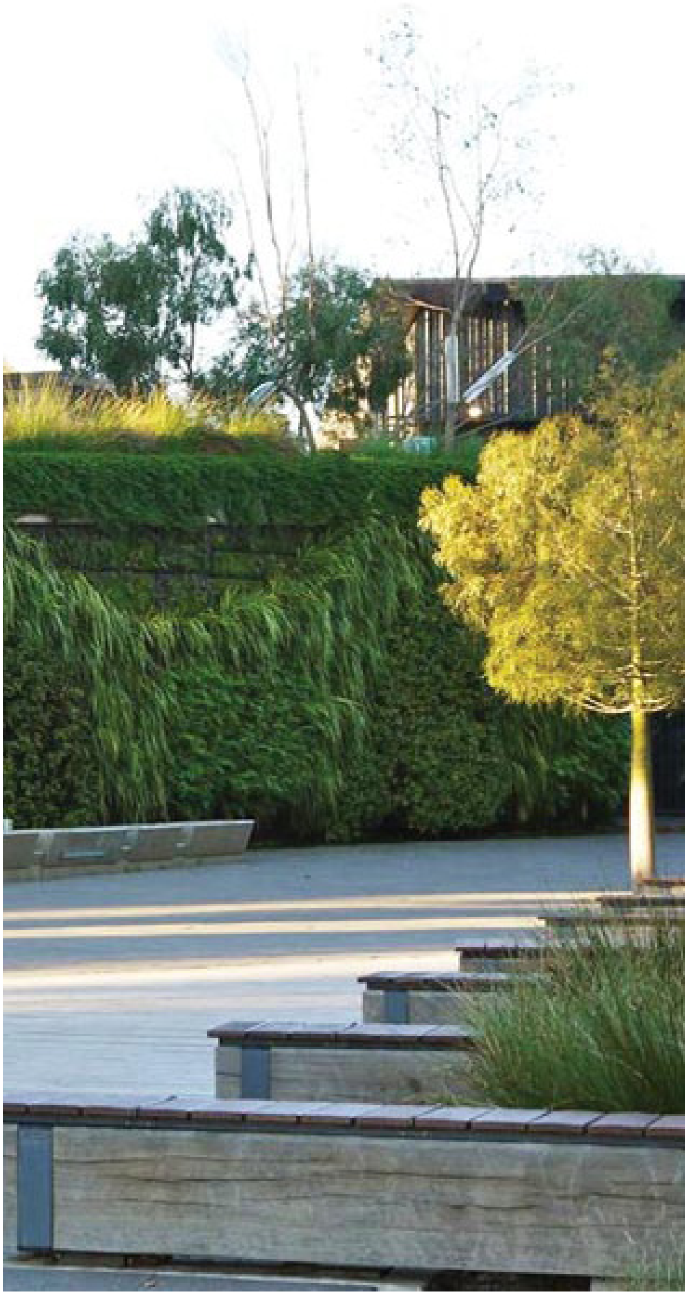
There are no mandatory requirements for green roofs or walls on buildings in South Australia. In South Australia, proposed green walls and roofs need to meet the requirements of the Development Act 1993; the Environment Protection Act 1993; the Natural Resources Management Act 2004; the Local Government Act 1999; and the Public and Environmental Health Act 1987.

The South Australian Department of Planning and Local Government provides free professional design services for state government buildings wishing to incorporate green roofs and walls. The Bushtops for Green Roofs and Walls incentives program allows access to concept design and development services via Planning SA's Principal Urban Designer's expertise in green roof and living wall design Hopkins, 2008).

The South Australian government also established the sustainability Building Innovation Fund (BIF) to fund demonstration projects featuring innovative, new, cutting-edge ways to reduce the carbon footprint of existing commercial buildings. The fund provided $2 million worth of grants between 2008 and 2012. The grants were offered to owners of office buildings and some hotels and shopping centres. The fund supported the commercial property sector agreement between the South Australian Government and the Property Council of Australia (South Australian Division) made under South Australia's climate change legislation. These incentives programs supported and enabled the creation of new roofs gardens throughout the state. For example, the BIF provided financial assistance for the green roof on the GP Plus Health

Care Centre in Marion.

The Technical Manual for water-sensitive urban design in Greater Adelaide (Department of Planning and Local Government, 2010) helps councils and planners apply WSUD to developments and buildings in Greater Adelaide. The Manual discusses green roofs in the context of stormwater management for their potential to reduce runoff volume and improve runoff quality. However, the document Water sensitive urban design: Creating more liveable and water sensitive cities in South Australia (Department of Environment, Water and Natural Resources, 2013) makes no reference to green roofs or green walls.



Green wall at Adelaide Zoo (source: Fytogreen, 2016)

6. Mandatory or voluntary approaches to green roofs and green walls

In Australia, constructing green roofs and green walls is voluntary. There are no policies or legislation requiring green roofs or walls. International case studies reveal a mix of mandatory and voluntary approaches to the implementation of living architecture in cities across Europe, Asia and North America. This section reviews a number of types of mandatory or voluntary policy approaches which have been used globally. There are four different types of policy instruments:

1. Information and advocacy
2. Incentives
3. Government demonstration and provision
4. Regulation (Maddison and Denniss, 2009)

For each of these different types of policy instruments, there are a range of mechanisms which can be implemented. They are summarised below in table 6. Mandatory approaches fall into the regulation category, while voluntary approaches can be information and advocacy, incentives, or government demonstration and provision.

Mandatory

Europe leads the way in mandating green roofs, especially in cities throughout Germany where mandatory green roof regulations have been in place locally and nationally for over thirty years (Ansel and Appl, 2009). For example, in Munich, all suitable flat roofs over $100m^2$ are to be installed with a green roof. In Stuttgart, all new developments with flat or pitched roofs (up to 12 degrees) are required to be greened to specific standards (IGRA, n.d.). Since 1993, when the Federal Nature Conservation Act was introduced, the city has required that

Table 6 Green roof policy mechanisms

Policy instrument	Advocacy	Incentive	Government provision	Regulation
Community information, engagement, participation	✓			
Guidelines and toolkits	✓			
Incentives during the planning process for proposals that incorporate green roofs: • Increased floor area ratios • 'Green door' fast tracking of planning approvals • Waiving planning fees • Exempting certain works related to green roofs		✓		
Stormwater fee discount with increased pervious surfaces		✓		
Grants, rebates, financing for installation		✓		
Leadership, including demonstration green roofs			✓	
Integrated government decision-making on urban infrastructure and land use planning			✓	
Integrated government decision-making: ensure existing regulations do not pose a barrier for green roof installations			✓	
Mandatory green roofs/rooftop landscaping on all new buildings (may only apply to specific building types, such as commercial, multi-residential, or to buildings above a certain threshold area)				✓
Planning scheme overlays (identifying specific areas for mandated green roofs on new buildings)				✓
Green building certification (voluntary or mandatory sustainability rating schemes)		✓		✓
Data collection, monitoring, evaluation	✓		✓	
Research	✓		✓	
Awards, recognition programs	✓	✓	✓	

(source: Pianella et al. 2016, p. 800)

all new buildings be 'greened' as compensation for the loss of valuable habitat and green space. The city council provides a 50% reduction in stormwater fees for green roofs as well as direct financial incentives (subsidies) for the cost of installation and materials. In Berlin, the subsidy program 'Courtyard Greening Program', implemented between 1983 and 1996, was designed to encourage greening of courtyards, as well as the roofs and walls associated with them, to improve urban climate, quality of life for residents, and urban appearance. During the period of the program, 54 ha of courtyard and roofs were greened and 32.5 ha of facades were greened. On average, each square meter was subsidized with 19.10 € which included separate amounts for construction and design (Ngan, G. 2004).

Other cities throughout Europe have also mandated green roofs. For example, in Basel, Switzerland, the city's building and construction law was amended in 1992 to include the requirement that all new and renovated flat roofs be greened. The purpose of increasing green roofs in the city was originally initially driven by energy-saving programmes, and subsequently by biodiversity conservation (Kazmierczak, A. and Carter, J. 2010). The City of Basel has also used incentive programs, awards and grants to help promote green roofs. Researchers from the Zurich University of Applied Sciences also played a key role. They worked to influence decision-makers in Basel to amend the building regulations and offer financial incentives to increase green roof coverage. In Linz, Austria, green roofs are required on new buildings, with reimbursement of up to 5% (reduced from 30% in 2005) of the cost of green roof installation as an incentive. In Copenhagen, Denmark, all new roofs with a roof pitch under 30° are to be landscaped, providing there is no structural engineering reason preventing it. Since 2010 green roofs have been mandated in most new local plans.

In North America, Toronto made green roofs compulsory in 2009. It was the first North American city to pass a by-law requiring green roofs on new building developments. New residential, commercial and institutional buildings with a minimum Gross Floor Area (GFA) of 2,000m² are required to install a green roof, or pay a penalty for not doing so. Requirements for green roof coverage increase with building

Green wall, The Commons, Melbourne (source: Wuttke, A. n.d.)

footprint sizes and can only be reduced with financial penalty and permission from the chief planner. Since April 2012, green roofs are required on all new industrial buildings (City of Toronto, 2017).

In Asia, skyrise greening is compulsory on all government buildings in Singapore. In Tokyo, Japan, the impact of the urban heat island effect led to the government establishing an informal incentive program that provided a free consulting service. This was followed by a subsidy program which resulted in 7000m² of rooftop greening (Urbis, 2007). Tokyo then accelerated the process by mandating that all new private buildings larger than 1000m² and public buildings larger than 250m² must green 20% of the rooftop or pay an annual penalty of US$2000. In the first year (2000 to 2001) this law had a dramatic effect when it doubled the net area of green roofs in the city from 52,400m² to 104,400m² (Urbis, 2007). The Green Tokyo Plan (2000) set the goal of 1,200 ha (12,000,000m²) of rooftop greenery by 2015. The government has also constructed a series of demonstration projects on public buildings to encourage uptake (IGRA n.d.).

Voluntary

There are a host of cities across the world which have voluntary approaches to green roof policy. They often implement incentives such as grants, subsidies, free consultation services, tax reductions to promote the construction of green roofs and walls.

In the United States, the cities of Portland and Chicago have employed a range of voluntary policy mechanisms to encourage the uptake of green roof and walls. Between 2008 and 2012, Portland put in place the Eco-roof floor area ratio (FAR) bonus which allowed developers an extra 3 square foot per foot of green roof without additional permits (City of Portland, 2017). The city also offer grants for reducing storm water runoff by installing a green roof, and all city owned buildings are required to have 70% roof coverage with an eco-roof. In Chicago, the city provides financial assistance for buildings meeting specific green roof and efficiency criteria, and has established a green permit program for fast tracking planning permits (City of Chicago, 2017). The City of Chicago grants a density bonus option to developers whose buildings have a minimum vegetative coverage on the roof of 50% or 186 m² (whichever is greater), usually in the form of a green roof, as well as a storm-water retention credit for green roofs. The City also created a demonstration project in 2001 when it established a green roof on its city hall (American Society of Landscape Architects, 2002).

In Europe, the City of Rotterdam has used its strategic planning document 'Making sustainability a way of life for Rotterdam: Rotterdam Programme on Sustainability and Climate Change 2015-2018' to set the goal for living architecture. It has implemented a series of policy mechanisms including grants, a subsidy scheme, tax benefits, campaign periods, demonstration projects, information days and personal advice. In Italy, the city of Faenza has established a bio-neighbourhood incentive program for developers as part of its planning regulations. As part of the program, if developers create buildings with green roofs, walls and water retention systems, in addition to contributing to public green spaces, then they are allowed to extend the external surface area of their buildings in excess of approved standards (City of Melbourne, n.d.).

In Asia, Singapore leads the region with its implementation of living architecture. There are a wide range of voluntary policy mechanisms in place including grants, awards programs, certification schemes and GFA density bonuses. Section 5 and the Case Studies details this further. In Hong Kong, the government has a well established program of roof and vertical greening for government buildings. The Government has been incorporating roof greening designs where practicable into appropriate new government building projects since 2001. This includes schools, crematoria, hospitals, offices and community centres. Since 2006, the government has also been retrofitting government buildings with roof greening, and since 2008, vertical greening has been adopted in some government capital works projects including schools and government buildings (GovHK, 2016).

7. The business case

This section of the literature review explores the business case for expanding the living architecture industry in Australia by first identifying key ways that living architecture has been found to produce value, and second by presenting some findings from relevant attempts to evaluate the cost benefit analysis (CBA) of living architecture. Our analysis suggests that there are substantial opportunities for market growth in the living architecture industry.

Key ways in which living architecture delivers value

There are many economic, social and environmental benefits, which result from the installation of green roofs and walls. These benefits are either tangible which can be quantified or non-tangible, and not possible to quantify.

The accelerating rate of investment into Green Infrastructure is indicative of the value created for the diverse range of stakeholders who benefit. A key challenge to more widespread adoption of green walls and roofs is the clarity of the business case for specific investments, which are open to wide variety of design choices which affect the cost and benefits. Table 7 below provides a summary of key sources of value created from green architecture identified in the literature.

Notably, economic benefits can be divided into two categories;

1. **Those that benefit owners / occupants / investors directly** such as installation, replacement and repair, stormwater, include increases in property values, and energy savings leading to reduced operating costs for running less air conditioning in warmer months and less heating costs (through less heat loss through the external

Table 7 Summary of key drivers of value from green architecture

Value drivers	Main category of value delivered		
	Economic	Environment	Social / community
Supply of products and services			
Sale of fruit and vegetables	●		
Sale of flowers and other non-edible products	●		
Other value added products and services, such as provision of education services	●		
Direct cost savings			
Thermal energy saving leading to reduced demand for heating and cooling	●	●	●
Roof longevity in some cases	●	●	
Air quality			
CO2 sequestration and absorption			●
Removal of VOC (indoor and outdoor)		●	●
Quality of life			
Mental Health benefits such as reduced anxiety			●
Productivity benefits from increased amenity	●		

Value drivers	Main category of value delivered		
	Economic	Environment	Social / community
Stormwater management			
Absorption and storage of rain water leading to reduced demand from water supply	●	●	
Absorption and storage of rain water leading to reduced demand for stormwater services to manage urban water	●	●	
Reduction in urban water pollution such as through remediation of water quality	●	●	
Biodiversity			
Increased habitat		●	
Increased diversity in flora and fauna		●	
Urban Heat Island effect			
Reduce energy demand for cooling	●	●	
Acoustics			
Reduction of noise transfer			●
Tourism			
Increased direct and indirect employment and other economic activity	●		●
Real estate value			
Increase in property value	●		
Increase in surrounding property value	●		
Increased rent returns and reduced vacancy rates	●		
Increase in urban aesthetic			●
Other economic value			
New jobs for building infrastructure	●		
New jobs maintenance	●		

(source: authors)

walls and roofs);

2. **Other financial impacts** such as greenhouse gas savings, market based savings and community benefits.

A difficulty in quantifying the value from living architecture is that there are a variety of approaches to evaluate the net value. The most common approaches include cost-benefit analysis (Eckstein 1958; Prest and Turvey 1965, Pearce 1998), triple bottom line (Elkington 1997) and various combinations of life cycle assessment (LCA) and life cycle costing (LCC). As argued by Brown et al (2016), while these models enable analysis of the costs and benefits, they all are incomplete on some dimension, and hence have been criticised for not being sufficient in allowing for reliable evaluation of trade-offs between economic and environmental performance (Pearce 1976; Rambaud and Richard 2015; Brown 2016). For example, the economist David Pearce (1976) argued that conventional financial cost benefit analysis was not a sufficient basis for analysis of investments, largely because environmental costs and benefits are not included in the modelling. In the case of green architecture, this challenge is particularly salient as there are substantial direct costs incurred by property owners and investors (Downton 2013; City of Sydney 2017; GSA 2011), whereas the value created is shared by a range of different stakeholders including building tenants, the local community including the local economy. Perhaps in recognition of the shared value, a range of subsidies have been implemented to compensate investors. While more recent attempts to evaluate the business case for green architecture have included attempts to identify and quantify the value created with respect to economic, environment, and community / social value (e.g. GSA 2011), a more compressive approach which includes a more comprehensive set of value drivers is necessary.

Quantifying the value from living architecture

In this section we present the findings from some notable studies which provide an indication of the magnitude of the value created in some of the domains listed in table 7. A study in Toronto, Canada, modelled the effect of green roofs on the urban heat island. It concluded they would reduce local

Beare Park Amenities building, Elizabeth Bay (source: Fytogreen, n.d.)

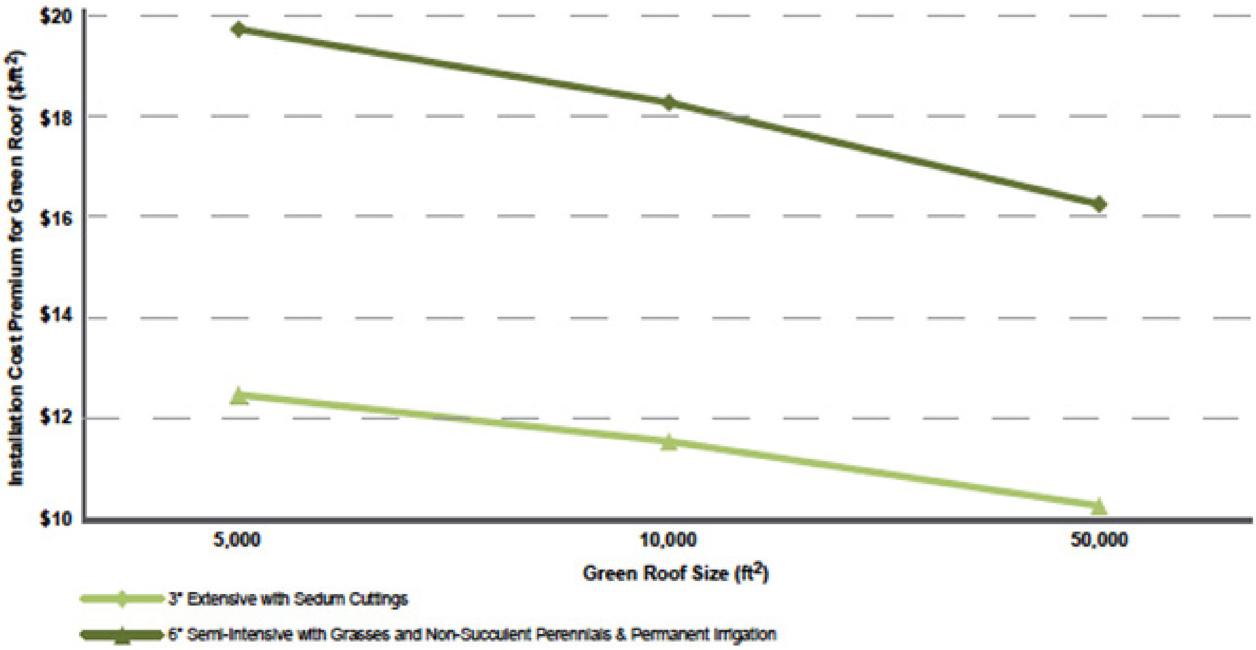
ambient temperature by 0.5°C to 2°C. The study calculated that this would result in C$12m of savings from reduced energy demand for cooling (Banting et al. 2005).

