Horticulture Innovation Australia

# Expanding The Living Architecture In Australia

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# Content

# Summary

Green roofs and walls 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 green roofs and green walls (GRGW) grow. Barriers to adoption do exist, largely around lack of awareness, professional guidance and direct experience of working on projects involving green roof and walls. These barriers will diminish over time as more buildings are designed or retrofitted. 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. NSW, 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 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 other approaches. 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 are found to be 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 vibrant and substantial GRGW industry. Finally ten recommendations are made to expand the living architecture in Australia through greater adoption of GRGW.

# Keywords

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

# Introduction

This is the final milestone report for project GC15001. 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. This project analyses whether a policy approach is suited to Australia, and if so; what type of policy is likely to archive overall policy objectives. It estimates the amount of additional GR retrofit that is likely to arise following adoption of the different approaches modeled. The objectives and outcomes will drive changes in policy, create 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 and adapted to suit Sydney and Melbourne. 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 it 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, 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 comprised data collected from additional literature including published papers and industry reports, Milestone Reports 1 and 2, Australian local government and commercial property databases. Four scenarios were selected from the case studies to model the potential increases that could be achieved if Australian cities were to adopt similar policies and incentive measures. We then modeled for a subset of Australia's most populous cities, namely the City of Sydney LGA 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. This is because the observed growth trajectory is informative about the 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.

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. 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 benefit 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 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 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 for their LGAs. 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. 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 heatwave 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 global 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. 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 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 document the 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 and 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 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.

**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). | 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 (LCCA) 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$70.9 per $m^2$ comparing green to black roofs. Negative net benefit of US$96.3 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$8.4 difference and one was US$122.6 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 ha 'green development' in Montrèal, Canada; comparing green infrastructure to conventional infrastructure using three methods. | Neutral or positive net benefit in favor 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_Green_Roofs_on_Public_and_Commercial_Buildings.action | 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 owners, tenant and community. | Positive net benefit. Key driver of value for owners is real estate value uplift. Most benefits accrue to the 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 60year 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. (2017)).

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.

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. 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.

**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, 2013; 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, 2013) |
| Replacement | Replacement | \$63.91/$m^2$ | Every 40 Years | \$55.54 - \$72.28 | (GSA, 2011; Sproul et al, 2013) |
| | Disposal | \$1.17/$m^2$ | Every 40 Years | \$1.06 - \$1.27 | (GSA, 2011; Sproul et al, 2013) |

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. (2017)).

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

**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 - $2.34 | (Carter and Keeler, 2007; GSA, 2011; McRae, 2016; Sproul et al, 2013; Wong et al, 2003) |
| | Property Value | 1485.80/m$^2$ | Lifetime Value | $734.7 - $2236.89 | (GSA, 2011; Perini and Rosasco, 2013) |
| | Stormwater Retention | 1.27/m$^2$ | Annually | $0.19 - $2.34 | (Clark, Adriaens and Talbot, 2008; Sproul et al, 2013) |
| Replacement | Avoided Membrane Replacement | 96.40/m$^2$ | Every 17 Years | $79.17 - $113.63 | (Clark, Adriaens and Talbot, 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. (2017)).

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). 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 stage 2, namely Toronto, London, Rotterdam and Singapore. 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 for City of Melbourne. The approximate Total Roof Area (m$^2$) of Buildings within the City of Sydney LGA is 9,341,483.42m$^2$ 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 576m$^2$. 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 880,000m$^2$ 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 328,000m$^2$. Assuming the average roof size is about 576m$^2$, 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.

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 100Ha 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.

