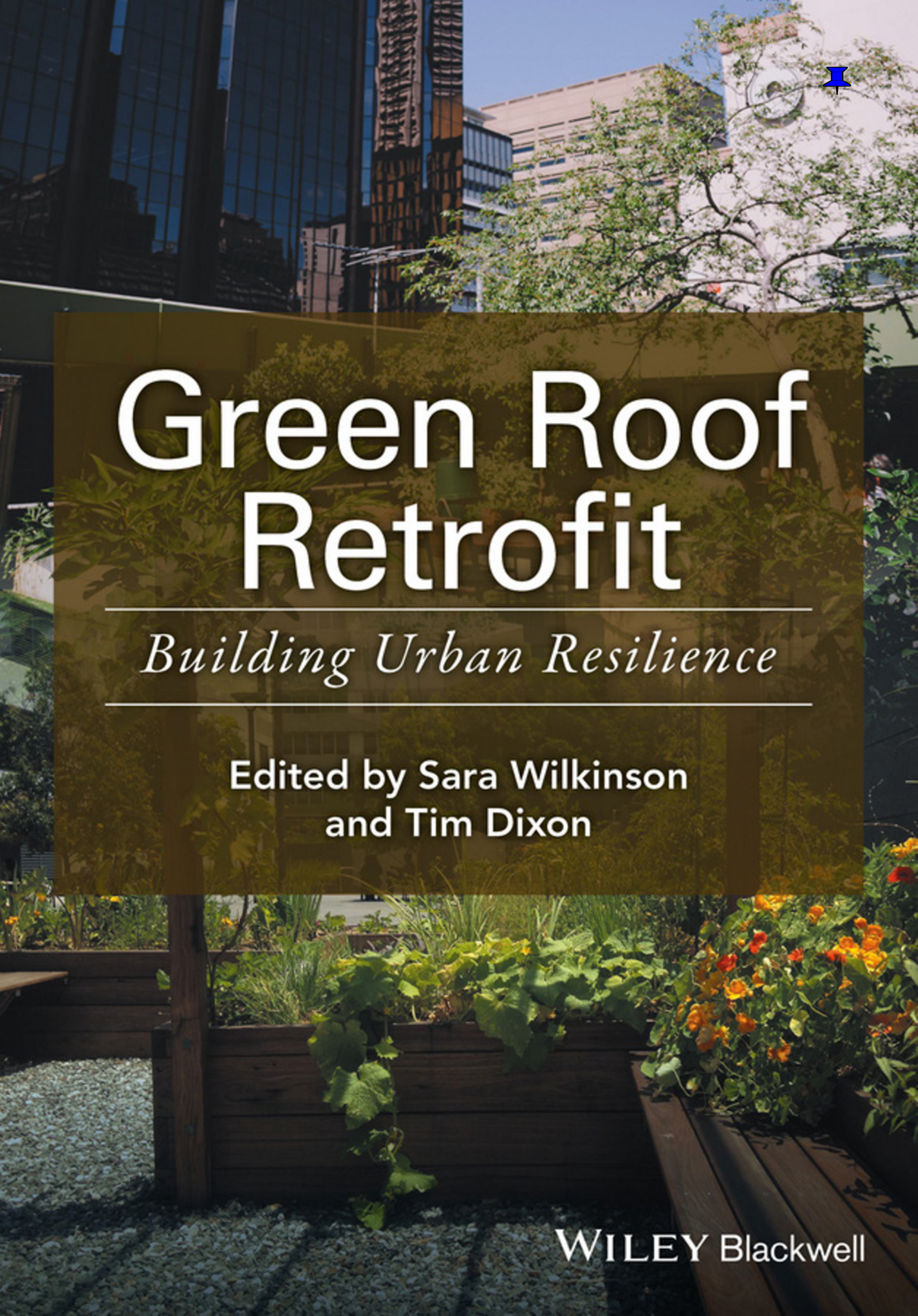

Green Roof Retrofit

Building Urban Resilience

Edited by Sara Wilkinson
and Tim Dixon

WILEY Blackwell

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Dr Ilaria Vanni is a teacher and researcher in the School of International Studies at the University of Technology Sydney. Her research is in the field of cultural history, with a focus on urban activism.

Dr Madalena Vaz Monteiro's PhD investigated the impact of plant structure and function on temperature regulation and the surface energy balance. Currently, she is involved with research aiming to better understand ecosystem services delivery by urban trees.

Foreword

When British Land first started creating green roofs on various London office buildings in 2004, it was challenging to take the idea from an ecologist's vision to the reality of a planted, healthy landscape. As a client, we were testing a new idea. We often needed to introduce our architects, structural engineers, contractors and property management partners to the concept – and then develop and test strategies together to deliver quality natural habitats on commercial buildings.