Canadian research has also estimated that buildings with a recreational green roof increase the property value by 11%, and that buildings with views of green roofs have a 4.5% increase in property value (Tomalty and Komorowski 2010). Peck et al (1999) estimated green walls increased Canadian property values between 6 and 15% with a midpoint of 10.5%. Des Rosiers et al (2002) estimated a more modest 3.9% increase in residential property in Quebec with green walls. To date, no research has examined economic impact of green walls or green roofs on Australian property values.

Perini et al (2011) examined vertical greening systems and the effect on airflow and temperature on the building envelope in a Mediterranean climate and Mazzali et al (2012) conducted studies into the thermo-physical performances of living walls via field measurements and numerical analysis. Their studies estimated savings of 40-60% on demand for air-conditioning. Three out of four Australians had a refrigerated cooler by 2014, and in 2009 in Victoria the average use was 107 hours of air conditioner use in warmer months, with older and unwell people have much higher rates of use, some 10 to 15 times higher (Summers and Simmons 2009). Economic modelling estimated that average costs for people running air conditioners were between $49 and $66 (based on $0.15 and $0.20 per kWh respectively). Costs can be up to 64% higher in the hotter areas such as Queensland and 61% lower in cooler areas such as ACT. For 2007, the estimated average cost of cooling for all Australian households was $49–66, which is now approximately $62-84 adjusted for inflation (ABS 2017; Summers and Simmons 2009). Another estimate by Sustainability Victoria in 2017 stated typical monthly costs for air conditioning in the State are $32 per month at the most expensive and at least $2.25 per month (CanStar Blue 2017). Therefore applying 50% savings of $16 to the highest costs are possible with green wall retrofit, so for Melbourne's 4.82 million population based on 75% usage total monthly savings of $57.84M are possible. For the least cost rate 50% savings of $1.12 to the least costs are possible with green wall retrofit, so for Melbourne's 4.82 million population based on 75% usage total monthly savings of $4.04M are possible. Similar savings are possible in Sydney.

To the authors knowledge, the most comprehensive a cost-benefit analysis to determine costs and benefits of green roofs compared to traditional, or black, roofs is a US study in 2013 (GSA 2011). Unsurprisingly, they find costs vary based on roof

Figure 7 Green roof costs



(Source: GSA 2011)

type (intensive or extensive) and size of roof, diminishing on a cost per foot as size increases (see figure 7).

The costs and numbers of maintenance visits are shown in table 8.

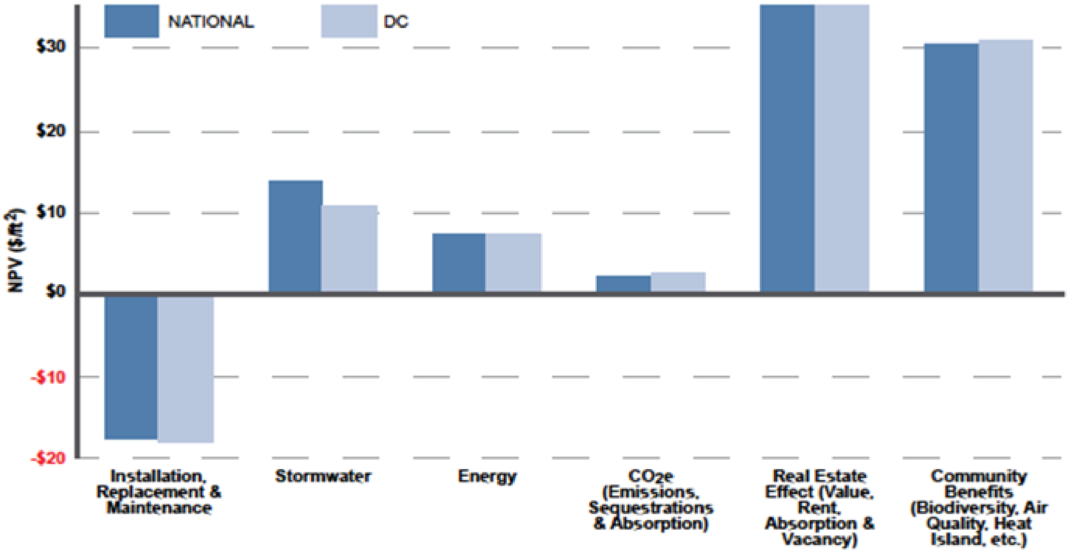
Table 8 Costs of installation and maintenance for intensive and extensive green roofs for CBA (source: GSA 2011).

Extensive roof
Installation costs /m² Annual maintenance 0.21 - 0.31 cents/sq ft. Year 1 set up = 3 visits crew of 2 Labour = 4hrs pp / sq ft or, 1.3 hours hrs/pp /1000 sq ft / visit 2 visits per year thereafter
Intensive roof
Installation costs /m² Annual maintenance 0.21 - 0.31 cents/sq ft. Year 1 set up = 4 visits crew of 2 Labour = 6hrs pp / sq ft or, 1.5 hours hrs/pp /1000 sq ft / visit 3 visits per year thereafter

(source: GSA 2011)

Figure 8, Tables 9 and 10 presents a summary of their estimate of net present value (NPV), which is a measure of the potential profitability of an investment. NPV takes the expected value of the future costs and benefits associated with an investment and accounts for the effect of inflation. A positive NPV means the investment will produce greater returns over the timeframe being considered than an alternate investment. Over a 50-year period, the installation, replacement and maintenance of a green roof has the greatest negative impact on net present value at a cost of approximately US$18 per square foot of roof. Stormwater and energy savings make up for this cost by providing a benefit of approximately US$19 per square foot of roof. Benefits to the community have the greatest positive impact on net present value at a savings of almost US$38 per square foot of roof.

Figure 8. NPV CBA results of green roofs versus traditional black roof in US.



(Source: GSA 2011).

Table 9 NPV CBA results of green roofs versus traditional black roof in US.

NATIONAL LEVEL RESULTS	ROOF SIZE (ft²)		
	5,000	10,000	50,000
Impact on Owners/Occupants/Investors			
Initial Premium, $/ft² of roof (extra cost of installing a green roof instead of a black roof)	-$12.6	-$11.4	-$9.7
NPV of Installation, Replacement, & Maintenance, $/ft² of roof	-$18.2	-$17.7	-$17.0
NPV of Stormwater, $/ft² of roof (savings from reduced infrastructure improvements and/or stormwater fees)	$14.1	$13.6	$13.2
NPV of Energy, $/ft² of roof (energy savings from cooling and heating)	$6.6	$6.8	$8.2
Net Present Value (installation, replacement & maintenance + stormwater + energy NPV)	$2.5	$2.7	$4.5
Internal Rate of Return (IRR)	*5.0%*	*5.2%*	*5.9%*
Payback, years	*6.4*	*6.2*	*5.6*
Return on Investment (ROI)	*220%*	*224%*	*247%*
Other Financial Impacts (less realizable)			
NPV of CO_2e, $/ft² of roof (emissions, sequestration & absorption)	$2.1	$2.1	$2.1
NPV of Real Estate Effect, $/ft² of roof (value, rent, absorption & vacancy)	$120.1	$111.3	$99.1
NPV of Community Benefits, $/ft² of roof (biodiversity, air quality, heat island, etc.)	$30.4	$30.4	$30.4

(Source: GSA 2011).

Table 10 NPV CBA results of green roofs versus traditional black roof in Washington DC

WASHINGTON DC RESULTS	ROOF SIZE (ft²)		
	5,000	10,000	50,000
Impact on Owners/Occupants/Investors			
Initial Premium, $/ft² of roof (extra cost of installing a green roof instead of a black roof)	-$10.7	-$9.5	-$8.0
NPV of Installation, Replacement, & Maintenance, $/ft² of roof	-$18.1	-$17.9	-$17.7
NPV of Stormwater, $/ft² of roof (savings from reduced infrastructure improvements and/or stormwater fees)	$11.0	$10.5	$10.2
NPV of Energy, $/ft² of roof (energy savings from cooling and heating)	$6.8	$6.8	$8.3
Net Present Value (installation, replacement & maintenance + stormwater + energy NPV)	-$0.2	-$0.6	$0.7
Internal Rate of Return (IRR)	*4.3%*	*4.2%*	*4.7%*
Payback, years	*6.6*	*6.5*	*6.0*
Return on Investment (ROI)	*198%*	*194%*	*209%*
Other Financial Impacts (less realizable)			
NPV of CO_2e, $/ft² of roof (emissions, sequestration & absorption)	$2.6	$2.6	$2.6
NPV of Real Estate Effect, $/ft² of roof (value, rent, absorption & vacancy)	$98.4	$88.2	$74.1
NPV of Community Benefits, $/ft² of roof (biodiversity, air quality, heat island, etc.)	$30.9	$30.9	$30.9

(Source: GSA 2011).

The Internal Rate of Return (IRR), a measure of the expected annual financial benefit yielded by an investment over a given time frame (e.g., an IRR of 5% implies a stream of cash growing, on average, at 5% per year) is also calculated. This benefit can be compared with the expected yields of other investments over the same period. Payback is the number of years it takes to recoup an initial investment through the income from that investment. Finally the Return on Investment (ROI) is calculated; this is the percentage of money gained, or lost, on an investment, relative to the initial cost. In regards to the ROI, on a national level, a dollar invested in a green roof today suggests a return of $1.29 in today's dollars after 50 years. For Washington DC, the same dollar invested would yield one dollar in return (in today's dollars); in other words, the green roof investment is the same as an average, alternative investment of 4.4%. If CO2e and community benefits were added in, that same dollar invested would result in US$3.19 and US$3.57, respectively. A sensitivity analysis was conducted to identify the more important variables based on their ability to impact the total NPV (presented in table 11).

Table 11 Sensitivity of the influence of changes in key variables on NPV

HARD COST VARIABLES	CHANGE IN TOTAL NPV PER 1% CHANGE IN VARIABLE
Roof Longevity (1-year change)	13.24%
Installation Costs	11.32%
Discount Rate	4.89%
Maintenance Costs	3.38%
Energy Savings	2.51%
Stormwater Equipment Cost	1.44%
Stormwater Surcharge	1.35%
Green Roof Risk Contingency	1.21%

(Source: GSA 2011).

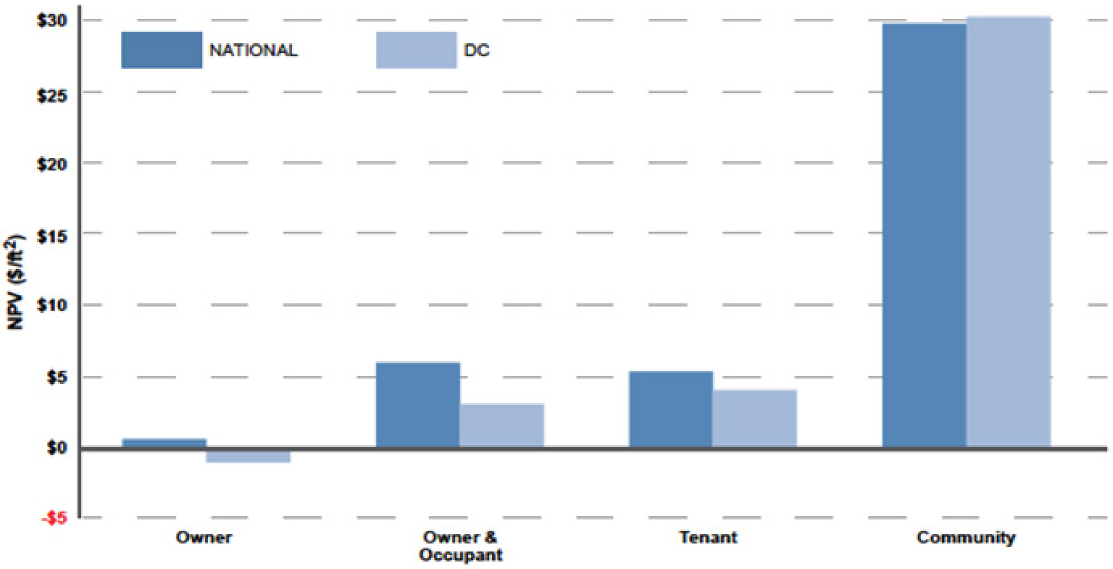
The results in Table 12 and Figure 9 indicate NPV per square foot of roof based on relationship to real estate.

Table 12 NPV of a green roof based on relationship to real estate

	OWNER	OWNER/ OCCUPANT	TENANT	COMMUNITY	MARKET EXPECTATION (YEAR 1)
NATIONAL	$0.06	$6.0	$5.4	$29.8	$12.9
WASHINGTON DC	-$1.0	$3.1	$4.1	$30.3	$10.0
TOP 2 DRIVERS	Maintenance Costs & Avoided Stormwater Infrastructure	Maintenance Costs & Avoided Stormwater Infrastructure	Maintenance Costs & Energy Savings	Biodiversity & Urban Heat Island	Longer leases & Rent

(Source: GSA 2011).

Figure 9 NPV of a green roof based on relationship to real estate



(Source: GSA 2011).

The additional cost of green roof installation is mostly made up for by its increased lifespan or longevity; however, added maintenance costs are significant (GSA 2011). Over a 50- year period, the stormwater, energy, carbon dioxide equivalent (CO2e), which measures the potential global warming effect of a greenhouse gas) and community earnings of green roofs more than compensate for the increased premium of installation and maintenance.

Building and site characteristics, stormwater regulations and energy costs vary considerably, long-term savings of green roofs compensate for maintenance costs. The fewer floors a building has, the greater the energy savings will be as the roof to floor area ratio is greater. Also the greater the surface area of a green roof as a proportion of overall site surface area, the greater the stormwater management savings will be. These savings are predicted to increase as stormwater regulations become more stringent over time and green roofs are increasingly viewed as an acceptable stormwater mitigation measure (Wilkinson & Dixon, 2016). As energy prices increase, the energy-related savings will increase also.

Additional analysis suggests the costs and benefits vary significantly depending on stakeholder perspective. Owner/operators might yield strong financial benefits from replacing non-green roofs of their assets with green roofs. GSA estimated (2013) in the National Capital Region of the US, if green roofs were to replace conventional roofs on all 54 million square feet of real estate (approximately 5.9 million square feet of roof area), their CBA projects a 50- year NPV of US$22.7 million, or US$0.42 per square foot of building area. The community benefits in the National Capital Region could total almost US$180 million, or US$3.30 per square foot of building area. To date this calculation has not been undertaken for Melbourne or Sydney.

Consideration should be given to competing initiatives. The GSA CBA did not consider whether existing buildings needed a new roof (GSA 2011). The decision to install a green roof should consider the impact of work on user, occupants and tenants. The GSA analysis supported the general CBA finding that green roofs offer great potential savings and benefits. The specific real estate effect of green roofs, or their impact on real estate economics from a market and financial perspective, yields varying benefits that can affect a building's net operating income and market valuation (GSA 2011. Peck et al, 2009). A onetime valuation of this real estate effect is similar to the NPV of the actual benefits, whereas according to GSA (2013), the NPV of these ongoing savings and a greater building value are hard to realise. Furthermore the aspects considered in the community portion of the CBA are a part only of the actual impact of a green roof. If real estate value and the productivity of adjoining properties were included, the benefits would potentially far outweigh the costs (GSA 2011). Similarly, the value and productivity of the building itself could add to the already positive NPV. Finally they asset that market acceptance of green roofs and the value of the work occurring in the space are two areas that need to be better understood before they can be accounted for (GSA 2011).

AECOM (2017) provide a good example of the application of a more integrated assessment of the value generated from living architecture is the report Green Infrastructure: A vital step to Brilliant Australian cities. In their report they present analysis that the doubling the tree canopy at the Green Square development project in Sydney would result in a 'noticeable improvement in property value, health and wellbeing, suitability for walking, amenity, calming of traffic and other factors (p. 22). They highlight the relation between the number of trees and size of canopy, which drive both cost and benefits. We adapt their analyst in Figure 10 below.

In this section we reviewed the key ways in which living architecture drives value and presented a number of notable studies which attempt to quantify the value. In our final report from this project, we will present an integrated assessment for Sydney, which may be adapted for to other locations. The focus will be on devising a number of plausible trajectories for the development of a living architecture industry.

8. Conclusions and further study

In this section of the literature review, the conclusions for each section are presented and recommendations for areas of further research are identified.

There are a numerous drivers for the establishment of a living architecture (green roofs, walls and facades) in cities. As urban populations increase and cities become bigger, there is an increase in greenhouse gas emissions, air pollution, impervious surfaces urban temperatures and a loss of tree canopy cover and land for food production. Living architecture can help mitigate these issues. Green roofs, walls and facades have multiple social, economic, ecological, environmental, and public health benefits.

Barriers to the establishment of a living architecture include social, economic, technological and environmental barriers. Costs are a significant barrier, as well as a lack of experience in the industry, especially in terms of construction and management of green roofs, walls and facades. The capacity of the construction industry for green roofs is in a developing phase and not fully ready to roll out the green roof installation on a wider scale in buildings, precincts, and city scales. Further training and skill development is required to increase uptake. While there is significant potential to retrofit existing buildings, the feasibility of this is determined by the ability of the buildings to sustain the associated structural loads. There is also a lack of appropriate policy and regulations to integrate living architecture practices at the design phase of new buildings and also to retrofit existing buildings.

Resilience and resilient cities is a concept that will increase in importance in the coming decades. Action at the building level is vital and ultimately filters up to city, regional and national scales. For example retrofit of all structurally adequate roofs and walls in Sydney and Melbourne would lead to mitigation of the urban heat island, which will increasingly impact health and livability of our major cities. Similarly improvement in storm-water attenuation and decreases the impacts of flash flooding will occur as a result of mass green roof and wall retrofit. Resilience issues relating to Sydney Melbourne, Toronto, Singapore, London and Rotterdam are similar and can be mitigated through specification of living architecture such as green walls and roofs. Two resilience issues of heatwave and rainfall flooding can be alleviated through living architecture; questions arise as; to what extent is green roof and wall retrofit required to make a difference? Rainfall flooding is an issue also for Rotterdam, Singapore and Toronto, whilst heatwave affects Rotterdam and Singapore.

Our review of international policy across Singapore, London, Stockholm, Toronto and Rotterdam demonstrated a variety of approaches taken by policy makers in each of these cities. There is a mix of mandatory and voluntary policy mechanisms to increase installation of green roofs and walls. These cities have different drivers for the implementation of green roofs and walls, most often related to issues of increasing the resilience and livability of the city. Cities with more developed living architecture industries have a range of policy approaches to encourage and/or mandate green roofs and walls (Pianella et al. 2016). The approaches adopted in these cities are expanded and critiqued in the Case Study report accompanying this report.

There is no consistent policy approach to green roofs and walls across the different states of Australia. None of the states have a policy for green roofs and green walls, however the City of Sydney and City of Melbourne councils have created policies for each of their LGAs. NSW, Victoria, South Australia and Western Australia all have varying numbers of documents (including guidelines and policies) which make reference to green roofs and green walls. Overall there is a lack of policy to promote living architecture in Australia.

Mandatory or voluntary approaches are the key policy mechanisms for increasing the uptake of green roofs and green walls. There are four different types of policy instruments which can be utilised: information and advocacy; incentives; government demonstration and provision, and regulation. Mandatory approaches fall into the regulation category, while voluntary approaches can be information and advocacy, incentives, or government demonstration and provision. International case studies demonstrate a range of approaches, although our research reveals that there are more voluntary approaches in place than mandatory.