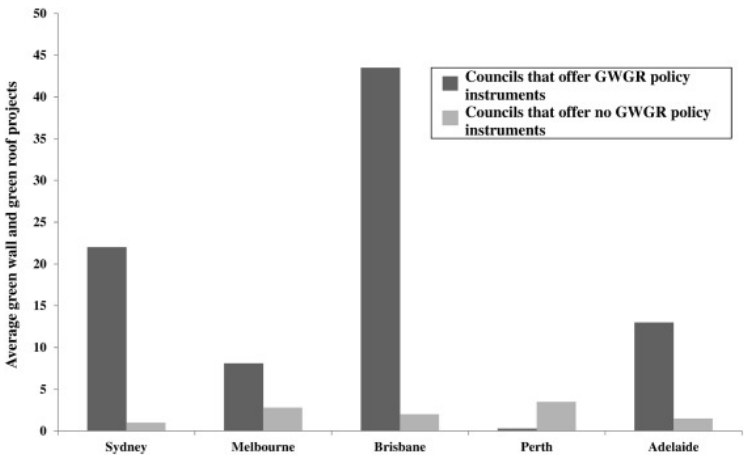
The City of Melbourne and three other councils use the *Growing Green Guide 2014* (Carpenter, 2014). The support mechanisms are awareness and guidance. Since the 2014 release of guidance document, the average uptake of GRGW across all Greater Melbourne councils increased though it is not measured and 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 is in the form of awareness and guidance however, there has been a negligible increase in GRGW uptake since release of guidelines.

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 policies 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 3 other councils endorse the *Growing Green Guide 2014* (Carpenter, 2014) | 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 |
| 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. |
| 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 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 (COM, 2013. City of Sydney, 2014).

Internationally there is increasing awareness in the general public of the value of GWGR projects (Pérez-Urrestarazu et al., 2016), 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. 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 (COM, 2013). 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. Adelaide City Council offers more limited guidance on the installation and maintenance in their 'Green Infrastructure Guidelines (Adelaide City Council, 2014) and has experienced less adoption. It discusses the benefits, design considerations and maintenance considerations very briefly and lacks local case study examples (Adelaide City Council 2014). 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:

- 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, namely (Tayouga and Gagne, 2016):
    - 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).
    - Provision of ecosystem services, where the GRGW infrastructure performs equally or better than traditional infrastructure.
    - Financial incentives, including '*both directs, such as grants and subsidies, and indirect, such as energy cost savings, incentives*' (p. 9).

Our analysis would suggest a;

(i) predominantly voluntary approach for retrofit and
(ii) 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.

Given that 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 ten recommendations with respect to future research and critical education / information infrastructure:

1. Develop a comprehensive cost benefit analysis of GRGW value potential for key cities. This would include a thorough GIS, extending the work of Ahrestani (2011).
2. Further evaluation of GRGW potential for LGAs outside Sydney and Melbourne (Perth, Brisbane and Adelaide).
3. Investigate potential for 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.

4. 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.
5. Further quantification of the $CO_2$ emissions, UHI attenuation, stormwater attenuation 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.
6. Establish a mechanism whereby data is collected, stored and made available about the cost and benefits of GRGW installations. 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.
7. 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).
8. Develop streams of research targeting the evaluation of plant, growing medium and irrigation for each business model to reduce the risk to industry participants to invest in value adding enterprises and start-ups which are also more likely to succeed.
9. 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.
10. Analyse the extent to which 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, Jasper Ryan, 2017, *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;

- The Building Surveying or Property Journal RICS. *Green Roofs, and Mandatory or Voluntary approaches for More Resilient and Liveable Australian Cities?*
- ANZPJ API. *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<br>• Annandale<br>• Barangaroo<br>• Beaconsfield<br>• Camperdown<br>• Centennial Park<br>• Chippendale<br>• Darlinghurst<br>• Darlington<br>• Dawes Point<br>• Elizabeth Bay | • Erskineville<br>• Eveleigh<br>• Forest Lodge<br>• Glebe<br>• Haymarket<br>• Millers Point<br>• Moore Park<br>• Newtown<br>• Paddington<br>• Potts Point<br>• Pyrmont | • Redfern<br>• Rosebery<br>• Rushcutters Bay<br>• St Peters<br>• Surry Hills<br>• Sydney<br>• The Rocks<br>• Ultimo<br>• Waterloo<br>• Woolloomooloo<br>• Zetland |

**Panel B: Localities**

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

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.