Over the years, as we have installed different green roof styles and commissioned studies, we have learned and shared many lessons. Today, we know more, for instance, about drainage and the potential for (or, more often, lack of) water retention. We understand the need for roof and terrace access to align with internal floor levels. We know which substrates last through British winters and how to plan for rooftop winds. We recognise issues and opportunities relating to visibility from surrounding buildings, and more. Happily, we have not been the only ones to recognise the benefits of green roofs and to learn these lessons.

Green roofs have gone mainstream around the world over the past 10 years. From London to Sydney, Hamburg to Istanbul, Singapore to Rio de Janeiro, they are a recognised strategy for urban green infrastructure. In London, there are now about 700 green roofs, covering 175,000 m^2. I am pleased that British Land has played a small but important part in this success story – creating green roofs on 12 new buildings and retrofitting three on existing buildings, with more on the way. Green roofs are no longer an unusual concept, and there are standard design formats and green roof types that architects and others understand and can design or install.

However, many of the technical benefits of green roofs remain to be analysed and understood. And so this book and the research it describes are much needed, particularly at a time when strengthening urban resilience is a critical policy issue.

Of particular relevance to cities and property owners are the prospects for retrofitting green roofs and the infrastructure benefits that all green roofs provide. Given the acres of existing roof space in cities around the world, what kind of buildings are particularly suitable for the additional structural load of retrofitting green roofs? With increasing incidence of flooding in many areas, how much rainwater can a 50 cm soil substrate attenuate, and can we make basement flood attenuation tanks correspondingly smaller? Also, how can we deliver green roofs that fulfil multiple functions, such as biodiversity, human enjoyment, aesthetics and food production?

Approaches to modelling urban heat island impacts are particularly useful for policy-makers. As climate change increasingly affects city temperatures, with knock-on effects on people's health and energy consumption, it is important to be able to calculate the benefit of green roofs for temperature management. Likewise, the proposed methodology for calculating the attenuation potential of green roofs should be of immediate assistance in factoring green roofs into strategies for our changing weather futures.

In addition, this book helpfully advances research on the social and biodiversity functions of green roofs for organisations interested in strategies to support human health, ecology and food production in urban areas. An in-depth analysis of a range of case studies explores how green roofs fulfil a range of functions – adding visual interest, creating garden spaces, growing food, introducing habitats for animal biodiversity and contributing to healthy environments through air-quality filtration, water management and temperature control. My colleagues are particularly interested in this social potential of green roofs. Following examples in the USA and Asia, we are exploring how to use our roof spaces to further promote people's health and wellbeing in the places we create.

I am delighted to recommend this book for its timely and substantial contribution to industry practice, and for improving our understanding of green roofs and their multiple benefits. The editors (Sara Wilkinson and Tim Dixon) have drawn together a diversity of authors to provide technical analysis of the practical and policy advantages of green roofs for cities facing climate change, with diverse case studies from Australia, the UK and Brazil. The research insights can also be tapped by property owners and designers to realise the commercial, social and environmental benefits of green roofs – from improving resource management in our cities to creating opportunities for bees, butterflies, birds and people to flourish in the built environment.

Green roofs have enormous potential in urban areas around the world. I hope that this book will aid cities and organisations in developing and growing acres of delightful and valuable habitats for people and the planet.

Sarah Cary
Head of Sustainable Places
British Land

Acknowledgements

Multidisciplinary projects are always challenging, exciting and fun, and working on this book together with our contributing authors has been no exception. The starting point was an increasing recognition that green roofs can really make an important difference in helping build 'urban resilience' (or the ability of our urban areas to be flexible and agile enough to bounce back from the anticipated and unanticipated environmental shocks stemming from rapid urbanisation, climate change and resource depletion). This is at the heart of the book, and is one of the key reasons so many cities globally are engaging with city-wide projects to green their environments – particularly so that they can adapt and mitigate for climate change.

The inspiration for this book arose from Sara Wilkinson's membership of the City of Sydney Technical Advisory Panel from 2012 to 2014. During that time, Sara met with a multidisciplinary group of academics, practitioners and policy makers to work on ways to increase the uptake of green roofs within the City of Sydney. Lucy Sharman was the City of Sydney Green Roof & Green Walls Officer, and being a member of the group really raised awareness of the multiple benefits of green roofs. Sara wishes to thank Lucy for that. As a building surveyor she was well aware of the need to retrofit our urban environments, but being part of the group increased the belief that collectively, we can create and deliver change. Membership of the group led to a number of new and exciting green roof research collaborations and projects with mental healthcare professionals, disadvantaged groups and sustainable urban agriculture entrepreneurs. Sara wishes to thank the RICS Research Trust, City of Sydney and NSW Environmental Trust for funding some of that research, which features in this book. Sara still works with other academic members of the Technical Advisory Panel group, who have contributed to this book. The Technical Advisory Panel has evolved and broadened now into the National Green Infrastructure Network (NGIN), comprising academics and practitioners from several Australian universities and national research organisations as well as NSW state policy makers.