Cost Benefit Analysis undertaken in the US indicated a viable case for large-scale retrofit of green roofs. Evidence of increases in residential property value with more green infrastructure exists in Canada of between 6 and 15%, and it is recommended a study is undertaken to model the percentage of uplift in value in various Australian cities and suburbs. On a city scale, modelling in Toronto Canada showed the UHI could be attenuated by 0.5°C to 2°C through green roof retrofit. If green walls and living walls are added to this calculation reductions would be greater. Liveability of both Melbourne and Sydney will be affected by predicted temperature increases and we need to provide this empirical data for those cities.

The figure on the following page summarises diagrammatically the positive and negative impacts of living architecture in the form of green roofs and walls have in new build and retrofit. The diagram illustrates the value returned at individual level and at societal level. It shows the case for adoption of green infrastructure is compelling. The figure also illustrates the costs incurred in implementation of the measures. The questions which remain unanswered in Australia are; how much green infrastructure do we need to retrofit in order to achieve resilience? What is the cost benefit analysis for this? And what does the business case look like? Finally, is this more likely to be delivered through a market lead approach, a mandatory approach, or a hybrid of the two approaches? The final submission will present different scenarios and the modelling to demonstrate the case for mandatory or voluntary approaches and their respective strengths and weaknesses.

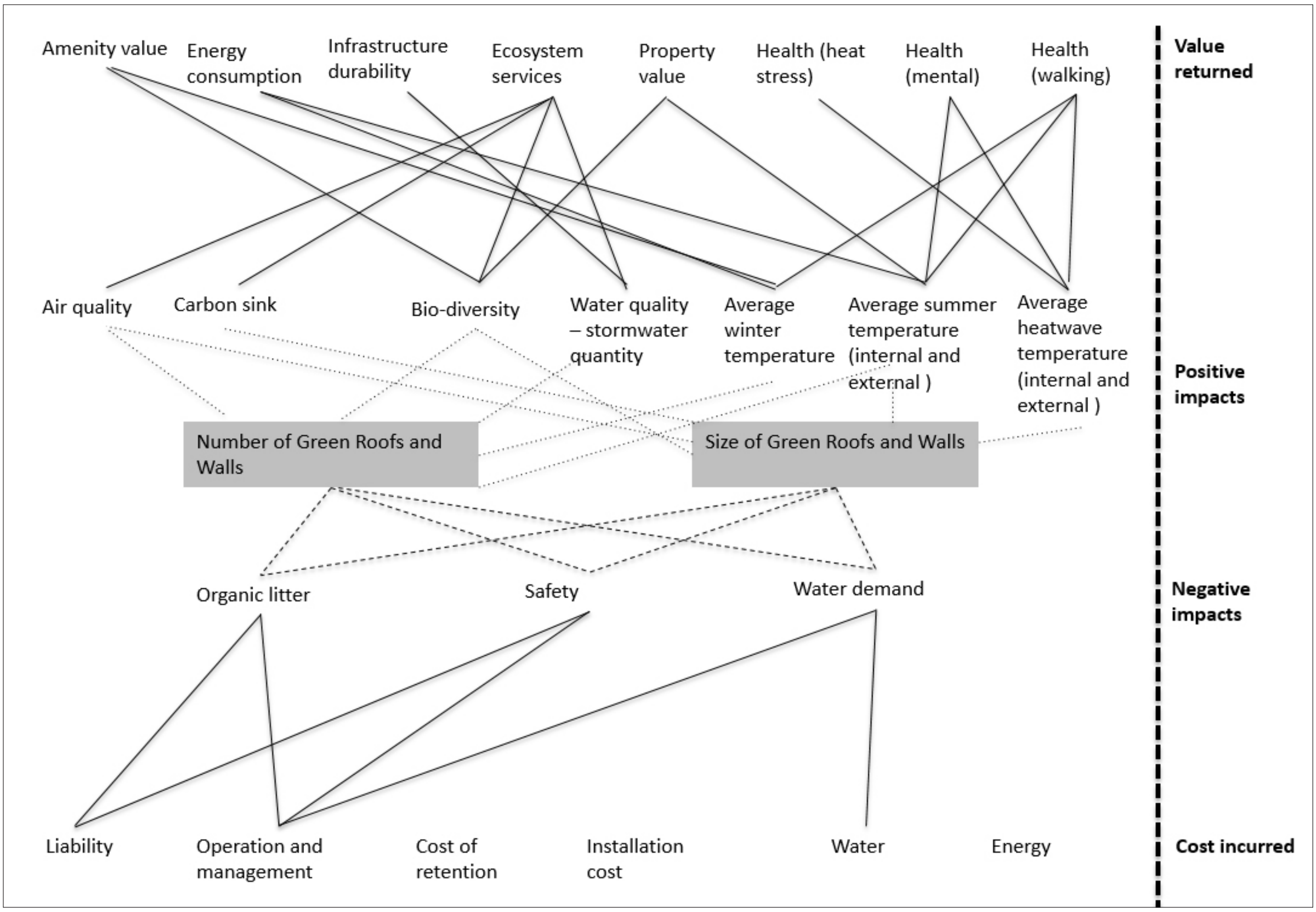
The recommendations for actions to promote the uptake of living architecture include the following actions.

1. Recommend the use of the RICS Best Practice Guidance Note on Green Roofs and Walls.
2. Articulate to clients the primary and co benefits of living architecture when briefing client on new build and retrofit options.
3. Offer traning and education opportunities to stakeholders in respect of new build and retrofit installation and maintenance.
4. Highlight to clients relevant issues relating to resilience, and its growing importance and the application of green infrastructure (green roofs and walls) as a way to alleviate heatwave and rainfall flooding issues and the benefits of future proofing developments.
5. Explore opportunities to adopt and adapt, where necessary, effective measures used internationally.
6. Lobby for a coherent national policy in respect of green roofs and walls in Australia.
7. Establish evidence of value uplift in property with green roofs and green walls - specifically the green roof and green wall contribution.

The recommendations include the following areas of further study are needed.

1. Model the percentage of uplift in residential and commercial property value in Melbourne and Sydney and various suburbs through various scenarios of low, medium and high levels of green roof and wall retrofit.
2. Model the reduction in UHI in Melbourne and Sydney and various suburbs through various scenarios of low, medium and high levels of green roof and wall retrofit.
3. Model the reduction in storm-water attenuation in Melbourne and Sydney and various suburbs through various scenarios of low, medium and high levels of green roof and wall retrofit.
4. Model the business case and CBA for adoption of green roofs and green walls based on a voluntary approach, a mandatory approach and a hybrid approach based on appropriate and transferable measures adopted internationally. Each approach to be modelled on weak and strong levels.

Figure 10 Relationship between costs and benefits of green roofs and walls



(source: authors)

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Musee du quai Branley, Paris (source: Ian, 2010)

Appendix 6 – Milestone report 2: Green walls and roofs: A mandatory or voluntary approach for Australia? Case Studies

CASE STUDIES

Green roofs and walls: A mandatory or voluntary approach for Australia?

Green Cities: Expanding the living architecture industry in Australia (GC 15001)

Prepared by University of Technology Sydney
on behalf of Horticulture Innovation Australia

6 June 2017

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Cover image: Skyville @ Dawson, Singapore (N. Pelleri, 2017)

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Green roof, Grounds of Alexandria, Sydney (source: S.Wilkinson, 2016)

EXECUTIVE SUMMARY

Green roofs and walls are essential to deliver liveable, sustainable and resilient cities of the future. As we grow our urban settlements and increase our populations, green infrastructure offers more benefits than ever before. We examined the international planning policy frameworks of five international cities in Asia, Europe and North America and two Australian cities in this report. Our review showed that these cities have implemented a range of approaches to facilitate the installation of green roofs and green walls. The approaches taken varied, depending on a range of factors. They include governance structure, climate, location, proposed climate change impacts and urban density.

The following five international cities were selected for review:
- London, England;
- Rotterdam, The Netherlands;
- Singapore;
- Stockholm, Sweden; and
- Toronto, Canada.

In Australia we reviewed;
- Melbourne, Victoria;
- Sydney, New South Wales.

These cities were chosen for the range of approaches to green roof and green wall policy adopted by each. The international cities have well established green roof and green wall policies and can be considered best practice examples. They also reflect cities with a mix of populations, sizes, densities, coastal and inland locations, governance structures and climates. They demonstrate innovative and diverse approaches, which have encouraged the uptake of living architecture.

As part of this project, we visited each of the selected cities throughout 2016 and 2017. Site visits and interviews with key stakeholders were conducted to provide an in-depth investigation of the policy approaches in each city. Interviews were conducted with government, university and industry representatives. We visited buildings with green roofs and green walls to review innovative precedents.
Each case study briefly describes the city, overviews the planning policy context and describes the mandatory and/or voluntary requirements for green roofs and green walls in each location. A summary of key findings follows with an analysis of how these mandatory or voluntary requirements have been effective for that particular city. Tables summarise key information such as approaches, incentives and uptake, at a glance, enabling the reader to compare and contrast the cities easily.

City authorities can mandate green roofs and walls or adopt a market led, so called voluntary approach, where the 'market' determines whether to install green roofs or walls. Some voluntary approaches are enhanced through incentive programmes which can be financial in the form of grants, or allowances for building to greater densities, thereby offsetting the costs of green roof and wall installation against higher capital and rental values. In each international city studied, green roof and wall policies are well established and diverse approaches are adopted.

Singapore leads in respect of adoption of green roofs and walls, and also has the greatest variety of voluntary measures. The city has been very proactive and markets itself as a 'garden' city. Singapore saw a great advantage in being literally 'green', to attract investment, visitors and commerce to the city. This approach has resulted in an 805% increase in green roofs and walls in the city and a flourishing economy. Toronto has the second largest recorded area of green roofs in our study, delivered through a mandatory approach, which commenced in 2010. They have increased their total green roof area to 346,000m². Their mandatory program is enhanced with financial incentives of grants for structural assessment and the green roof itself. London has increased its green roof area by 360% over 11 years purely on a voluntary approach and illustrates the capacity of voluntary approaches to deliver very good outcomes.

In contrast, Melbourne and Sydney have not initiated their green roof and wall policies until comparatively recently, in 2015 and 2012 respectively. In 2015 the City of Melbourne had 5 hectares (5000m²) green roofs and rooftop gardens. Of the total area of rooftops, some 880 hectares in the City, the 5 hectare figure represents a tiny 0.5% of the total rooftop space. The number of green walls and facades totalled 50 in 2016 and are located mostly in the central city and Docklands. By March 2014, the City of Sydney had recorded more than 98,000m² of green roofs and walls installed in the local government area however green roofs equate to less than 1% of the total roof space available in the City of Sydney.

Given the increases in green roofs and walls that have resulted internationally, we should be optimistic that similar increases can occur here. How much of an increase can we expect to see in Melbourne and Sydney? The final stage of the research models the rates of increase we can expect to see in Melbourne and Sydney over various time periods, based on contemporary rates of development in both cities and applying different scenarios as seen in Singapore, Toronto, London, Stockholm and Rotterdam.

A green roof on a pitched roof in Newtown, Sydney (source: S.Wilkinson, 2016)

1. INTRODUCTION

This section of our research presents a range of international case studies. We examine the international planning policy frameworks of five international cities in Asia, Europe and North America. Our review reveals that these cities have implemented a range of approaches to facilitate the installation of green roofs and green walls. These approaches vary, depending on a range of factors. They include governance structure, climate, geographical location, proposed climate change impacts and urban density.

The following five cities were selected for review:

- London, England;
- Rotterdam, The Netherlands;
- Singapore;
- Stockholm, Sweden; and
- Toronto, Canada.

These cities were chosen for the range of approaches to green roof and green wall policy adopted by each. They have well established green roof and green wall policies and can be considered best practice examples. They also reflect cities with a mix of populations, sizes, densities, coastal and inland locations, governance structures and climates. They demonstrate innovative and diverse approaches which have encouraged the uptake of living architecture.

As part of this project, we visited each of the selected cities throughout 2016 and 2017. Site visits and interviews with key stakeholders were conducted to provide an in-depth investigation of the policy approaches in each city. Interviews were conducted with government, university and industry representatives. We visited buildings with green roofs and green walls to review innovative precedents.

Each case study begins with a brief description of the city, followed by an overview of planning policy context and a description of the mandatory and/or voluntary requirements for green roofs and green walls in each location. This is followed by a summary of key findings and an analysis of how these mandatory or voluntary requirements have been effective for that particular city. Throughout the document, we present a number of tables to summarise key information such as approaches, incentives and uptake, at a glance. This enables the reader to easily compare and contrast the cities.

The final part of this section is a discussion of the approaches taken by each of these international cities. We will review the similarities and differences between the approaches taken by policy makers in each of these cities and to start to think through what sort of approach might suit the Australian context.

Skryrise greenery in Singapore (source: N.Pelleri, 2017)

2. LONDON, ENGLAND

The City of London

London is the capital city of the United Kingdom (UK), located on the River Thames. Between 2011 and 2015 London's population grew at twice the rate of the UK as a whole, and could reach almost 10 million by 2025. In mid-2011, the population of the city stood at 8.2 million, but over four years it increased by 469,000 to just under 8.7 million. The Metropolitan area has a population of around 13.9 million people. London was founded by the Romans 2000 years ago and the ancient core, the City of London retains its 1.12-square-mile (2.9 km2) medieval boundaries. Greater London is governed by the Mayor of London and the London Assembly. This case study is focused on the City of London.

London is a global city in the arts, commerce, education, entertainment, fashion, finance, healthcare, media, professional services, research and development, tourism, and transportation sectors. It is a financial and cultural centre and its urban area is the second most populous EU city after Paris. Post BREXIT, its' importance as an investment and financial centre may alter, but at the time of writing this is unknown.

London has a temperate oceanic climate, similar to all of southern England. Despite a reputation for being a rain soaked city, London receives less annual rainfall that Rome, Bordeaux, Sydney and New York. Temperatures range from recorded highs of 38.1°C in 2003 to a low of -16.1°C in 1962. Summers are mild and warm, with an average July high of 24°C. Typically London has 31 days above 25°C annually and four days above 30°C. During the European heatwave in 2003 there were 14 consecutive days above 30°C and two consecutive days of 38°C which lead to hundreds of heat related deaths. Temperatures, as well as sea levels are predicted to rise. London is predicted to experience increasing risks of flooding, overheating and drought, hotter drier summers and warmer wetter winters. As a large city, London has a considerable urban heat island effect with the centre being, at times, 5°C warmer than the suburbs and outskirts.

Planning context

London has several tiers of planning policy. The current Local Plan, adopted in January 2015, sets out the vision and planning policies for the City. The Local Plan contains planning policies for the City of London dealing with the location and distribution of land uses in the City. It looks forward to 2036 and provides for any additional employment, housing and other uses that will be required over the extended plan period. The Issues and Options consultation is the first stage of consultation in which the City of London are seeking views on key issues. The Local Plan has a key role to play in maintaining the City of London's status globally. For example, how do stakeholders provide an attractive, built environment that delivers new office floorspace? The ways in which people are working is becoming more flexible. How does this affect the type of office space needed in the future? Furthermore, the City of London needs to provide for the needs of residents and visitors, and needs to consider how much housing should be provided and where.

The ability to efficiently connect with people and places is crucial to the City of London's continued success. With more people working, living in and visiting the City, the City of London needs to consider management, improvement or changes needed to the transport infrastructure, and any pressures that major public transport improvements place on how the City works. Furthermore, the City needs to consider the role IT will play in the city's future and how IT developments support the increase of agile working in the City. Infrastructure needs such as electricity, gas, water and sewerage infrastructure and growth are also taken into account.

Within the City of London, protecting and enhancing the unique character of the City is an important issue for the Local Plan. The characteristics that give the City its distinctive sense of place need balancing with the needs of the future City while preserving and celebrating important heritage. The challenge of climate change also needs to be addressed for example, delivering more and improved open spaces, greener streets and roof gardens. The role, if any, of amenity spaces and viewing galleries in buildings have in providing space for City workers, residents and visitors are an important consideration. With the 2036 City Plan in mind, the overall question is; What should the City look and feel like in 2036?

In respect of national planning policy and guidance, Local Plans are required to be consistent with national planning policy contained in the National Planning Policy Framework (NPPF). The NPPF sets out the broad policy approach to be taken across a range of planning issues and establishes a presumption in favour of sustainable development. Further detail is provided in the Planning Practice Guidance which is regularly updated to ensure guidance remains current. The Mayor of London prepares a spatial development strategy, called the London Plan, and keeps it under review. The City's Local Plan, like those produced by the London boroughs, must be in general conformity with the London Plan. The London Plan forms part of the statutory development plan and there is no need to repeat its policies within the City's Local Plan.

In the City of London Local Plan, the Mayor produces supplementary planning guidance to provide further detail on particular policies in the London Plan. The Mayor's guidance is considered in preparing the new Local Plan, particularly where it relates to policies that specifically affect the City such as guidance on the Central Activities Zone. The Mayor publishes a range of other strategies, including for housing and transport, that may be relevant to aspects of the Local Plan. Local planning authorities are required by legislation to cooperate on the planning issues that cross administrative boundaries. This requires constructive, active and on an ongoing engagement on strategic matters in plan-making, including sustainable development, land use and strategic infrastructure.

The City Corporation works closely and co-operates with neighbouring boroughs, the Mayor of London, Transport for London and other partners on strategic planning issues. These relationships are important and the City Corporation needs to take account of planning policies and proposals in adjoining areas, and further afield (where necessary) that may affect, or be affected by, the policies and proposals in the City's Local Plan. This approach is needed to ensure that the City's economic growth continues to bring significant benefits

APPROACH	
VOLUNTARY	MANDATORY
●	
KEY POLICY	
City of London Local Plan (2015)	
UPTAKE	
2005	2016 (MARCH)
14,750 m^2	53,200m^2

Green wall at the National Gallery in London (source: Scriniary, 2011) for London as a whole, and that cross-boundary connections between the City of London and the neighbouring boroughs are dealt with in a coordinated manner (see figure 1).

The Local Plan takes into account other strategies prepared by the City Corporation or its partners, covering various social, economic and environmental issues. The intention is that the Local Plan can help to facilitate the delivery of such strategies where their objectives involve the use or development of land and may provide a mechanism to co-ordinate and balance the requirements of different strategies. The Local Plan has to be evidence based. The NPPF indicates that evidence gathering should be proportionate, but specifies certain types of evidence that are likely to be needed. The City Corporation has an extensive evidence base and much of the evidence for the Local Plan will come from this existing data or that published by other organisations, including the Mayor in support of the London Plan.

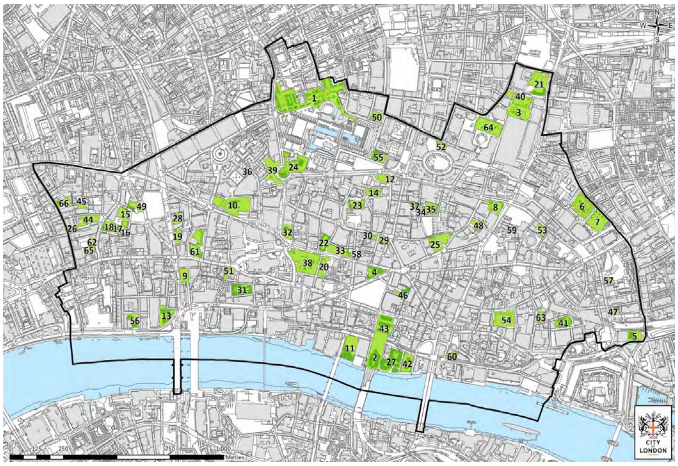
Figure 1. Strategic context - The City of London's location within the Central Activities Zone City Corporation strategies.