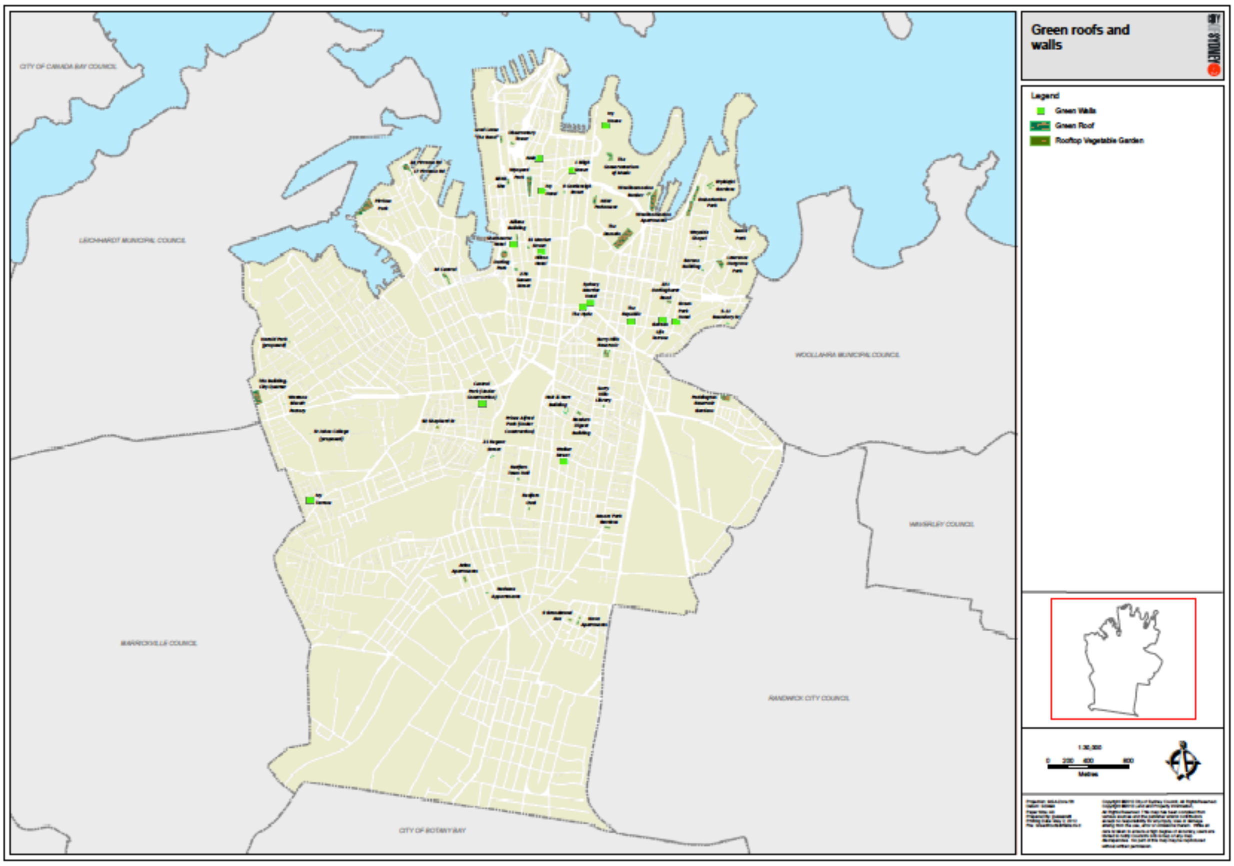
**Table A1.2. Sydney metropolitan councils and total number of GWGR projects and policy instrument type.**