Writing a book is always a journey, and we were fortunate on this particular journey to have the company and wise counsel of a truly international and multidisciplinary group of 20 academics. The geographical spread of knowledge and expertise ranged from Brazil to the UK, Europe and Australia, covering a wide range of climates and temperature zones. We really wanted to create a resource that covered every type of green roof retrofit and as many professional, technical, legal and stakeholder aspects as possible. The disciplines that have contributed include Building Surveying, Horticultural Science, Civil Engineering, Urban Planning, Architecture, Urbanism, Environmental Sustainability Consultancy, Entomology, Flood & Disaster Prevention Management, and Social Sciences. This is a rich and empowering environment in which to work, and we would like to thank all our contributing authors for their expertise and inputs to the text. This is the first book we are aware of that covers such a breadth of reasons to adopt green roofs from the retrofit perspective, and our aim is to facilitate the retrofit of greater numbers of green roofs as a result.

We also wish to personally thank the staff at Wiley Blackwell, Madeleine Metcalfe and Viktoria Vida for their support and help in delivering the book, and Sarah Cary of British Land for her foreword.

Finally, writing a book always takes time. Without the support and encouragement of family and friends the task would be much harder, so Sara would like to thank Ted, Ruskin, Maureen and Lindsay. Tim would also like to thank his family for all their help and support during the editing and writing process.

Sara Wilkinson and Tim Dixon

1

Building Resilience in Urban Settlements Through Green Roof Retrofit

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1.0 Introduction

The ‘challenge of achieving sustainable development in the 21st century [will] be won or lost in the world’s urban areas’ (Newton and Bai, 2008: 4) and a major issue is the contribution that the built environment makes to greenhouse gas (GHG) emissions and global warming. Typically each year 1–2% of new buildings are added to the total stock; it follows that informed decision-making in respect of sustainable adaptation of existing stock is critical to deliver emissions reductions. Within cities, local government authorities are encouraging building adaptation to lower building-related energy consumption and associated GHG emissions. Examples include San Francisco in the USA and Melbourne in Australia. For example, the City of Melbourne aims to retrofit 1200 commercial central business district (CBD) properties before 2020 as part of their strategy to become carbon neutral (Lorenz and Lützkendorf, 2008). Office property contributes around 12% of all Australian GHG emissions and adaptation of this stock is a vital part of the policy (Garnaut, 2008). Whilst Australian cities date from the early 19th century, the concepts of adaptation and evolution of buildings and suburbs are not as well developed or entrenched as in other continents like Europe. However, the issue of the sustainable adaptation of existing stock is a universal problem, which increasing numbers of local and state

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governments will endeavour to address within the short to medium term. In most developed countries we now spend more on building adaptation than we do on new construction. Clearly there is a need for greater knowledge and awareness of what happens to commercial buildings over time.

There are a range of definitions for 'urban resilience', and a marked lack of agreement as to what the concept means. However, there is an underlying meaning which covers the ability to bounce back from external shocks, and Meerow's et al's (2016: 39) definition provides a comprehensive and up to date focus: 'Urban resilience refers to the ability of an urban system….to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current of future adaptive capacity'. Green roofs therefore not only offer an important element in developing urban resilience across a range of scales (building, neighbourhood and city), but also in helping create adaptive capacity to deal with future environmental disturbances, both of which are key themes explored throughout this book.

This book is intended to make a significant contribution to our understanding of best practice in sustainable adaptations to existing commercial buildings in respect of green roof retrofit by offering new knowledge-based theoretical and practical insights, and models grounded in results of empirical research conducted within eight collaborative construction project team settings in Australia, the UK and Brazil (see Section 1.6 below). The results clearly demonstrate that the new models can assist with informed decision-making in adaptations that challenge some of the prevailing solutions based on empirical approaches, which do not appreciate and accommodate the sustainability dimension. Hence, the studies collectively offer guidance towards a balanced approach to decision-making in respect of green roof retrofit that incorporates sustainable and optimal approaches towards effective management of sustainable adaptation of existing commercial buildings; from strategic policy-making level to individual building level.