(Source: City of London Local Plan, 2016).

Mandatory requirements

In respect of green roofs and green walls, in order to achieve the highest levels of sustainability, it has to be integral to the design process from the beginning. The current Local Plan encourages the installation of green roofs and green walls in appropriate locations. An interactive map is provided to show the location and details of buildings in the City of London with green roofs case studies to educate others and provide a resource (see figure 2). Sustainability requirements such as those for energy and carbon emissions are set out separately from the design policies and it may be desirable to combine them.

Figure 2. Green roof sites in the City of London 2017



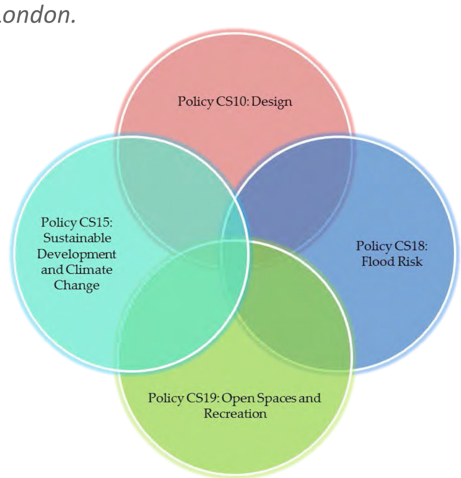
(Source: City of London Local Plan, 2017 file:///Users/113984/Desktop/Green-roof-case-studies-map%20London.pdf).

Planning policies for green roofs, roof gardens and terraces are set out in the City of London Local Plan (adopted 15th January 2015), Core Strategic Policy CS19: Open Space and Recreation: 'To encourage healthy lifestyles for all the City's communities through improved access to open space and facilities, increasing the amount and quality of open spaces and green infrastructure, while enhancing biodiversity, by…
'1(v) encouraging high quality green roofs, roof gardens and terraces, particularly those which are publicly accessible, subject to the impact on the amenity of adjacent occupiers.'

The amenity value of green roofs, roof gardens and terraces are also linked to other Local Plan policies, as set out in figure 3. The multiple benefits of green roofs are acknowledged and cross referenced in the numerous relevant different policy documents. All Local Plan policies related to green roof

provision are as follows:
• CS10 (Design).
    DM 10.2 (Design of green roofs and walls).
    DM 10.3 Roof gardens and terraces).
    DM 10.8 (Access and inclusive design).
• CS15 (Sustainable Development and Climate Change).
    DM 15.1 (Sustainability requirements).
    DM 15.2 (Energy and CO2 emissions assessments).
    DM 15.4 (Offsetting of carbon emissions).
    DM 15.5 (Climate change resilience and adaptation).
    DM 15.6 (Air quality).
• CS18 (Flood Risk).
    DM 18.1 (Development in the City Flood Risk Area).
    DM 18.2 (Sustainable drainage systems (SuDS)).
    DM 18.3 (Flood protection and climate change resilience).
• CS19 (Open Spaces and Recreation).
    DM 19.1 (Additional open space).
    DM 19.2 (Biodiversity and urban greening).
    DM 19.3 (Sport and recreation).

Figure 3. Policy considerations for green roofs in City of London.



(Source: City of London Local Plan Monitoring Report – Green Roofs Local Plan Policy CS19: Open Spaces and Recreation, 2016)

Green wall on the Hotel Athenaeum, London (source: S. Lapinski, n.d.)

Voluntary requirements

The measures outlined above are voluntary. In addition, there are voluntary sustainability rating tools such as BREAAM (Building Research Establishment Environmental Assessment Method) which have scope for gaining points for green roofs. BREEAM is the equivalent of Green Star in Australia and LEED in the USA.

BREEAM is used by four main groups: developers; property agents; design teams and property managers. Developers use it as an internationally recognised approach allowing comparable certification levels between developments, and higher visibility in the market (Fuerst & McAllister 2011). Property agents use it to improve environmental credentials and acknowledge uplift in market value of some developments (Robinson & McAllister & 2015). Design teams use BREEAM to achieve higher levels of building performance. Property or facility managers use it to reduce running costs, monitoring building performance, empowerment of occupiers and improvement of portfolios.

There is no legal requirement to undertake BREEAM, however, it can be a contractual element which forces the design team to achieve a predetermined certification level. These contractual agreements could be a condition of funding, as is the case for all Governmental buildings, or in order to achieve planning permission from the relevant authority.

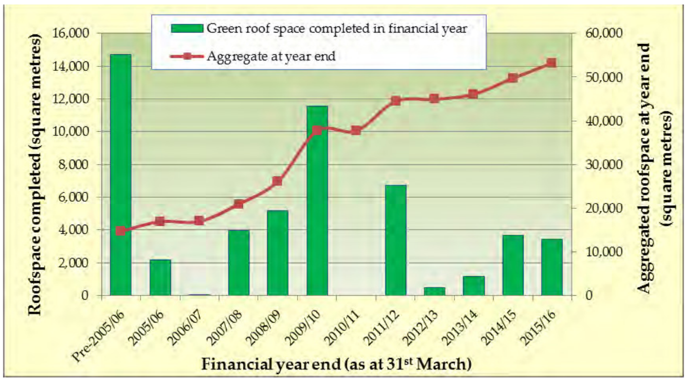
Currently green roofs can gain credits within the BREEAM categories of Health and Wellbeing, Management, Energy, Waste, Pollution and Land Use, and Ecology. It is possible to achieve credit for Design, New Construction, In Use and Retrofit versions of BREEAM. No separate classification exists for green roofs per se.

Research has shown that voluntary sustainability tools tend to appeal to a small section of the commercial market, typically very high quality developments where developers and owners are aware of the premiums in capital value which can be delivered (Newell et al, 2011).

Policy effectiveness

Before April 2005, 14,750m² of green roof space existed in the City, as a result of schemes implemented in the 1990s and early 2000s, although the first green roofs were provided to the Barbican Estate built in the 1970s. A consistent increase in the amount of green roof space occurred between April 2005 and March 2009; followed by a sharp increase from 26,100m² in March 2009 to 37,700m² in March 2010. However no new green roof space was provided in 2010 and 2011. From April 2011 to March 2015, green roof space increased, mostly during 2011/12, 2014/15 and 2015/16. As at 31st March 2016, just under 53,200m² of green roof space was provided in the City of London (see figure 4).

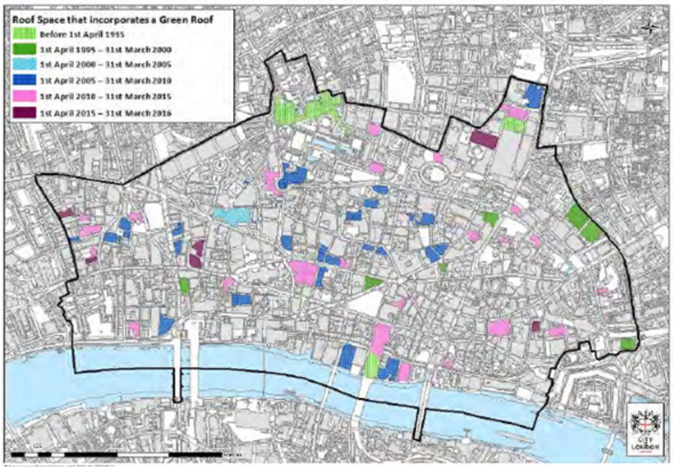
Figure 4. Green Roof Space in the City of London by year



(Source: City of London, 2016).

When the year of completion and the location of the green roofs in the City are considered (see figure 5), it is apparent that in the earlier periods some clustering took place around single or smaller numbers of large projects before 1995 (The Barbican) and Middlesex Street Housing in the east (before 2000). Between 2005 and 2010, provision of green roofs was mainly located in the central and western part of the City. However after 2010 the locations seem more dispersed throughout the City and may reflect a maturation of the market and more widespread acceptance of the technology, as well as growing evidence of additional capital value enhancements attributed to green commercial buildings (Spenser and McAllister, 2015. Fuerst & McAllister, 2011. Newell et al, 2011).

Figure 5. Location of Green Roofs in the City by year.



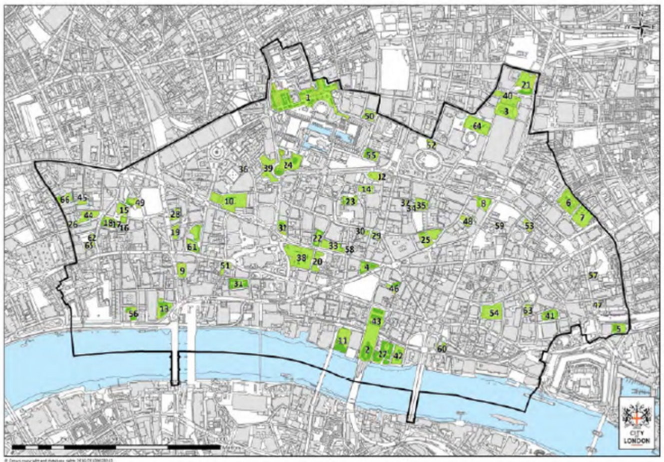
(Source: City of London, 2016).

As of 2016, the split between the provision of extensive and intensive roof types are as described below. 52% extensive roofs built between 2005 and 2016. Intensive roofs account for 39% of the total, and there is a cluster on intensive roofs located nearer to the Thames to possibly take advantage of river views there. Mixed use green roofs account for the remaining 9% of the total and are located sporadically in the City. Before 2005, the vast majority of green roof space was intensive, but since 2007, extensive green roofs have become more popular than intensive green roofs.

Most of the green roof space does not have full public access for amenity and this responds to the mostly commercial building land use in the City and private ownership of the buildings with green roofs. People in offices and residential buildings do benefit from views of green roofs, which Lee (2015) found to enhance performance in her study in Melbourne, Australia. Some sites have access for tenants and occupiers and are intended for recreational / amenity use. Provision of sites for biodiversity, namely birds, bats and bees, is a driver in the City of London and some roofs have no access except for maintenance, to provide habitat and encourage urban biodiversity.

Policy includes aims in respect of flood risk mitigation, reduction of the urban heat island effect and energy and CO^2 emissions. The City has recorded which roofs are designed specifically to address these policy aims and posit benefits have accrued, however they do not have quantitative data in respect of the amounts of reductions in stormwater or temperature attenuation. The total number of green roofs in the City of London is shown in Figure 6.

Figure 6. Total Green Roofs in City of London 2016



(Source: City of London, 2016).

Clearly the City of London has experienced a progressive increase in the total amount of green roof space, across a range of locations across the City. The documentation and reports which are available to the public are useful and informative. The City Planning department is proactive and supportive of owners proposing to adopt green roof technology and this is making a difference to the level of uptake of green roofs

3. ROTTERDAM, THE NETHERLANDS

The City

Rotterdam is a major port city in The Netherlands. It is the country's second-most populous city after Amsterdam, with a population of approximately 630,000 in 2014 (World Population Review, 2017). Rotterdam is part of the larger Randstad conurbation, which has a population of over 7 million. Rotterdam has an area of 325.79 km² (land 208.80 km², water 116.99 km²). It is one of the largest ports in the world, and the largest in Europe. The success of its port and logistics industry is due in part to its location on North Sea, which enables access to the Rhine–Meuse–Scheldt delta. The city is located in a delta where the river Maas flows into the North Sea, and most of the city is located approximately 5 metres below sea level (IGRA, 2015). Given that Rotterdam is home to the largest port in Europe, and the headquarters for corporations including Unilever, Eneco and Roboco, many people come to the city for job opportunities. Rotterdam has a vibrant culture and rich history which make it a popular place to live, and it is also a popular tourist destination. The city is expected to grow at a slow but steady rate. Population growth is mainly a result of foreign people coming to the city for employment opportunities.

Rotterdam has a mild, temperate climate. It rains regularly throughout the year, and the average annual rainfall is 782 mm. Summers are very changeable and very mild. August is the warmest month of the year. The average temperature in August is 16.9°C. A heat wave is declared if there are more than 5 days above 25°C. It rarely snows in winter, although there are usually a few days with temperatures below 0°C. January is the coldest month and has an average temperature of 2.5°C. Temperatures, as well as sea levels, are predicted to rise in and around the city. Given the location of the city in a delta, sea level rise will have especially significant effects on Rotterdam.

Planning context

The Netherlands is a decentralised unitary state with national, provincial and municipal levels of government. Spatial planning law is made by the Dutch national government, and the key piece of planning legislation is the Spatial Planning Act (2008).

The Municipality of Rotterdam is responsible for planning in the city. It has a comprehensive planning system that regulates land use prior to decision-making, and regularly enters into public-private partnerships. Higher level policy guidance comes from the 'Vision for the Randstad' provincial structure document (Mees and Driessen, 2006).

Climate change is a significant threat to the low-lying city. Climate change adaptation plans for Rotterdam have been developed by the government, and they typically focus on water management of the delta city. The city is facing serious urban water challenges, in terms of sea level rise, river discharge, flooding and stormwater management. The government has acknowledged the role that green infrastructure can play to assist with reducing these challenges. In particular, green roofs have been identified for their potential to help alleviate some of these issues by slowing and storing water during peak events such as storms and floods. Green roofs also have other benefits for the city. They enhance Rotterdam's green appeal, save energy by keeping homes cooler in summertime, double the life of the roof and enhance the city's biodiversity (City of Rotterdam, 2016).

Mandatory requirements

The Municipal Council of the City of Rotterdam does not have any mandatory requirements for green roofs or walls in place.

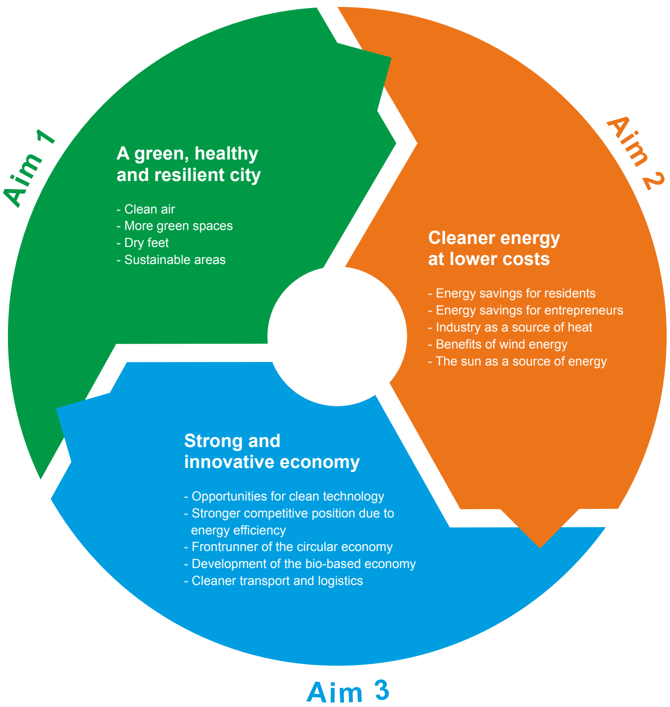
Voluntary requirements

A series of strategic documents have been produced for Rotterdam, to guide sustainable development throughout the city. The 'Rotterdam Urban Vision: Spatial Development Strategy 2030' (Municipality of Rotterdam, 2007) started to address these issues. The document identified two key goals for the city. They were, firstly, an attractive city and, secondly, a strong economy.

The Rotterdam Climate Change Adaptation Strategy (Rotterdam Climate Initiative, 2013) outlined how the city would become a 'climate proof' city by 2025. As part of this plan, a green roof stimulation policy was introduced in

2008. It set a long-term goal to generate 600,000m² of green roofs in the city by 2025. The city's aim was to have at least 160,000m² of green roofs installed in Rotterdam by the end of 2014 (Rotterdam Climate Initiative, 2012). In 2016 this goal was updated when the 'Making sustainability a way of life for Rotterdam: Rotterdam Programme on Sustainability and Climate Change 2015-2018' document was approved by the Municipal Council of the City of Rotterdam on 17 March 2016. It identified three aims for making Rotterdam a sustainable city. They are 'a green, healthy and resilient city', 'cleaner energy at lower costs' and a 'strong and innovative economy' (see figure 7). As part of this strategy, a target to install 40,000m² of green roofs every year, in partnership with the local water boards, was set.

Figure 7 Three aims in Rotterdam Programme on Sustainability and Climate Change 2015-2018



(Source: City of Rotterdam, 2016)

APPROACH		
VOLUNTARY	MANDATORY	
●		
KEY POLICY		
Making sustainability a way of life for Rotterdam: Rotterdam Programme on Sustainability and Climate Change 2015-2018 (City of Rotterdam, 2016)		
UPTAKE		
2012	2017	2030 goal
100, 000 m²	220, 000 m²	800, 000m²

Green roof in Rotterdam (source: S. Wilkinson, 2016)

The Municipal Council of the City of Rotterdam has implemented a wide range of tools to promote the construction of green roofs and achieve their goal for green roofs. They include:

- a grant / subsidy scheme,
- tax benefits,
- campaign periods,
- demonstration projects,
- information days and
- personal advice.

Since 2008, a grant scheme has provided financial incentives for the construction of green roofs (Mees and Driessen, 2011). In partnership with the two local water boards, Hollandse Delta Water Board and the Water Board of Schieland and Krimpenerwaard, the Municipal Council of the City of Rotterdam grants a subsidy of €25 per m² to encourage the installation of green roofs, although the city plans to gradually phase this out. The two local water authorities reimburse an additional €5 per m², bringing the total subsidy to €30 per m². This subsidy covers about half of the initial costs of an extensive green roof (IGRA, 2015). The subsidy is awarded on the condition that each square meter retains at least 15 litres of water. This is reflective of the water issues in the city and the benefits of green roofs in terms of urban water management. The subsidy program is part of Rotterdam's climate adaptation program for the Rotterdam Climate Initiative: Rotterdam Climate Proof (2012).

There are also tax benefits for installing green roofs in the city. Green roofs fall under the Environmental Investment Deductibility Tax 5 which is the highest form of tax deductibility (36%). Green roofs can also help improve the 'ecolabel' of a house and lower the property transfer tax. For houses with energy label A this tax is 2%, compared to 6% for G label (Geisler et al, n.d.).

The municipal council is taking the lead, and where possible, it is building green roofs on top of municipal properties. To date, green roofs have been built on top of the Municipal Archives building, the Central Library, the head office of Unilever Nederland, the Maasstad Hospital, the Sophia Children's Hospital, the museum Villa Zebra and many others. Building green roofs on top of third-party property, such as housing associations and businesses, is also encouraged. In addition, the city is also conducting research in the field. In particular it is researching the desirability of mandatory green roof installation and the options of longer-term guarantees (City of Rotterdam, 2016).

The uptake of green roofs in Rotterdam has increased significantly in the past 10 years. In June 2012, Rotterdam reached the milestone of having more than 100,000m² of green rooftops (Rotterdam Climate Initiative, 2012). These green roofs were built between 2008 and 2012 (Geisler et al, n.d.). In 2014, there were more than 200 green roofs throughout the city covering an area of more than 200, 000m² (International Green Roof City Network, n.d.). In 2015 the city had 218,000m² of green roofs, ranging from extensive sedum roofs to intensive rooftop gardens. Approximately 130,000m² were installed with the subsidy from the municipality and water boards. In 2017, Rotterdam has over 220,000m² of green roofs (City of Rotterdam, 2017). The current goal is to achieve 800,000m² of green roofs by 2030 and install green roofs on at least 50 per cent of municipal buildings (Geisler et al, n.d.).