| 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.**

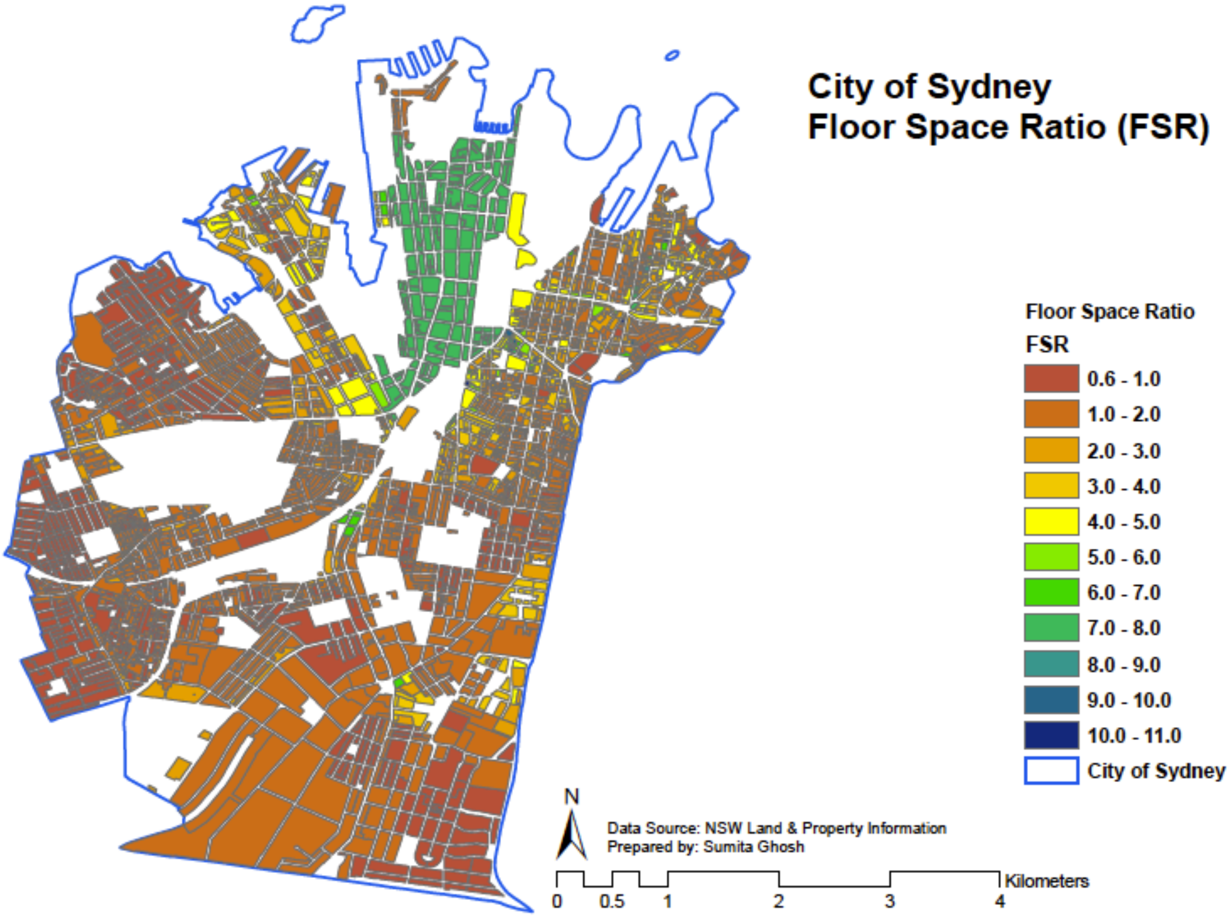



(Source: City of Sydney, 2017)

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.

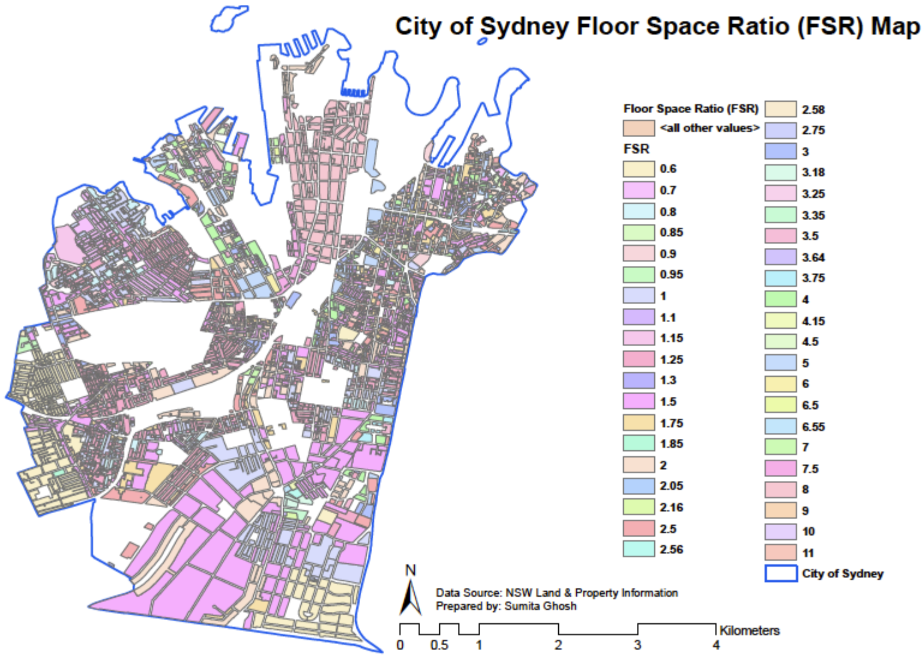
The City of Sydney floor space ratio (FSR) as per City of Sydney Local Environmental Plan shown in figures A1.4 and A1.5 shows the variability across the LGA, with lower FSR to the south and west where low-density residential and industrial land uses predominate. The CBD has the highest FSR for the LGA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

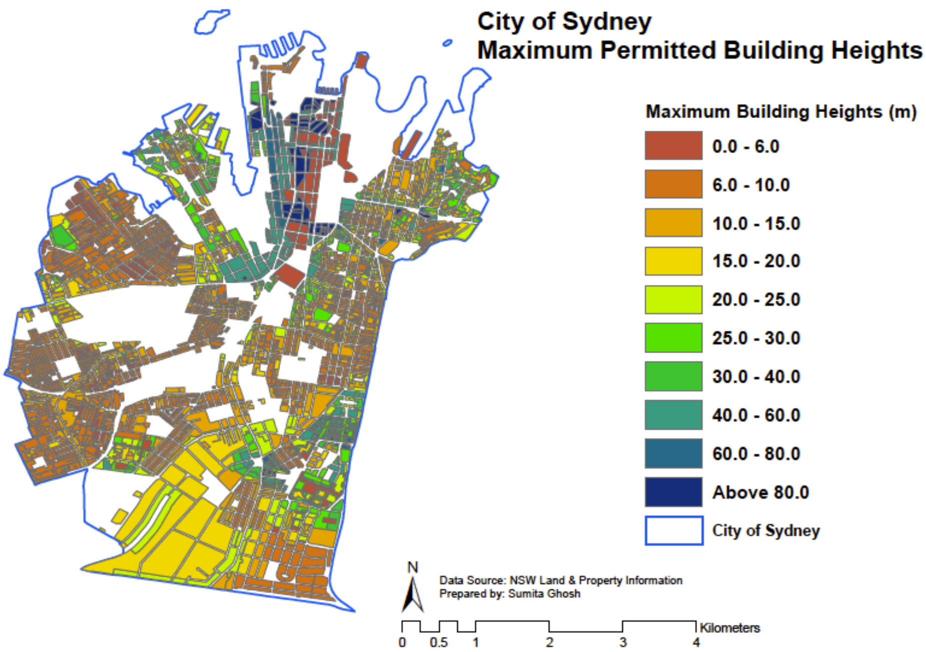
**Figure A1.5 City of Sydney LGA Floor Space Ratio (FSR).**




(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).