Policy effectiveness

The rates of uptake of living architecture demonstrates the effectiveness of policy in Rotterdam. In the past five years, the amount of green roofs have increased by 120% or 120,000m². Most of this gain was delivered in the three years from 2012 to 2015. The city has used its strategic planning document to set the agenda for living architecture, and supplemented it with a series of tools to encourage uptake.

Cross institutional collaboration also plays an important role in driving change in Rotterdam. The Rotterdam Climate Initiative plays a key role in setting sustainability policy for the city. Under this initiative, a series of key stakeholders (the Port of Rotterdam Authority, Deltalinqs, DCMR Environmental Protection Agency Rijnmond and the City of Rotterdam) work as partners to enhance the sustainability of the city, the port and industry (Rotterdam Climate Initiative, 2017).

The organisation has released a series of strategic planning documents to guide sustainable development which recognises the importance of the city, the port and industry, to the long term sustainability of Rotterdam.

Green roof on Groothandelsgebouw, Rotterdam (source: Rotterdam climate initiative, 2010)

4. SINGAPORE

The City

Singapore is an example of a compact, high-rise, high-density city with a high level of infrastructural and industrial development. It is one of the world's most densely populated countries, with approximately 5.5 million people living on an island 697 square kilometres in size, less than 17 times smaller than Sydney. Singapore is an island located off southern Malaysia, in south-east Asia. It is a global finance, commerce, finance and transport hub. It has strong arts, commerce, technology, entertainment, professional services, research and development, and tourism sectors. Singapore was founded in 1819, as a trading post of the East India Company. In 1826 the islands were ceded to Britain and became part of its Straits Settlements. It gained independence from the UK in 1963 and became a sovereign nation in 1965.

It has a hot and humid, tropical climate. The island receives abundant rainfall, high and uniform temperatures, and high humidity all year round. Temperature and relative humidity in Singapore, does not show large month-to-month variation. Singapore's climate is characterised by two monsoon seasons separated by inter-monsoonal periods. The Northeast Monsoon occurs from December to early March, and the Southwest Monsoon occurs from June to September. It rains an average of 178 days of the year, and much of this rain is heavy and accompanied by thunder. The long-term mean annual rainfall total is 2328.7mm (Meteorological Service Singapore, 2017).

Planning Context

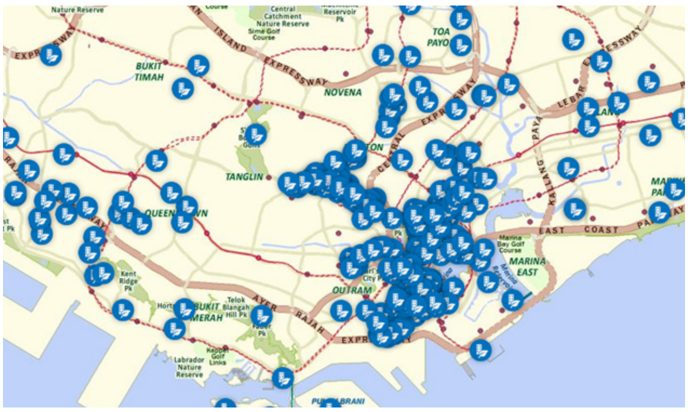
Singapore is a city-state. It has a centralised government with a top-down style of governance. As such, there are no provincial and municipal levels of government. Urban greening has been a key part of the government's plan since 1968, when the country's founding Prime Minister, Lee Kuan Yew, announced his vision for the country, which centred around the idea that Singapore would be not a 'concrete jungle' but a 'garden city', to attract foreign investment and to increase liveability. As such, the government has identified the need to strategically plan for and prioritise sustainable development as part of its city planning. This reflects the particular issues facing the city, not only in terms of land scarcity, but also of water shortages and energy generation.

The city-state's first Green Plan, produced in 1992, focused on strengthening performance in being 'Clean and Green'. This was followed by the Singapore Green Plan 2012 (Ministry of the Environment and Water Resources, 2002). It built on the 1992 plan and aimed to go beyond 'clean and green'. The Singapore Green Plan 2012 acknowledged the global challenges of environmental degradation and sustainable development and focussed on responding to the challenges of sustaining a healthy environment while pursuing economic progress. The current strategic plan, Sustainable Singapore Blueprint 2015, sets out the current vision and planning policies for the nation. Published in 2014 by the Ministry of the Environment and Water Resources and the Ministry of National Development, this document builds on the foundation of the first Sustainable Singapore Blueprint which was published in 2009. That document outlined plans for a 'Lively and Liveable' Singapore, and established targets including the amount of recreational waterways and skyrise greenery. The vision for Singapore, as outlined in the Sustainable Singapore Blueprint 2015 is a:

- A Liveable and Endearing Home
- A Vibrant and Sustainable City
- An Active and Gracious Community

Given the density of the urban form and the strong demands on land, the city has encouraged 'skyrise greening' as a way to integrate urban greening throughout the city and work towards the vision of a city in a garden. Skyrise greening is 'the integration of greenery into the superstructure of buildings' (CUGE 2011). There are many examples of green roofs and walls throughout the city (see figure 8).

Figure 8 Rooftop and vertical greenery sites in south Singapore.



(Source: NParks, 2017)

Singapore has established a comprehensive program to promote rooftop greening in order to reach its ambitious goal of 200 hectares of Skyrise Greenery by the year 2030 as outlined in the Sustainable Singapore Blueprint 2015. In 2009 there was 10 hectares (ha) of skyrise greenery (Ministry of the Environment and Water Resources and Ministry of National Development, 2014). This increased to 61ha in 2013, 72ha in 2015, and today there is 80.5 hectares of skyrise greenery in Singapore across 182 projects (National Parks Board, 2017).

Mandatory requirements

Most of the policy instruments in Singapore are voluntary. However, for public sector projects, it is mandatory to implement skyrise greenery. This demonstrated how the public sector is taking the lead in terms of environmental sustainability requirements. The government also requires that, for some land sales, any development must be constructed with higher levels of Green Mark certification.

Voluntary requirements

Implementation of skyrise greenery is encouraged by various government policies. In 2009, the Urban Redevelopment Authority (URA) introduced the Landscaping for Urban Spaces and High-Rises (LUSH) program which aimed to consolidate existing and new green initiatives and to encourage more skyrise greenery in private developments. LUSH provides floor area incentives. It encourages building owners and developers to provide well-planted and designed communal green space at both the ground and upper levels of buildings, such as sky terraces, through the provision of Gross Floor Area (GFA) incentives. More than 50% of eligible new residential developments applied for at least one LUSH incentive between 2012 – 2014, and more than one third of shopping centres, offices and hotels have benefited from these incentives. In July 2014, LUSH 2.0 was released. It covers a wider range of development types across Singapore, and more green features, including communal ground gardens, now qualify for GFA incentives.

APPROACH	
VOLUNTARY	MANDATORY
●	●

KEY POLICY
Sustainable Singapore Blueprint (Ministry of the Environment and Water Resources and Ministry of National Development)
Skyrise Greenery Incentive Scheme (NParks)
Landscaping for Urban Spaces and High-Rises (URA)
Green Mark Scheme (BCA)

UPTAKE		
2009	2017	2030 goal
100, 000m²	805, 000m²	2, 000, 000m²

Skyrise greenery on Shaw House in Singapore (source: N.Pelleri, 2017)

Also in 2009, the National Parks Board (NParks) introduced the Skyrise Greenery Incentive Scheme (SGIS). The SGIS provides financial incentives to developers by financing up to 50% of green roof and green wall installation costs on residential and non-residential buildings. To date, the SGIS has assisted in greening more than 110 existing buildings by retrofitting them with extensive green roofs, edible gardens, recreational rooftop gardens and green walls. The incentive scheme is effective from 1 April 2015 and will expire on 31 March 2020 or when the incentive scheme funds are exhausted. NParks has also produced documents to encourage and increase awareness of skyrise greenery. The 'Guide to Skyrise Greenery' and Guide to Skyrise Greenery – safe practices' were published in 2015, with inputs from other government agencies including the Building and Construction Authority, Housing and Development Board, National Environment Agency, and the Ministry of Manpower.

In 2007, the Centre for Urban Greenery and Ecology (CUGE) was established by the National Parks Board and the Singapore Workforce Development Agency to conduct research, share knowledge and provide accredited training to professionals and the public on all aspects of urban greening and ecology. CUGE has developed standards as guidelines for rooftop and skyrise greenery. These technical guidelines are aimed for industry professionals and cover a range of topics including design loads, safety, waterproofing and irrigation.

Since 2008, the National Parks Board has hosted the annual Skyrise Greenery Awards. The objectives of the Skyrise Greenery Awards are:

1. To create awareness and promote Skyrise Greenery in urban development.
2. To inspire creative and original landscaping ideas in Skyrise Greenery.
3. To recognise the architect/ owner/ designer/ management team who pays particular attention to Skyrise Greenery.
4. To encourage innovative use of greenery and landscaping to create a positive environment to live, work and play in.
5. To encourage ownership and participation in greening up our high-rise urban built up.

The awards are for commercial/industrial developments, educational institutions, community facilities, residential (multi-units) and residential (small-scale) projects. The most outstanding skyrise greenery development in each category receives a SGD$8,000 cash prize (approximately AUD$7,400). The Skyrise Greenery Awards are supported by government and industry organisations including the Building and Construction Authority (BCA), Landscape Industry Association of Singapore (LIAS), Singapore Green Building Council (SGBC), Singapore Institute of Architects (SIA), Singapore Institute of Landscape Architects (SILA) and the Urban Redevelopment Authority (URA).

In 2012 the National Parks Board also established the Landscape Excellence Assessment Framework (LEAF). LEAF recognises projects that showcase innovations in design and greenery implementation, which demonstrate high quality landscapes and enhance biodiversity (see figure 9). It is a certification program developed to encourage more greenery

Figure 9. LEAF Assessment criteria

PART	CRITERIA	COMPONENT
1. Greenery Provision	Greenery provision • Green plot ratio • Percentage of ground-level greenery • Skyrise greenery Plant materials • Percentage of native plant species (as defined in NParks' Flora & Fauna Web) • Diversity of plant species Landscape design • Integration of greenery with architecture Habitat creation • Biodiversity-sensitive planting and landscape design	70%
2. Landscape Management	Plant sourcing • Sourcing of plants from accredited nurseries Site verification • Overall impression of maintenance • For existing developments, visual assessment of health of greenery Sustainable greenery practices • Maintenance productivity measures • Irrigation system	30%
3. Bonus	Additional efforts to • Educate people through information signs, brochures, websites, and so on • Promote, encourage or facilitate community gardening • Retain suitable on-site trees • Any other greenery- or nature-related efforts	

(source: NParks, 2015)

in Singapore's urban landscape projects, and can be used as a marketing tool. In 2016, there were 32 certified projects.

Singapore's Building and Construction Authority (BCA) also supports the design and construction of environmentally sustainable buildings. In 2005, the Authority launched the BCA Green Mark Scheme. It aims to guide Singapore's construction industry towards sustainability in the built environment as well as to raise awareness among developers, designers and builders from project conceptualisation and design to construction. It is a certification scheme and several points in its scoring system can be achieved through the installation of green roofs and walls. The latest version of the scheme, Green Mark 2015, was released in 2015 to provide a platform to recognise and make mainstream high performance green buildings.

Finally, all Housing and Development Board (HDB) projects, which houses 80% of Singapore's population, integrate skyrise greenery. The HBD produced the HDB Landscape Guide in 2013 to assist consultants as they prepare concept design and documentation drawings. The HDB works closely with designers and maintenance contractors to ensure that skyrise greenery meets HDB standards and long-term maintenance requirements.

Policy effectiveness

Whilst most skyrise greenery policy instruments are voluntary, development in Singapore has wholeheartedly embraced the concept of skyrise greenery, and the wide range of incentives and grants play a large role in the amount of uptake across the city state. Buildings with skyrise greenery are common throughout the city-state. Private developers also use skyrise greenery as a form of branding and marketing, to position themselves as environmentally sustainable developers. Architectural firms such as WOHA use skyrise greening to give their companies an identity They may also have requirements as part of their own internal environmental policy which encourage green roofs and walls.

Political drive has played an important role in championing policy initiatives and projects in Singapore. This case study demonstrates the power of having a clear vision, backed by effective urban planning policies and a supporting legal framework, along with effective governance. The development of institutions to operationalise greening policies has supported Singapore's goal to become a city in a garden. There is also a focus on continual revision and improvement in their systems and policies and use of a wide variety of approaches to achieve their vision. Collectively, these initiatives reflect a strong commitment from the Singaporean government to allocate resources to urban greening through green walls and green roofs.

The Parkroyal on Pickering in Singapore features a range of vertical greening (source: N.Pelleri, 2017)

5. STOCKHOLM, SWEDEN

The City

Stockholm is the capital of Sweden. It is the most populous city in the Nordic countries. Just over 20% of Sweden's population, approximately 2.3 million people, live in the Stockholm Metropolitan area. The city is located on the central coast of eastern Sweden, on the Baltic Sea archipelago. Stockholm is spread across 14 islands, connected by 57 bridges. The area has a long history, having been settled since the Stone Age, in the 6th millennium BC and was founded as a city in 1252. Stockholm is the cultural, media, political, and economic centre of Sweden. It plays a key role in the economy of the country, with the Stockholm region accounting for over a third of the country's GDP.

The city has a cool temperate climate, with cold winters and mild summers, reaching an average of maximum temperature of 20ºC. The average annual temperature is 10 °C, and the average rainfall is 762 to 1524 millimetres a year. Due to the city's high northern latitude, daylight varies widely throughout the year. In the middle of summer the city receives more than 18 hours of daylight. In late December there is only around 6 hours of daylight.

Planning Context

The governance structure is comprised of the federal government, county councils and municipalities. There are 290 municipalities, and they are responsible for education, welfare, employment, infrastructure development and culture. There are 20 county councils. Stockholm is the capital of Stockholm County. They are self-governing local authority organisations responsible for wider areas, covering more than one municipality, but having a narrower focus; mostly specialised on medical issues. The county council and municipality stand as equals in the Swedish system. Regulatory power for land use and construction is at the municipality level, embodied in the Planning and Building Act (PBA), which formulates regional plans, for example, for Stockholm. There are 26 municipalities in the Stockholm region (county). Regional plans were formulated in 1958, 1973, 1978, 1991, 2001 and 2010. In accordance with the PBA, the Swedish planning system consists of the;

- regional plan,
- comprehensive plan,
- area regulations and
- detailed development plan.

The 2010 Regional Plan integrates economic and physical development, with an of aim of sustainable development including economic, ecological, social and cultural aspects; and increasing regional growth focusing on accessibility and innovative environments. The Plan influences the location of new housing developments for a predicted population growth of 300-500,000 in areas close to existing urban areas, and aims to produce a dense urban environment accessible by public transport.

The end of the 20th century marked a new epoch in urban development in Stockholm, which the 1999 City Plan summarised as "building the city inwards". This has meant supplementary building in existing neighbourhoods and the renewal of harbour and former industrial areas as mixed-use neighbourhoods. Hammarby Sjöstad, located on the edge of the city and a former industrial area, is the most prominent redevelopment and continues to generate considerable international interest, especially for its environmentally friendly profile.

Stockholm needs to plan for housing, parks, infrastructure and workplaces for about 200,000 new residents by 2030. This means that many urban functions will share or compete for available space. A challenge is meeting future needs while preserving the city's beauty, heritage and character. Another difficulty is finding space for public works infrastructure, which is often difficult to co-locate with housing. Global climate change is one of the world's most pressing problems and Stockholm aims to be fossil fuel-free by 2050. Its dense city structure provides the basis to expand district heating and public transportation systems and create a sustainable living environment. The biggest challenge is to increase accessibility, and minimise harmful climate and environmental effects attributable to transportation.

Stockholm reflects a wide range of social and economic disparities, among social groups and across areas of the city. The greatest challenges are in the labour market, where disparities are more pronounced than in other regions of the country. The built environment has an important role to play in reducing physical barriers and linking neighbourhoods.

The City Plan has four strategies to meet these challenges and create a world class city. Focus on strategic nodes, to strengthen central Stockholm planning to develop the central areas of the city will continue, along with several strategic development areas close to the inner city. A dense and diverse city core supports Stockholm's competitiveness, providing the conditions necessary for sustainable mobility and links hitherto isolated areas. This means expanding the inner city beyond its historic borders. To achieve a balanced development pattern, a focus on densification and development of outer city nodes is needed to provide good access to a range of services, culture and jobs. Moreover, it will create new possibilities to expand and modernise the public transportation system and use current infrastructure more effectively.

Stockholm Royal Seaport is one of the largest urban development areas in northern Europe with 12,000 new homes and 35,000 workplaces. Planning work started in the early 2000s and this new city district will be fully developed around 2030. Located along the foreshore of the Baltic Sea, the site lies next door to the Royal National City Park and is ten minutes away from central Stockholm by bicycle. The industrial site around the gasworks area will be transformed into an urban district that interacts with port operations and the existing residential areas. A mixed use development, called Norra Djurgårdsstaden, is being designed with sustainable development principles, including living architecture elements.

Mandatory requirements

The Building and Planning Act requires municipalities to produce and update a comprehensive plan to guide detailed plans and building permits, but no dedicated legislation mandates green roofs or walls. Swedish municipalities have extensive authority over local land use, referred to as

APPROACH	
VOLUNTARY	MANDATORY
	●
KEY POLICY	
Green Space Factor	
Green Points System	
UPTAKE	
2000	2017
n/a	n/a

Vertical farming in Stockholm (source: S. Wilkinson, 2016) a 'planning monopoly'. Land use and building is regulated through legally binding municipal detailed development plans. Building permits are issued in compliance with detailed plans for new building, renovations and additions. The plan serves as policy guidance for the entire city's areas and functional responsibilities. It is vital that the City Plan is updated to reflect new situations and provide guidance for detailed plans. A rolling urban development planning process periodically updates the City Plan to adapt to current issues.

The City Planning Administration is responsible for comprehensive and detailed planning. The City Plan must be approved by the City Council. The new city plan will function more as a strategic navigation tool than a traditional land use plan. The City Plan shows how Stockholm will meet its Vision 2030 goals and provides clear guidance regarding the city's intentions and objectives. During 2006, all the city's departments, administrations and companies, along with external partners, formulated a vision for Stockholm's development and sustainable growth; named "Vision Stockholm 2030". The vision presents three coherent themes for the city's development, and essential characteristics that show what it will be like to live in, work in and visit Stockholm in the year 2030. It aims to be versatile and full of experiences, innovative, growing and; importantly, the citizen's city.

Voluntary requirements

Stockholm has mandatory requirements discussed above, however these requirements do not specifically mandate green roofs or green walls. A voluntary system exists called the Green Space Factor (GSF). The GSF aims to secure a certain amount of green cover in every building lot, and to minimise sealed or paved surfaces in developments. It was initially piloted in Malmo and Lund a decade ago, but is now used in Stockholm. It is applied to the whole building lot, and includes building areas and open space, including courtyards. Developers submit plans showing how they propose to achieve a Green Space Factor of 0.5, which is checked by landscape architects at the city planning office. The system was adapted from Germany, where it is used in Berlin and Hamburg. It has also been used in Seattle and, through the GRaBS (Green and Blue Space Adaptation for Urban Areas and Ecotowns) project, some UK partners have adapted it (Kruuse, 2011). The GSF assigns factors to different surface types, which are multiplied by the area of each within the courtyard and summed; the total is divided by the courtyard area to give the overall Green Space Factor, which must reach a specified target level. For example, the minimum GSF for Malmo's Bo01 project was 0.5. The GSF is calculated as:

$$\text{GSF} = \frac{(\text{area A x factor A}) + (\text{area B x factor B}) + (\text{area C x factor C}) + \text{etc.}}{\text{Total courtyard area}}$$

Factors assigned to different surface types vary from 1, for vegetation, which is in contact with ground water (i.e. where there is no underground parking beneath) and open water, to 0 for sealed areas. High factors are assigned to green roofs (0.6), large trees (20), and wall areas covered with climbing plants (0.7). Figure 10 shows the factors applied to different surfaces.