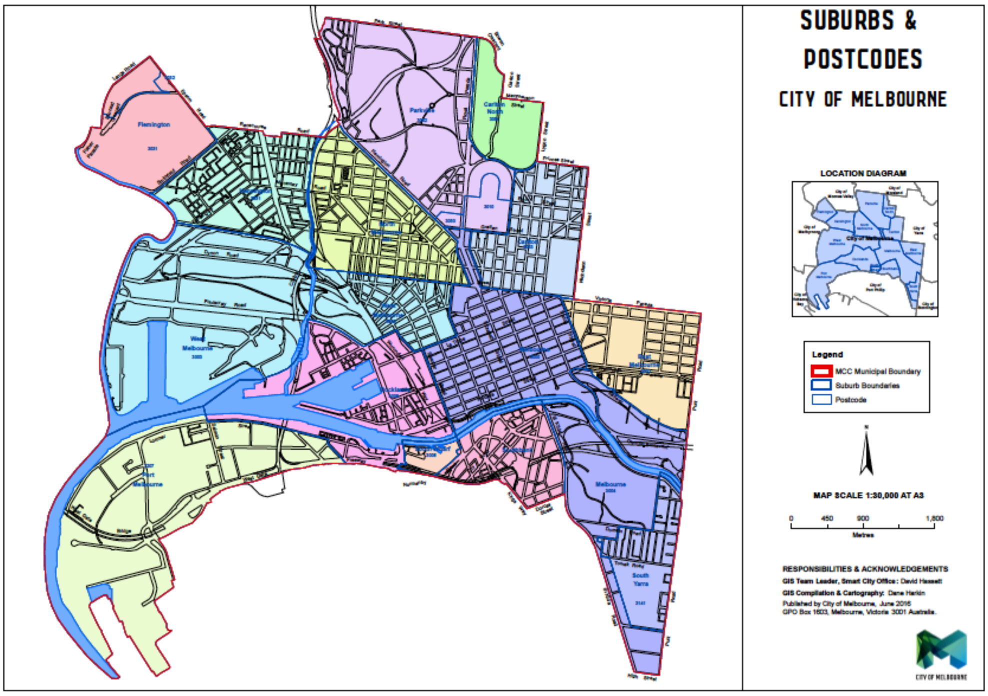
## *Melbourne*

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**

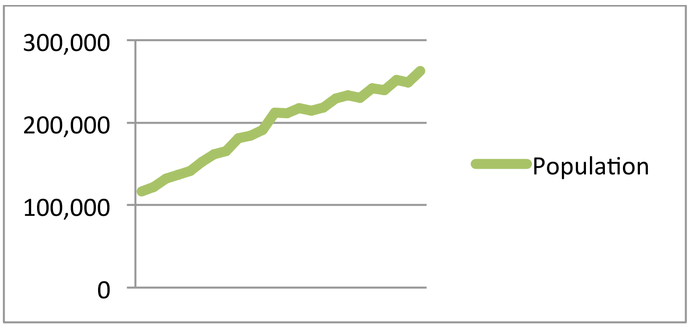



(Source: City of Melbourne, 2017).

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**

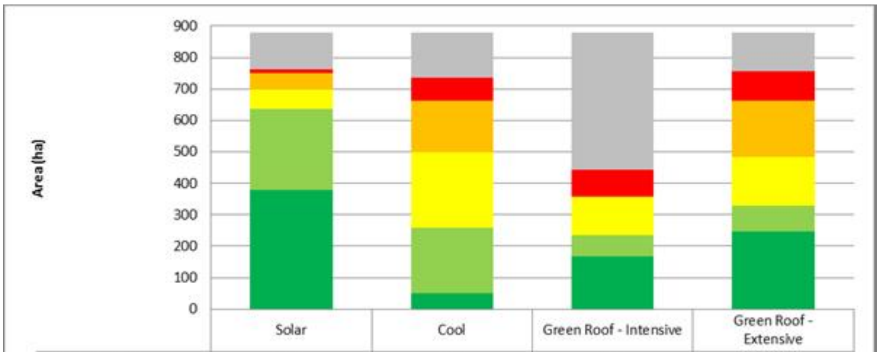
The total area of rooftops in the City of Melbourne is 880,000 $m^2$ of 880 hectares (COM, 2017). As only a small proportion of these areas are used for building services equipment, the potential for green roof retrofit to benefit building owners, the community and the environment is significant (COM, 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.**