Figure 10 The GSF factors applied to different surfaces.

SURFACE TYPE	FACTOR
Vegetation on ground	1
Vegetation on trellis or façade	0.7
Green roofs	0.6
Vegetation on beams, soil depths between 200-800mm	0.7
Vegetation on beams, soil depths more than 800mm	0.9
Water surfaces	1
Collection and retention of stormwater	0.2
Draining of sealed surfaces to surrounding vegetation	0.2
Sealed areas	0
Paved areas with joints	0.2
Areas covered with gravel or sand	0.4
Tree stem girth 160 - 200mm (20 Sq .M per tree)	20
Tree stem girth 200-300mm (15 Sq .M per tree)	15
Tree stem girth >300mm (10 Sq .M per tree)	10
Solitary bush higher than 3 metres (2 Sq .M per bush)	2

(Source: The GRaBS, 2017).

The complete list of the Green Space Factors is given in figure 11 below;

Figure 11 List of Green Space Factors

	GREEN POINTS
1	A bird box for every apartment
2	A biotope for specified insects in the courtyard (water striders and other aquatic insects in the pond)
3	Bat boxes in the courtyard
4	No surfaces in the courtyard are sealed, and all surfaces are permeable to water
5	All non-paved surfaces within the courtyard have sufficient soil depth and quantity for growing vegetables
6	The courtyard includes a rustic garden with different sections
7	All walls, where possible, are covered with climbing plants
8	There is 1 square meter of pond area for every 5 meters of hard-surface area in the courtyard
9	The vegetation in the courtyard is selected to be nectar rich and provide a variety of food for butterflies (a so-called ‘butterfly restaurant’)
10	No more than five trees or shrubs of the same species
11	The biotopes within the courtyard are all designed to be moist
12	The biotopes within the courtyard are all designed to be dry
13	The biotopes within the courtyard are all designed to be semi-natural
14	All stormwater flows for at least 10 meters on the surface of the ground before it is diverted into pipes
15	The courtyard is green, but there are no mown lawns
16	All rainwater from buildings and hard surfaces in the courtyard is collected and used for irrigation
17	All plants have some household use
18	There are frog habitats within the courtyard as well as space for frogs to hibernate
19	In the courtyard, there is at least 5 square meters of conservatory or greenhouse for each apartment
20	There is food for birds throughout the year within the courtyard
21	There are at least two different old-crop varieties of fruits and berries for every 100 square metres of courtyard
22	The façades of the buildings have swallow nesting facilities
23	The whole courtyard is used for the cultivation of vegetables, fruit and berries
24	The developers liaise with ecological experts
25	Greywater is treated in the courtyard and re-used
26	All biodegradable household and garden waste is composted
27	Only recycled construction materials are used in the courtyard
28	Each apartment has at least 2 square meters of built-in growing plots or flower boxes on the balcony
29	At least half the courtyard area consists of water
30	The courtyard had a certain colour (and texture) as the theme
31	All the trees and bushes in the courtyard bear fruit and berries
32	The courtyard has trimmed and shaped plants as its theme
33	A section of the courtyard is left for natural succession (that is, to naturally grow and regenerate)
34	There should be at least 50 flowering Swedish wild herbs within the courtyard
35	All the buildings have green roofs

(Source: The GRaBS, 2017).

The GSF results in a certain amount of green cover across the building lot. It rewards surface cover types which tend to be of a higher functionality than others by assigning them a higher factor, and it is possible to layer the different surface cover types to achieve a higher GSF (e.g. an area of grass planted with trees results in a higher GSF than an area of grass with no tree cover).

However it does not fully encompass the quality of the green cover. For example, using the GSF mown and manicured lawns are of equal value to a natural meadow which supports greater biodiversity; and an extensive green roof with a thin growing substrate for vegetation has equal value to an intensive green roof with a thicker substrate which supports increased biodiversity and can attenuate more stormwater run-off. To overcome this issue, in the courtyards of the Western Harbour in Malmö, 'Green Points' were added to the GSF to achieve additional qualities. Developers were given a list of 35 Green Points and had to choose 10. The 10 points were described in the detail plans. Among the points, some aim to aid biodiversity such as the use of bat boxes and wild flowers in the courtyards, whilst others improve the architectural qualities of the yard or help with stormwater management. A full list of 35 Green Points, from which developers selected 10, is shown in figure 11 above. Some of the yards have semi-natural biotopes as a result of the Green Points, while the one with the highest GSF achieved its result with lawns and large areas of green roofs.

Malmö, in the Western Harbour project, has now been using green planning tools such as the GSF and the Green Points System for more than a decade. During this time, barriers such as initial scepticism of planners and developers have eroded, and the tools have evolved to better achieve their goals. For example, since the Bo01 development, the GSF has been improved and is part of an environmental building programme used in all new developments in Malmö and Lund. From its initial use as a means to reach a certain amount of green cover, it is now recognised as an instrument to encourage incorporation of green infrastructure in new development. Green infrastructure is recognised for the wide range of benefits it delivers; for example in helping to adapt to climate change, helping to manage temperature extremes, reduce flood risk and help other species adapt to changed conditions. Including the GSF and Green Points system in wider planning systems can ensure that not just exemplar developments such as Bo01, benefit from the provision of green infrastructure, but that it becomes the norm across all developments.

Policy effectiveness

In 2013 a study conducted by Vartholomaios et al (2013) concluded that the GSF in Stockholm had not had sufficient time to determine how effective it had been, whereas a GSF in another Swedish city, Malmö, had been running for longer and had increased its GSF from 5 to 6 in order to increase the impact of the measure. This suggests that, in hindsight, it was deemed that the bar was set too low. In the same year, the OECD (2013) concluded that Stockholm's mechanisms of regional governance were possibly not strong enough to help it fully realise its green growth potential and compete internationally on green technologies. Other policies on waste, water and energy efficiency implemented since 2007 have been effective and are being monitored to measure uptake (OECD, 2013). It is acknowledged that Stockholm has a reputation as a leader in urban sustainability. Whilst the City of Stockholm is a leader in reducing local greenhouse gas emissions, this is achieved through widespread district heating and cooling systems and the application of a vehicle congestion charge rather through the adoption on green infrastructure including green walls and roofs.

6. TORONTO, CANADA

The City

Toronto, the provincial capital of Ontario, with a population of over 2.7 million, is the largest Canadian city. Toronto is the centre of the Greater Toronto Area (GTA), the most populous metropolitan area in Canada and is the focal point of the so-called 'golden horseshoe'; an urbanised region, which accommodates 9.2 million people. It is a multicultural city and an international centre of business, finance, art and culture. European settlement occurred from the 1790s onwards and the current area covered by the city totals 630.2km².

Toronto is located on a broad sloping plateau, which is intersected by a large number of rivers, ravines and urban forests. The city has a semi-continental climate, with a warm, humid summer and a cold winter. The climate is modified by the city's location on the shores of Lake Ontario, and the lake water makes Toronto warmer in winter and cooler in summer than it would otherwise be. Toronto winters are severe, with snow on the ground most days between mid-December and mid-March, and snow deeper than 1 cm is seen on 65 days a year typically.

140 neighbourhoods make up the city. Nearly half the city's population are migrants, and 200 ethnic origins are registered. The downtown area is noted for its high-rise office and residential buildings towering 80 plus storeys. There has been much redevelopment of waterfront and former industrial building stock. Figure 12 shows an aerial photograph of Toronto from 2004.

Figure 12 Aerial photograph of Toronto in 2004

(Source: Public Domain)

Mandatory requirements

The City of Toronto's Strategic Plan 2013 – 2018 is the divisional playbook for advancing the city's building agenda. With the Official Plan Vision as a foundation, five strategic directions are supported by key initiatives and a series of actions that form a framework to guide priorities and activities. The action statement, 'Planning a Great City, Together!' summarises their vision. The Mission Statement is a call to action and an affirmation of the work that the division undertakes.
"As leaders and partners in an innovative culture, we build a great city through excellence in planning and influential policy. We implement Toronto's Official Plan for a sustainable, connected city of neighbourhoods where life and business flourish." (City of Toronto, 2017).

The Strategic Plan sets out the framework for;

- Setting priorities and improving processes,
- Enhancing and strengthening capacity of the division,
- Clear, consistent and compelling communication,
- Pursuing deep collaborations and finally;
- Measuring success.

The Official Plan seeks to deliver a city that is attractive and safe, a city to evoke pride, passion and a sense of belonging for its inhabitants and a city, where people of all ages and abilities, can enjoy a good quality of life. Toronto aims to be a city with:

1. Vibrant neighbourhoods that are part of complete communities;
2. Affordable housing choices that meet the needs of everyone throughout their life;
3. Attractive, tree-lined streets with shops and housing that are made for walking;
4. A comprehensive and high quality affordable transit system that allows people to move around the city quickly and conveniently;
5. A strong and competitive economy with a vital downtown that creates and sustains well-paid, stable, safe and fulfilling employment opportunities for all Torontonians;
6. Clean air, land and water;
7. Green spaces of all sizes and public squares that bring people together;

8. A wealth of recreational opportunities that promote health and wellness;
9. A spectacular waterfront that is healthy, diverse, public and beautiful;
10. Cultural facilities that celebrate the best of city living; and
11. Beautiful architecture and excellent urban design that astonishes and inspires. (City of Toronto, 2017).

The downtown, or CBD area, covered by the City of Toronto is shown in figure 13.

Figure 13 Downtown area City of Toronto, Canada.

(Source: City of Toronto)

The city Building & Policy Development group undertakes activities that aim to improve the built and natural environments, in order to integrate land use and transportation, to optimise the City's waterfront assets, to enhance access to community services and facilities, to build a foundation for a strong and diverse economic base, to conserve heritage resources, to design "Special Places" as part of public realm infrastructure and guide revitalisation while ensuring the creation of sustainable neighbourhoods.
The City of Toronto Green Roof Bylaw requires green roofs on new commercial, institutional and residential development with a minimum Gross Floor Area (GFA) of 2,000m² as of January 31, 2010. From April 30, 2012, the Bylaw required compliance with the Bylaw for new industrial development. A green roof screening form is a tool to determine whether an owner is required to build a green roof.

The green roof coverage requirement is graduated, depending on the size of the building. The table 1 below shows how the requirement ranges from 20-60 per cent of Available Roof Space for commercial, institutional and residential development. Available Roof Space is defined as the total roof area minus areas designated for renewable energy, private terraces and residential outdoor amenity space (to a maximum of 2m²/unit). A tower roof on a building with a floor plate less than 750m² is also excluded from available roof space.

Table 1 Requirements for coverage of available roof space in Toronto Green Roof Bylaw.

Gross Floor Area * (Size of Building)	Coverage of Available Roof Space (Size of Green Roof)
2,000 - 4,999 m²	20%
5,000-9,999 m²	30%
10,000-14,999 m²	40%
15,000-19,999 m²	50%
20,000 m² or greater	60%

(Source: City of Toronto, 2017). Note: Residential buildings less than 6 storeys or 20m in height are exempt from being required to have a green roof.

The Green Roof Bylaw applies to new building permit applications for industrial buildings or additions to industrial buildings where the GFA is 2,000 m2 or greater and the application was made on, or after, April 30, 2012. Under the Green Roof Bylaw, industrial buildings are required to provide one of the following:

1. a Green Roof covering the lesser of 10% of Available Roof Space or 2,000 m2; or
2. a roof that uses Cool Roofing Materials for 100% of the Available Roof Space and complies with the stormwater

management performance measures required through the Site Plan Approval process. Where the Site Plan Approval is not required, the first 5 mm from each rainfall or 50% of annual rainfall volume falling on the roof is retained or collected for re-use at least through systems that incorporate roof surfaces.

For all development where a green roof is required under the Bylaw, applicants may apply for a Variance or an Exemption where the requirement is not met. A Variance allows a smaller amount of green roof than is required under the Bylaw, provided that a cash-in-lieu payment of $200/m² is made for the reduced green roof area, and the application is approved by the Chief Planner. An Exemption from the green roof requirement is necessary when a green roof is not proposed for a development. An Exemption requires the approval of the Chief Planner and a cash-in-lieu payment of $200/m² if the application is approved.

Applicants can use the Green Roof Screening Form as a tool to determine quickly whether a project will be required to provide a green roof and the size of green roof that must be provided. For new development requiring Site Plan Approval, green roof statistics should be provided with the Site Plan application to facilitate compliance with the Green Roof Bylaw at the time of Building Permit Application. Applicants complete the template for the Green Roof Statistics and copy it onto their Roof Plan submitted as part of all Site Plan Control application or Building Permit applications. For associated Building Permit Applications, the applicants are required to complete a Green Roof Declaration Form. For new development requiring a Building Permit, applicants are only required to complete the Green Roof Declaration Form for submission at the time of Building Permit Application.

Whether constructing a green roof voluntarily, or as required by the Green Roof Bylaw, all green roofs in the City of Toronto, at a minimum, must conform to the Toronto Green Roof Construction Standard. The Standard can be found in Article IV of the Green Roof Bylaw (Municipal Code Chapter 492, Green Roofs). It complements the other sections of the Green Roof Bylaw which relate to definitions, coverage requirements, exemptions, and applications etc. The Toronto Green Roof Construction Standard aims to govern the design and construction of green roofs by setting out minimum requirements that meet the City's objectives and the Ontario Building Code requirements. Mandatory provisions are included in the Toronto Green Roof Construction for the following:

- Green Roof Assembly
- Gravity Loads
- Slope Stability
- Parapet Height and /or Overflow Scupper Locations
- Wind Uplift
- Fire Safety
- Occupancy and Safety
- Waterproofing
- Drainage
- Water Retention
- Vegetation Performance
- Plant Selection
- Irrigation
- Maintenance

Voluntary requirements

There are voluntary sustainable building rating tools for commercial and residential buildings that include credits covering some of the benefits provided by green roofs. These include BREEAM Canada and Green Globes, both of which cover new and existing buildings. Owners decide whether they wish to have their buildings evaluated under the schemes and charge an evaluation fee. In contrast, the City of Toronto uses economic incentives to increase the uptake of green roofs.

Incentives

To incentivise the market, grants are offered by the City for green and cool roofs. The current grant for green roofs in 2017 is C$100/m² of green roof provided, and requests exceeding C$100,000 are subject to council approval. An online application process is provided and applicants must apply before construction commences. In 2017 the incentive amount was increased. Structural assessment grants are now offered and new construction projects by not-for-profit organizations are now eligible. The buildings must be located within the City of Toronto and include all existing buildings and new buildings with a GFA of less than 2000m². Land uses include commercial, industrial, institutional, residential and all new construction projects (of any size) by Toronto Public and Separate School Boards and all new construction projects (of any size) by organisations incorporated as not-for-profit corporations. To be eligible, the green roof must comply with the requirements of the Toronto Green Roof Construction Standard discussed above. The green roof is required to have a minimum coverage of available roof space in accordance with table 1 above. Applicants must provide the following documentation:

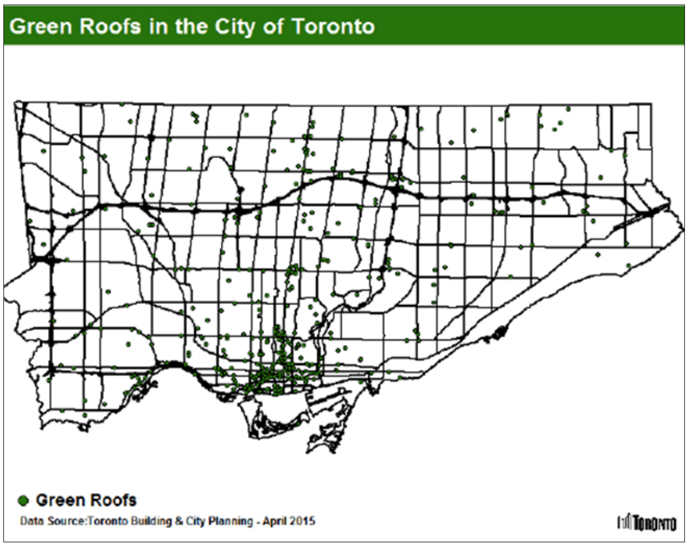
1. Photo of the roof prior to construction (not applicable for new construction).
2. Roof plan.
3. Green roof design plans and details.
4. Maintenance plan.

If owners wish to retrofit a green roof to an existing building, there is a Structural Assessment Grant (SAG) of C$1000, or whatever the cost is, to assist with determining if the building can carry the additional loads. If proceeding with green roof, and after the green roof has been approved, completed and verified by program staff, the SAG amount is added to the final green roof grant payment and dispersed as one total amount. Conversely if the structural engineer determines that the building cannot support the additional load, the applicant is not required to install a green roof, but is eligible for the SAG funding.

Green Roofs and Building Permits

Since January 31, 2010, the Toronto Green Construction Standard has applied to all new building permit applications where a green roof is proposed. There are no additional fees for a building permit to construct a green roof that is part of an application for a new building or an addition to an existing building. A separate fee is charged for a permit to construct a stand-alone green roof. Figure 14 shows the total number and location of green roofs in Toronto in 2015.

Figure 14 Number and location of green roofs Toronto in 2015



(Source: City of Toronto)

Tools

Tools, as summarised below, have been developed to help applicants with respect to green roofs.

- *PAL/PPR Project Reviews*

While not specific to green roof programmes, these services help identify at the pre-application stage whether a green roof may be required as part of a development construction project.

- *Green Roof Bylaw Screening Form*

This is a diagnostic tool to help determine whether the Green Roof Bylaw may apply to an application, and if any proposed Green Roof meets the requirement of the Bylaw. The form is not required as part of a building permit or site plan application, but helps applicants and staff in reviewing projects.

- *Green Roof Designer Checklist*

This checklist is a voluntary tool to help designers in reviewing green roof projects, by providing a summary of Ontario Building Code and Green Roof By-law provisions. This form is not required as part of a building permit.

Submittals
The following forms and templates are a requirement of the application process.

1. *Green Roof Statistics Template*

This template is required to be submitted for Site Plan Control Applications or Building Permit applications (where no site plan application is required) where a green roof is mandatory. The table must be completed and copied directly onto the Roof Plan submitted.

2. *Green Roof Declaration Form*

The Green Roof Declaration Form is required for all new buildings or building additions applications with a gross floor Area exceeding $2000m^2$, or where a green roof is proposed.

3. *Green Roof Inspection Report - Checklist*

The inspection checklist is required to be submitted upon completion of the installation of the green roof to verify that the installation conforms to the Toronto Green Roof Construction Standard: Mandatory Provisions.

Toronto Green Roof Construction Standard: Supplementary Guidelines
Toronto Building has prepared this guideline document to the green roof construction standard, in consultation with the City's Green Roof Technical Advisory Group. The document contains "best practices" in green roof design, provides designers and the public with additional information on the Toronto Green Roof Construction Standard and contains illustrations to assist with calculating required green roof coverage.

Effectiveness of policy

Policy has been very effective in increasing uptake of green roofs in Toronto. During the five years from February 1, 2010 - March 1, 2015, 300 new green roofs were created in the city, totalling over 250,000 sqm. As of May 2017, 400 new green roofs covering an areas of 346,000 sqm green roof have been issued permits for (since 2010). This figure includes any roofs that come in under the ecoroof incentive program (50 green roofs as of year end 2016). This demonstrates how mandatory policy can have significant effects. The combination of the Green Roof Bylaw, the Green Roof Construction Standard and a grant program has produced a city which now features approximately 500 green roofs (City of Toronto, 2017). The Green Roof Construction Standard, grant program, and various tools and templates produced by the City of Toronto help to enable industry to implement the mandatory Bylaw.

Toronto City Hall Podium roof (source: LiveRoof, 2010)

7. MELBOURNE, AUSTRALIA

The City

Melbourne is the Australian state of Victoria's capital city and a business, administrative, cultural and recreational hub. Melbourne is located on the south-east coast of Australia. The entire metropolitan area covers 9990.5 km^2 with a population of around 4.5 million. The City of Melbourne municipality covers 37.7 km^2 and had a residential population of 136,336 in 2016, which is forecast to grow to 150,874 in 2018. It is made up of the city centre and 15 inner suburbs. Each suburb has a distinctive character with different building types, businesses, dwellings and communities.

Metropolitan Melbourne's suburbs spread over 40 km southwards, 30 kms to the Dandenong ranges in the east, up to 20 km to the north and to the west. Its temperate climate is influenced by its location at the apex of one of the world's largest bays, Port Phillip Bay. Summers are warm to hot (average maximum is 25 degrees Celsius), spring and autumn are mild and sometimes balmy (average maximum is 20 degrees Celsius), whereas winters are cool (average maximum is 14 degrees Celsius).

The population is diverse with many groups of all ages, from many cultures. Residents include young professionals, international students and older couples. Each day around 909,000 people use the city, and annually Melbourne welcomes over a million international visitors.

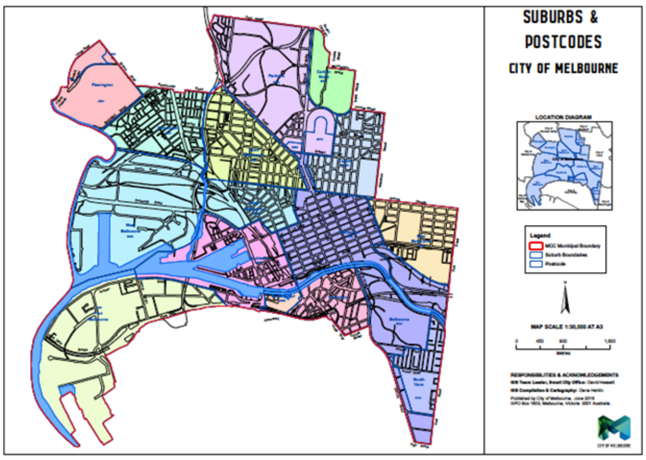
Melbourne City Council oversees the municipal area (including the city centre and several inner suburbs) and represents Melbourne in local, national and international forums. The City of Melbourne works with other local councils and the Victorian Government. The City of Melbourne's seven neighbouring councils are Hobsons Bay, Port Phillip, Stonnington, Yarra, Moreland, Moonee Valley and Maribyrnong.

The City of Melbourne is the most important employment location in Victoria. In addition to retail, dining, and recreational assets, significant dwelling growth has made Melbourne a popular place to live and visit. A summary of space throughout the City in 2016 is:

- Residential 6,689,500 m^2
- Office 5,412,700 m^2
- Parks and reserves 4,877,400 m^2
- Outdoor sports/recreation 1,574,900 m^2
- Under construction 1,615,200 m^2
- Unused 1,787,100 m^2
- Retail 803,600 m^2

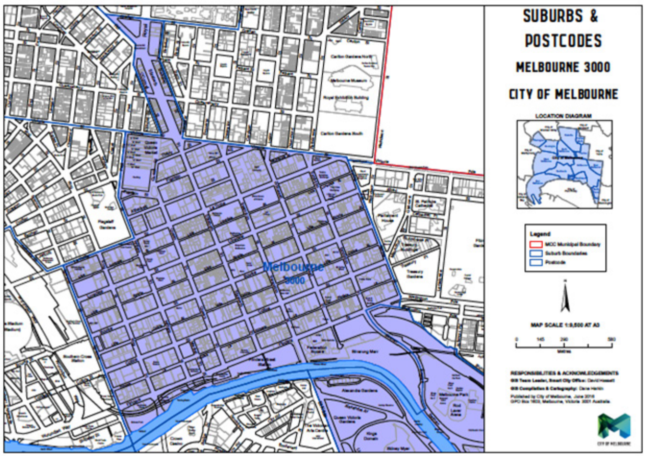
The total area of built space is 32,907,600 m^2. With un-built space totalling 18,035,000 m^2, there is a total space of 50,942,600 m^2. In 2016, there were 9800 houses and townhouses, 55,700 residential apartments, 5500 student apartments (a total of 71,000 dwellings). Top employers the City of Melbourne in 2016 are business services at 78,700, finance and insurance at 62,900, and health care and social services providing 41,200 jobs. The Census of Land Use and Employment (CLUE) offers information about economic activity, tracks the changes in land use and identifies key trends in employment, based on information collected from businesses in the municipality. Figure 15 shows a map of the suburbs and postcodes of the City of Melbourne. Figure 16 shows the CBD area, the Hoddle Grid laid out in the 1830s when Europeans settled in the area. Figure 17 shows a thermal image or heat map of the same area highlighting the hot and cooler area. Typically hard surfaces such as rooftops, roads and pavements are hottest. In 2014 Melbourne was one of the first cities to join the Rockefeller Foundations 100 Resilient Cities program and published its Resilience Strategy.

Figure 15 Map of Melbourne



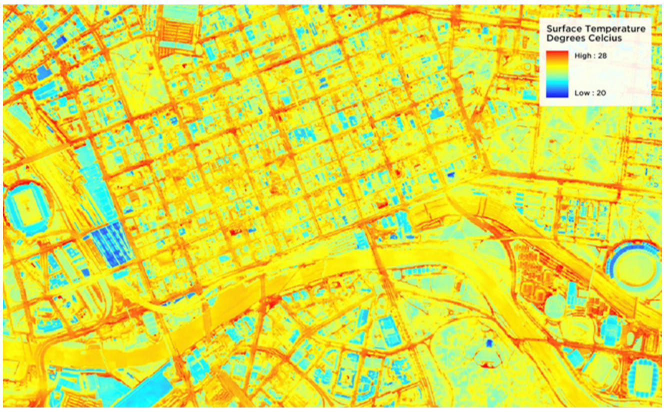
(Source: City of Melbourne, 2017)

Figure 16 Map of Melbourne CBD



(Source: City of Melbourne, 2017)

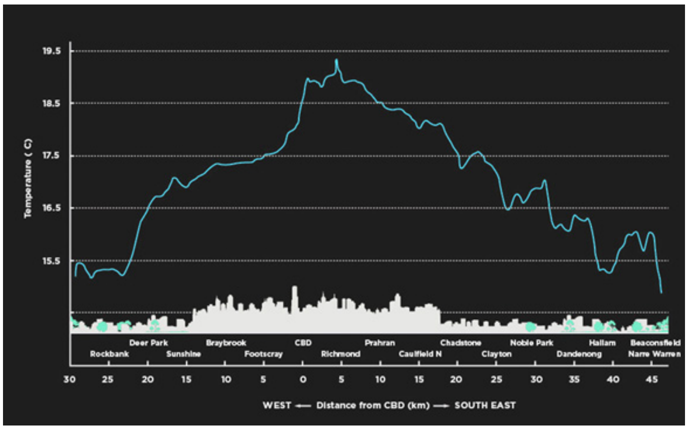
Figure 17 Heat map of Melbourne showing CBD



(Source: City of Melbourne, 2017)

Heat is perceived as an issue for Melbourne and features as one of the resilience issues in the 100RC (100RC, 2016). Figure 18 shows the Urban Heat Island (UHI) profile for the city and temperatures peak in the centre where building density is highest. In January 2014 a three day long heatwave, where temperatures exceeded 44 degrees Celsuis, lead to an additional heat related 203 deaths in Melbourne (Steffen et al, 2014); this figure will increase as there is an increasing density of development and an ageing population, unless action is taken in mitigation of the UHI.

Figure 17 Heat map of Melbourne showing CBD



(Source: City of Melbourne, 2017)

Planning Context

In Australia, governance exists at Federal, State and Local levels. Planning schemes are legal documents setting out policies and provisions for the use, development and protection of land in Melbourne under the auspices of the Victorian state, Department of Environment, Land, Water and Planning. Planning schemes cover a large range of aspects, including limits for building heights, as well as ensuring orderly and sustainable use of land. Every Victorian local government municipality has a planning scheme to govern the use, development and protection of its land, underpinned by current and future needs. These vary from one municipality to another and are prepared by a local council or the Minister for Planning and then approved by the Minister.

The Melbourne Planning Scheme covers land in the City of Melbourne municipality. It contains state and local planning policies, zones and overlays and other provisions that affect how land can be used and developed. All properties have planning controls that specify when planning permits are required. The City of Melbourne will investigate suspected breaches of the Melbourne Planning Scheme. Enforcement orders or prosecution can result from carrying out works without appropriate permits.

The State Planning Policy Framework covers strategic issues of State importance. It lists policies under nine headings - settlement, environmental and landscape values, environmental risks, natural resource management, built environment and heritage, housing, economic development, transport and infrastructure. Clause 11 of the State Planning Policy Framework sets out Victoria's settlement policy, including relevant regionally specific policies applying to the area covered by this scheme. Regional policy in this scheme forms one of nine regionally specific policies that cover the state of Victoria, including Metropolitan Melbourne. The Local Planning Policy Framework contains a municipal strategic statement and local planning policies. The framework identifies long-term directions about land use and development; presents a vision for its community and other stakeholders and provides the rationale for the zone and overlay requirements and particular provisions in the scheme.

The Zone and Overlay requirements and Particular provisions show –

- The type of use and development allowed in each zone.
- Additional requirements for subdivision, buildings and works on land that is affected by an overlay.
- Requirements for any specific use or development.

The General provisions provide information on the administration of this scheme and other related matters. Definitions advise on the meaning of words in this scheme. The VicSmart planning assessment provisions set out a fast-track permit application process, including the classes of applications that are eligible for that process. Green roofs and facades are not mandated but are encouraged within the legislation. Other green infrastructure initiatives include the 2014 Urban Forest Strategy which sets out principles and targets to increase canopy cover from 20% to 40% by 2040 to help the City to achieve its vision of a healthy, resilient and diverse urban forest.

Mandatory requirements

The City of Melbourne does not have any mandatory requirements for green roofs or walls.

Voluntary requirements

The Rooftop Project was set up by the City of Melbourne in 2015 and is aligned to the City's Climate Change Adaptation Strategy and also the Open Space Strategy. The Rooftop Project aims to help owners and residents realise the potential to create a solar, cool or green roof (City of Melbourne, 2017a). The City notes that rooftops in central Melbourne make up 880 hectares of space, most of which are used as sites for air conditioners and heating equipment (City of Melbourne, 2017b). However, there is a large potential for rooftops to be used to benefit building owners, the community and the environment by adapting these spaces for solar energy, cool roofs or green roofs. Of the 880 hectares of rooftop, it is estimated that substantial areas can be retrofitted to green roofs, with 236 hectares (or 26.81%) suited to intensive green roof retrofit and 328 hectares (or 37.27%) suited extensive green roof retrofit (Jewell, 2015).

All rooftops in the City of Melbourne were mapped to see if they have the potential to be retrofitted into solar, cool or green roofs. This had not been done across a whole city previously and a website is provided for anyone to assess any

Figure 19 The Rooftop Project Map Melbourne

(Source: City of Melbourne The Rooftop Project Maps, 2017c)

rooftop in the City of Melbourne. Website visitors can explore the Rooftop Project maps and evaluate how a rooftop could be used (City of Melbourne, 2017c). Separate tabs of the map reveal what could work on any roof, users are able to zoom in to see rooftop details, and can access more information such as how to retrofit the roof, as well as contacts for assistance.

Melbournians can access further related information on green roofs and green infrastructure such as the;

- Growing Green Guide.
- Australian Government green roofs and walls factsheet.
- Green roofs Australasia.
- University of Melbourne Green Infrastructure Research Group.

The Climate Change Strategy update for 2017 notes that the City intends to 'implement findings of 2016-17 Council Plan actions to encourage green roofs and solar installations' though no details are provided as to the form this might take. Currently the City is reviewing other cities internationally which have adopted voluntary and mandatory approaches to determine which might work best for the City of Melbourne.

Policy effectiveness

In 2015, the City of Melbourne had 5 hectares (5000m^2) of green roofs and rooftop gardens. Of the 880 hectares of rooftops in the City, this 5 hectare figure is 0.5% of the total rooftop space. The number of green walls and facades totalled 50 in 2016 and are located mostly in the central city and Docklands.

8. SYDNEY, AUSTRALIA

The City

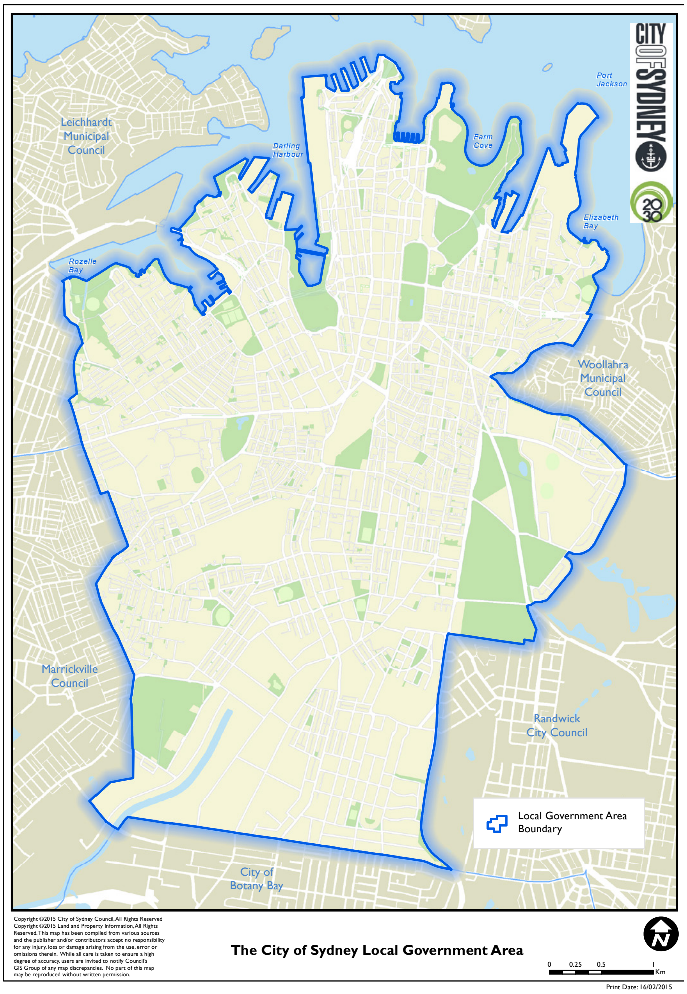
Sydney is the capital city of New South Wales, located on the east coast of Australia. It is the largest city, and most populous city in Australia. It is an important financial, educational, administrative, cultural, healthcare, media, professional services and recreational hub in the Asia-Pacific region. It is also a popular tourist destination, featuring the iconic Sydney Harbour Bridge and Sydney Opera House. The city is located on Sydney Harbour, at the mouth of the Parramatta River. The harbour and its headland parks are the setting for the city. The area of Sydney has been inhabited by indigenous Australians for at least 30,000 years. In 1788, the first British settlers, led by Captain Arthur Phillip, arrived to establish Sydney as a penal colony, and the first European settlement in Australia. Sydney has a humid subtropical climate with warm summers, cool winters and relatively uniform rainfall throughout the year. The city can experience extreme heat events, with the weather station at Observatory Hill in the CBD recording a high of 45.8 °C. The city also experiences the urban heat island effect.

The City of Sydney is the local government area (LGA), approximately 26.15 square kilometres, covering the Sydney central business district (CBD) and surrounding inner city suburbs of the greater metropolitan area of Sydney, New South Wales (NSW), as shown in figure 20. The City of Sydney LGA is the focus of this case study. The CBD is bounded by Circular Quay and Sydney Harbour to the north, Macquarie St to the east, Darling Harbour to the west and Central Railway Station and Liverpool St to the south. Suburbs within the boundaries of the City of Sydney LGA include Ultimo, Pyrmont, Haymarket, Woolloomooloo, Alexandria, Darlington, Erskineville, Newtown, Redfern, Glebe, Waterloo, most of Surry Hills and part of Paddington (see figure 21). There were 169,505 people in the Sydney local government area in the 2011 census, and as of 2017 that figure has increased to over 183,000 residents.

Figure 20 City of Sydney CBD Map

(Source: City of Sydney, 2017a)

Figure 21 City of Sydney Local Government Area (LGA) Map



(Source: City of Sydney, 2017b)

Planning Context

Sustainable Sydney 2030 is a set of goals produced by the City of Sydney to help make the city as green, global and connected as possible by 2030. Residents, visitors, workers and businesses were consulted about the kind of city they wanted. People wanted a city that cares about the environment, has a strong economy, supports the arts and that connects its people to each other and the rest of the world. Sydney 2030 is the strategy driving policy within the City of Sydney LGA. Green, Global and Connected is the framework for the strategy and is summarised in figure 22. The Green component highlights the need to increase green infrastructure and the connected refers to walkways, another form of green infrastructure.

Figure 22 Green Global Connected Sydney 2030

Green
We will be internationally recognised as a leader with outstanding environmental performance and new 'green' industries driving economic growth. We will reduce our carbon emissions, with a network of green infrastructure to reduce energy, water and waste water demands. We will plan for new housing opportunities integrated with vital transport, facilities, infrastructure and open space.
Global
Sydney will remain Australia's global city and international gateway with world-renowned tourist attractions and sustained investment in cultural infrastructure and facilities. Our city will contain premium spaces for business activities and high-quality jobs in the city centre and support social, cultural and recreational facilities to attract and retain talent. We will embrace innovation and new technologies to stimulate creativity and collaboration.
Connected
Central Sydney will be easy to get around with a walking and cycling network, and transit routes connecting our villages, city centre and the rest of inner Sydney. The City's villages will continue to be strong focal points for community life and will encourage a sense of belonging. Relative equality will be improved through increased affordable housing and better access to community facilities, programs and services across the local area. Cultural vitality will flow from high rates of participation in artistic expression, performance, events and festivals.