| | Solar | Cool | Green Roof - Intensive | Green Roof - Extensive |
|---|---|---|---|---|
| Not Feasible | 118 | 145 | 437 | 123 |
| Highly Constrained | 12 | 72 | 83 | 94 |
| Constrained | 53 | 163 | 2 | 178 |
| Moderately Constrained | 60 | 241 | 121 | 156 |
| Low Constraints | 257 | 208 | 67 | 80 |
| No Constraints | 380 | 51 | 169 | 248 |

(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 |
| 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 |

| Local government area | Total GWGR projects | Policy present[a] |
|---|---|---|
| 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 sources 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:
  - Carpenter, S., 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.

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*, vol 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*, vol. 61, no. 3, pp 190-206
- Sproul, J. et al, 2013, 'Economic comparison of white, green, and black flat roofs in the United States', *Energy and Buildings*, vol 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*, vol 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 2013 |
| | | $93.32/m^2$ | 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 2013 |
| | | $2.38/m^2$ | GSA 2011 |
| | | $0.49/m^2$ | Munby, 2005 |
| Replacement | Replacement | $55.54/m^2$ | Sproul et al 2013 |
| | | $72.28/m^2$ | GSA 2011 |
| | Disposal | $1.27/m^2$ | Sproul et al 2013 |
| | | $1.06/m^2$ | GSA 2011 |

(Source: Adapted from Brown et al. (2017)).

**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 2013 |
| | | $1.48/m$^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 2013 |
| | | $0.19/m$^2$ | Clark, Adriaens and Talbot 2008 |
| Replacement | Membrane Renewal | $79.17/m$^2$ | GSA 2011 |
| | | $113.63/m$^2$ | Clark, Adriaens and Talbot 2008 |

(Source: Adapted from Brown et al. (2017))

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. 2010.
- 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%20 Rate%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 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.<br><br>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* (Carpenter, 2014) | 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.<br><br>Since 2014 release of guidance document, average uptake of GRGW across all Greater Melbourne councils increased. |
| 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.<br><br>Negligible increase in GRGW uptake since release of guidelines |
| 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.<br>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.<br>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<br>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 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<br>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<br>Green Building Policy (2001)<br>Clean River Rewards (2005)<br>Stormwater Management Manual (1999) | Incentives density bonus, grants for retrofits, mandatory | Eco-roof floor area ratio (FAR) bonus allows developers an extra 3 $ft^2$per $ft^2$ 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<br>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<br>The Seattle Stormwater Code<br>Seattle's Green Factor Policy | Financial incentives | Floor area ratio (FAR) bonuses determined on a case-by-case basis<br>The Seattle Stormwater Code requires storm-water filtration and retention of run-off that can be achieved through the installation of green roofs.<br>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 $75/m$^2$up to $100,000 through incentive program | From 2010 to 2015, 260 GR projects measuring 19.6 ha created, adding to a total of 444 GR in Toronto. |
| Tokyo, Japan | Tokyo Green Plan 2012; Tokyo Metropolitan Government Environmental White Paper 2006 and Nature Conservation | Financial incentives | All new private buildings greater than 1000 m$^2$and public buildings greater than 250 m$^2$mandated to have at least 20% greened roof or | From 2000 to 2001, total area of green roofs in Tokyo increased |

| | | |
|---|---|---|
| Ordinance; Tokyo 2020; The Green Building Program 2002 and Tokyo Metropolitan Condominium Environmental Performance Labelling System; 10 Year Project for Green Tokyo 2006; Japanese national building law 2005 | incur US$2000 fine. The Green Building Program assesses and 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 | from 5.24 ha to 10.44 ha.<br>57.2 ha of green roofs and walls installed between 2007 and 2010. |

***End of report***