(Source: City of Sydney, 2017c)

The City will commit to partnerships and cooperation between governments, the private sector and the community to lead change. Ten strategic directions, reflecting aspirations and qualities, for Sustainable Sydney 2030 were developed as follows;

1. A globally competitive and innovative city
2. A leading environmental performer
3. Integrated transport for a connected city
4. A city for pedestrians and cyclists
5. A lively, engaging city centre
6. Vibrant local communities and economies
7. A cultural and creative city
8. Housing for diverse population
9. Sustainable development, renewal and design
10. Implementation through effective partnerships

In 2014 Sydney joined the 100RC and in 2015 commenced work on the Resilience Strategy. A preliminary report has been produced which identifies heat as one of the issues facing the city, and one which new and retrofit green roofs and walls could mitigate. Although not listed as a resilience issue for Sydney, the City of Sydney website states the area is flood prone and that since 1910, the local area has experienced 35 floods classified as serious, severe or minor. In 13 cases, high rainfall led to local flooding and four floods (November 1984, March 1975, January 1973 and August 1971) were classified extreme. The website states floods can occur at any time and in the future could be bigger than any previously recorded event, acknowledging potential changes to the local climate. Thus another reason exists to promote the specification of new and retrofit green roofs and walls.

Planning context

Sydney Local Environmental Plan (LEP) 2012

This plan applies to most of the City's local area and is made up of a written instrument and maps. Various planning instruments currently apply to development within the City's local area including for example;

- Sydney LEP 2012
- Sydney LEP (Glebe Affordable Housing Project) 2011
- Sydney LEP (Green Square Town Centre) 2013
- Sydney LEP (Green Square Town Centre – Stage 2) 2013*
- Planning Scheme Ordinance

A Planning and Development Committee deals with matters relating to:

- Development applications not dealt with by the Central Sydney Planning Committee and other applications for approval under the Environmental Planning and Assessment Act 1979
- Planning instruments such as LEPs, DCPs, policies
- Transport and access initiatives and issues
- Parking policy
- Local Pedestrian, Cycling and Traffic Calming Committee
- Referrals from other authorities for comment on any of the above matters
- Grants and sponsorships
- All applications for footway usage approvals.

The Committee is required to form the following Sub-Committees, to exercise the functions listed above through the Transport, Heritage and Planning Policy Sub-Committee, the Major Development Assessment (DA) Sub-Committee and the DA Sub-Committee. Under the Environmental Planning and Assessment Act 1979, the Planning and Development Committee, DA Sub-Committee and Major DA Sub-Committee have powers to determine DA's, grant deferred commencement consent, grant staged development consent and approve modifications to any of those consents, except where the Chairperson determines that an application be referred to Council for determination. They are authorised to approve submissions relating to the matters listed above, to other consent authorities.

The draft Central Sydney Planning Strategy 2012-2036 revises previous planning controls and delivers on the City of Sydney's Sustainable Sydney 2030 program for a green, global and connected city. The strategy will have a public exhibition and consultation period during 2017 following gateway determination from the Greater Sydney Commission. Planning for developments in central Sydney means planning for Sydney's ongoing competitiveness, appeal and resilience.

The City of Sydney's Sustainable Sydney 2030 strategy supports opportunities for additional height and density in the right locations, balanced with environmental sustainability initiatives and sets criteria for excellence in urban design. They align with planned developments in infrastructure and technology for an economically, environmentally and socially successful city. The Strategy promotes green walls and green roofs within development sites. The City of Sydney is working to create an urban forest with greater tree canopy and more diversity to provide the proven benefits to cities of plants and trees. For Central Sydney, this means increasing the average total canopy cover to more than 15 per cent by 2030.

Mandatory requirements

The City of Sydney does not have any mandatory requirements for green roofs or walls.

Voluntary requirements

The City is committed to increasing the number of high quality green roofs and walls in Sydney. In April 2014, the City adopted the green roofs and walls policy – the first of its kind in Australia. The website highlights the many environmental and community benefits of green roofs and walls and claims they are an integral part of any sustainable city. A dedicated green roofs officer was appointed from 2012 to 2014 to promote and support the adoption of green roofs and walls. The officer was supported by a Technical Advisory Panel from 2012 to 2014.

The Green Roofs and Walls Policy provides direction for Council to promote and foster better understanding and use of green roofs and walls in the Sydney's residential and commercial sectors. In addition, the Policy is also intended to support the green roofs and walls industry sector in Sydney. The Green Roofs and Walls Policy supports the strategic directions set out in key strategy's and plans:

- Sustainable Sydney 2030;
- Green Roofs and Walls Strategy;
- Greening Sydney Plan;
- Decentralised Water Master Plan;
- Urban Forest Strategy; and
- Urban Ecology Strategy.

The green roofs and walls definitions below were adopted as part of the Green Roofs and Walls Strategy 2012.

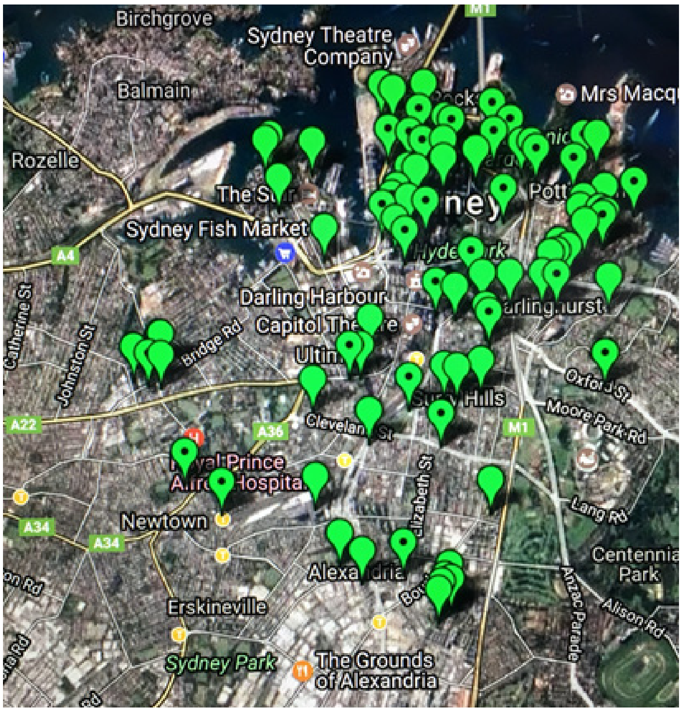
Term	Meaning
Green roof	A green roof is vegetation covering at least 30% of available rooftop space - that is, space which is not occupied by structures housing plant, equipment or stairway accesses. A green roof should provide measurable environmental benefits to the City of Sydney. The green roof includes a vegetated layer, growing medium, and a waterproof membrane. Plants grown in sectioned lots are acceptable, however, potted plants/planter boxes which cover less than 30% of available rooftop space are not considered as a green roof. Additional to the minimum 30% vegetation cover, a green roof can include facilities for renewable energy, water collection infrastructure, walkways, furnishings and the like.
Green wall	Green walls are either free-standing or part of a building that is partially or completely covered with vegetation. The wall may incorporate soil and/or inorganic material as the growing medium. There are two main types of green wall: green façades and living walls. Green façades are made up of climbing plants either growing directly on a wall or on specially designed supporting structures. The plant's shoot system grows up the side of the building while being rooted in the ground. With a living wall, modular panels are affixed to the wall and geo-textiles, irrigation and a growing medium combine to support a dense network of plants.

The City of Sydney encourages the installation of green roofs and walls through nine key activities in its policy statement. As such the City of Sydney will:

1. Play an active leadership role to raise awareness of the many benefits of green roofs and walls in the City of Sydney and nationally;
2. Address key barriers to the uptake of green roofs and walls, including developing resources that will fill gaps in technical and general information;
3. Support sustainably designed green roofs and walls through research, education and the development of guidelines and standards;
4. Continue to engage and collaborate with stakeholders including the Green Roofs and Walls Technical Advisory Panel, service providers, industry representatives and the broader community;
5. Promote the benefits of green roofs and walls through the provision of training, community and business presentations and educational opportunities;
6. Develop and support research partnerships which contribute to local knowledge about green roofs and walls;
7. Develop evidence and approaches which encourage and support the recognition of green roofs and walls in existing systems including the development application process, local planning controls, Environmental Upgrade Agreements and sustainability rating tools for buildings;
8. Take an active leadership role by implementing and promoting green roof and wall infrastructure on Council owned buildings, including investigating the potential for a green roof and wall demonstration site; and
9. Monitor the number and quality of green roof and green wall installations in the City of Sydney to measure the potential impact of this Policy.

To meet the policy objectives, a Policy Implementation Plan provides specific activities and time frames for the implementation of the Policy objectives. The key responsibility for this policy lies with the Strategic Planning and Urban Design unit at the City of Sydney. A number of resources, such as a guide and an interactive map (see figure 23) showing case study examples of existing provision, are provided to help individuals build green roofs and/or walls. A green roofs resource manual contains detailed information and a waterproofing guide provides information on waterproofing. Illustrative case studies are provided on local sites.

Figure 23 Interactive Map Showing Green Roofs and Walls in Sydney



(Source: City of Sydney, 2017d)

Policy effectiveness

By March 2014, the City of Sydney had recorded more than 98,000m² of green roofs and walls installed in the local government area however green roofs equate to less than 1% of the total roof space available in the City of Sydney. In 2017, 75 green roofs and walls were listed on the City of Sydney website. Of this number 53 are green roofs, 17 are green walls and 5 are sites with green roofs and walls. The series of voluntary policy mechanisms, including the Green Roof and Wall Policy and Green Roof Resource Manual, implemented by the City of Sydney have helped increase the uptake of green roofs and walls throughout the LGA.

9. DISCUSSION

The question to be answered here is; is the carrot more effective than the stick? Is a voluntary approach more effective in delivering more green roofs than a mandatory approach? These case studies demonstrate the approaches to green roof and green wall policy taken by policy makers across London, Rotterdam, Singapore, Stockholm and Toronto. These cities are facing significant issues, and green walls and green roofs can help alleviate some of them. In all the case study cities urban water management is a key issue. Heatwave is a driver for Singapore, Rotterdam and London, although interesting the trigger temperature for heatwave is low in Rotterdam (four days of 25 degrees Celsius) compared to Australia. London lists bio-diversity, provision of amenity space, sustainable development and climate change as drivers for green roofs. In Singapore, land scarcity and urban densification is a key issue. Creation of amenity space featured in all cities. These issues have led policy-makers to consider the benefits of green infrastructure, such as green roofs and green walls, and are drivers for the uptake of living architecture. Policy makers have recognized the potential benefits of green walls and green roofs, and have taken steps to encourage their uptake.

A mix of mandatory and voluntary approaches have been adopted within these cities (see table 3 summary). Table 2 summarises the amounts of green roof each city has delivered with its programs and/or legislation and policy approaches. In Toronto, planning policy has driven the uptake of living architecture. The Green Roof Bylaw mandates the installation of green roofs on new commercial, institutional, industrial and residential development with a minimum Gross Floor Area (GFA) of 2,000m². This mandatory approach has been combined with a grant program which provides C$100/m² of green roof and a structural assessment grant.

In Singapore, most policies instruments are voluntary but the culture of integrating skyrise greenery is ingrained into the development sector, boosted by incentives, grants, awards, certification schemes and government led development. This city has seen the greatest uptake of green roofs and walls, some 80%% increase over 10 years. For example, all public housing (some 80% of the total stock) is designed with skyrise greenery. The government also acknowledges that the density of the city means that there is little open green space. The government recognizes the need for urban greening, if it is to achieve the vision of 'a city in a garden', and sees skyrise greenery as a key method to achieve this. They promote green roofs and walls for their potential to increase liveability, providing green space for recreation, relaxation and social gathering. Table 3 shows they have a wide number of programmes that have been rolled out over the 12 years with a combination of incentives and awards, training and education. Given the very high proportion of social housing and the requirement for green roofs it is not surprising to see such high delivery of green roofs and walls in the city. Interestingly the amount of space provided in Singapore puts paid to the concerns expressed about the technological

Table 2 Amounts of green roof space delivered in case study cities

City	Area of green roof prior to programme (m²)	Year programme commenced	Total area (m²) of green roofs 2017	Percentage increase	Time period covered (years)
City of London, England	14, 750	2005	53, 200 (31.03.16)	360%	11
Rotterdam, The Netherlands	100, 000	2012	220, 000	120%	5
Singapore	100, 000	2009	805, 000	805%	8
Stockholm, Sweden	n/a	n/a	n/a	n/a	n/a
Toronto, Canada	n/a	2010	346, 000	n/a	6

(source: authors)

Table 3 Mandatory and voluntary approaches in non-Australian case study cities

City	Drivers for GR & GW	Programme Mandatory	Year programme commenced	Programme Voluntary	Year programme commenced	Programme approach
City of London, England	Flood Risk Open space (Urban greening, Biodiversity) Sustainable Development and Climate Change (air quality, carbon emissions, resilience)	Local Plan 2015 – CS19	2015	BREEAM	1990	Encourages green roofs and walls
Rotterdam, The Netherlands	Heatwave Rainfall Flooding	None	n/a	Green roof stimulation policy – Rotterdam Climate Change Adaptation Strategy	2008	Grant scheme – subsidy (approx. 50% of roof costs) Tax benefits (36% deductible)
Singapore	Heatwave Pollution and environmental degradation Rainfall flooding High density compact city Enhance biodiversity	Housing and Development Board project must integrate GI	2013	LUSH SGIS CUGE National Parks Awards LEAF certification Green Mark	2009 2009 2007 2008 2012 2005	Incentive Incentives 50% of costs Training and education Acknowledge best practices – cash prizes Recognises innovation Building certification – green roof credits
Stockholm, Sweden	Accommodating growing population and retaining a liveable city Sustainable development Public space Biodiversity Stormwater	Building & Planning Act		GSF Malmo / Stockholm Green Points System	2004 / 2009	Ensures that each plot has a minimum amount of greenery Encourages biodiversity
Toronto, Canada	Rainfall flooding Strategic Plan 2013-2018 Amenity and green social space Liveable city	Green Roof By-law	2010	Structural Assessment Grant Green roof grant		Based on roof size percentage must be green roof. C$1000 C$100/m²

(source: authors)

barriers highlighted in table 2 of the literature review report (Wilkinson et al, 2017) and implies these may be overcome in other countries with greater experience in designing, installing and maintaining green roofs and walls.

Planning policy has been used to promote sustainable urban redevelopment in Stockholm, however the implementation of the Green Space Factor (GSF) is voluntary, aiming to deliver a green cover across building lots. The GSF sets out a methodology for calculating the ratio of green space provided. Green roofs contribute to the GSF and have been installed firstly in Malmo, and now extensively throughout the Stockholm Royal Seaport redevelopment project. The Green Points scheme is very broad and comprehensive across a wide range of social and environmental sustainability attributes and green roofs are recognised. No quantitative data was available for Stockholm in terms of amounts of green roof space delivered and suggests that the city is either lagging compared to the other case study cities or that green roofs and walls are not deemed as attractive as other options.

Rotterdam also uses a voluntary approach to increasing the installation of green roofs and walls, through incentives, grants, tax benefits, and demonstration projects. The Municipality of Rotterdam achieved an increase of 120% of green roof area in the 5 years from 2012 to 2017 through its voluntary policy supported approach. The City of London achieved an increase of 360% of total green roof space over an 11 year period from 2005 to 2016, again using a policy supported voluntary approach. Similar rates of increase are noted with this approach, although the Dutch scheme has more economic incentives. Interestingly the period from 2012 to 2014 recorded all the new green roofs provision with no activity from 2015 to 2017 recorded. It is not known why the uptake of green roofs should apparently cease for the last 2 years and possibly indicates the vagaries of adopting voluntary market lead approaches as a means of delivering this vital infrastructure.

Finally, Toronto with it's mandatory approach, coupled with incentives has delivered 346,000 square metres of green roof space from 2010 to 2017. In 2011, there was 113,000 square metres of green roof provided so the increase in the 6 years since then has been 306%. This figure indicates that the mandatory approach has lead to reasonable results.

When Melbourne and Sydney are considered, both cities adopt a voluntary approach. The City of Melbourne's total of 5,000m² of green roof in 2016 is minute compared to the 805,000m² provided in Singapore, or the 346,000m² in Toronto, and less than ten times the area covered by green roofs in the City of London. Having stated this, their programs commenced typically eight years after the others and so they may experience similar increases in uptake over time (see table 4).

Overall, the most successful approach is that adopted in Singapore which is a largely voluntary programme with economic incentives, but also the requirement of the Housing and Development Board being such a large property owner is highly influential. The second ranked approach is the mandatory approach taken by Toronto, also supported with financial grants. The third most effective program is that of the City of London, a more free market scenario and a wholly voluntary approach. Finally Rotterdam's voluntary approach with more generous subsidies and tax benefits ranked fourth. This analysis shows that cities and their societies are complex and that it is too simplistic to say a voluntary or a mandatory approach is unequivocally the best approach to delivering more living architecture. The next stage in this project will be to consult with key stakeholders in major Australian cities to ascertain which combination of mandatory and voluntary measures will deliver the most green infrastructure to us over time.

Table 4 Mandatory and voluntary approaches in Melbourne and Sydney

City	Drivers for GR & GW	Programme Mandatory	Year programme commenced	Programme Voluntary	Year programme commenced	Programme approach
City of Melbourne	Heatwave Rainfall Flooding	None	n/a	Rooftop Project Green Star Growing Green Guide	2015 2006 2014	Encourages green roofs and walls Encourages green roofs and walls Encourages green roofs and walls
City of Sydney	Heatwave Rainfall Flooding	None	n/a	Green roofs and walls Policy Green Star	2012 2006	Encourages green roofs and walls Encourages green roofs and walls

(source: authors)

10. CONCLUSIONS AND RECOMMENDATIONS

Green roofs and walls are an essential component of liveable, sustainable and resilient cities.

This report has presented five international case studies and two Australian case studies to illustrate the drivers for adoption of green roofs and walls in each location. City authorities have a choice between mandating for green roofs and walls or adopting a market lead voluntary approach, whereby the market determines whether to install green roofs or walls. Voluntary approaches can be enhanced either through incentive programmes which can be financial in the form of grants, or allowances for building to greater densities, thereby offsetting the costs of green roof and wall installation against higher capital and rental values. In each city, green roof and wall policies are well established, although they have diverse approaches.

Singapore has the greatest variety of voluntary measures, six in total, and has been very proactive in marketing itself as a garden city. It saw an advantage in being seen to be literally 'green', in attracting investment and commerce to the city. This approach has resulted in a huge increase in green roofs and walls in the city and a flourishing economy. The city with the second largest recorded area of green roofs is Toronto, which adopted a mandatory approach in 2010. Toronto has increased their total green roof area to 346,000m². Their mandatory program is enhanced with financial incentives of grants for structural assessment and the green roof itself. London has increased its green roof area by 360% over 11 years purely on a voluntary approach. Compared to Toronto and Singapore, London has less sky-rise buildings and this lends itself to adoption of green roofs, especially for social amenity use.

Melbourne and Sydney have lagged in initiating green roof and wall policies compared to the other case study cities in this report. However, given the increases in green roofs and wall that have resulted, we should be optimistic that similar increases can occur here. The question is; how much can we expect to see in Melbourne and Sydney? The final stage of the research models the rates of increase we can expect to see in Melbourne and Sydney over time, based on contemporary rates of development and applying different scenarios as seen in Singapore, Toronto, Stockholm, London and Rotterdam.

Recommendations
In the light of the findings and discussion above, the recommendations are as follows;

1. Undertake scenario modelling of the potential uptake in green roofs in Melbourne and Sydney based on approaches taken in Singapore, Toronto, London and Rotterdam.
2. Lobby City of Melbourne and City of Sydney to adopt a greater range of approaches in respect of green roofs and walls.
3. Encourage City of Melbourne and City of Sydney to become world leaders in respect of green roofs and walls as part of their Resilience Strategies and their sustainability strategies such as Sustainable Sydney 2030.

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End of report