1.1 Background and Context: Green Infrastructure

Green infrastructure (GI) is a term used to describe all green and blue spaces in and around our towns and cities, and as such is very much a collective term embracing parks, gardens, agricultural fields, hedges, trees, woodland, green roofs, green walls, rivers and ponds (RTPI, 2013). The concept evolved for thinking in the USA and the 'greenway' movement, which highlighted the importance of using networks to manage green space and achieve multiple aims and objectives (Roe and Mell, 2013). In the North American context, therefore, GI was originally based around conservationist principles, and in Europe it has evolved into a holistic and cross-cutting agenda. In the UK, GI principles have now flowed into a range of policy, practice and guidance for built environment professionals. In England, national planning policy (through the National Planning Policy Framework, NPPF) (Communities and Local Government, 2012) places an emphasis on local planning authorities to plan strategically for networks of green infrastructure, and to take account of the benefits of GI in reducing the risks posed

Table 1.1 Examples of GI assets (TCPA, 2012)

Natural and semi-natural rural and urban green spaces	Including woodland and scrub, grassland (e.g., downland and meadow), heath and moor, wetlands, open and running water, brownfield sites, bare rock habitats (e.g., cliffs and quarries), coasts, beaches and community forests.
Parks and gardens	Urban parks, country and regional parks, formal and private gardens, institutional grounds (e.g., at schools and hospitals).
Amenity green space	Informal recreation spaces, play areas, outdoor sports facilities, housing green spaces, domestic gardens, community gardens, roof gardens, village greens, commons, living roofs and walls, hedges, civic spaces, highway trees and verges.
Allotments, city farms, orchards, suburban and rural farmland	
Cemeteries and churchyards	
Green corridors	Rivers and canals (including their banks), road verges and rail embankments, cycling routes and rights of way.
Sites selected for their substantive nature conservation value	Sites of Special Scientific Interest and Local Sites (Local Wildlife Sites and Local Geological Sites); Nature Reserves (statutory and non-statutory).
Green space designations	Selected for historic significance, beauty, recreation, wildlife or tranquillity.
Archaeological and historic sites	
Functional green space	Such as sustainable drainage schemes (SuDS) and flood storage areas.
Built structures	Green (or living) roofs and walls, bird and bat boxes, roost sites within existing and new-build developments.

by climate change. The NPPF defines GI as: ‘a network of multi-functional green space, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefits for local communities’ (Communities and Local Government, 2012: 52). Similarly, the UK’s natural environment white paper (HM Government, 2011) offers explicit support for green infrastructure as an effective tool in managing environmental risks such as flooding and heatwaves.

GI is seen very much as a multi-functional asset therefore and so relates to making the best use of land to provide a range of valuable goods and services (see Table 1.1). GI is also underpinned by the concept of ‘ecosystem services’, which are provided by the range of GI assets. Work by the UK National Ecosystems Assessment, for example, includes the following as key ecosystem services:

- Supporting services – those necessary for all other ecosystem services such as soil formation and photosynthesis.

- Provisioning services – such as food, fibre and fuel.
- Regulating services – including air quality and climate.
- Cultural services – such as recreational activities and wellbeing, aesthetic values and sense of place.

By thinking in this way about assets and services, it requires us to think more closely about the overall costs and benefits of GI as a service-producing infrastructure (UKGBC, 2015). One of the key attractions of GI is its multi-functionality, or its ability to perform several functions and provide several benefits on the same spatial area (EC, 2012). These functions can be environmental, such as conserving biodiversity or adapting to climate change, social, such as providing water drainage or green space, and economic, such as jobs creation or increasing property prices for owners.

As the European Commission (EC, 2012) suggests, a good example of this multi-functionality is provided by the urban GI of a green roof, which reduces stormwater runoff and the pollutant load of the water, but also helps reduce the urban heat effect, improves the insulation of the building and provides increased biodiversity habitat for a range of species. Thus it is this multi-functionality of GI that sets it apart from the majority of its 'grey' counterparts, which tend to be designed to perform one function, such as transport or drainage without contributing to the broader environmental, social and economic context (Naumann *et al*., 2011; EC, 2012). In this way GI has the potential to offer 'no regrets' solutions by dealing with a range of important problems and producing the maximum number of cost-effective benefits.

GI has a wide range of health and wellbeing and environmental benefits, through improved mental wellbeing and better physical activity, as well as reduced exposure to pollution and high urban temperatures (POST, 2013). Although in the UK some local authorities (such as Birmingham, London, Manchester and Plymouth) have developed GI strategies, this is variable, and with the exception of SuDS, new GI is not *required* by national legislation. In Australia, the adoption of GI is at state and city level and varies between states and cities. Plans and strategies have been made and adopted, only to be amended and moved to other agencies. As such, no coherent national policy exists currently.

1.1.1 Green Roofs

Green roofs are an important and growing element of GI. Green roofs have existed throughout history. Some of the earliest examples include the Hanging Gardens of Babylon in 500BC (Figure 1.1), the ziggurats of Mesopotamia and early Roman architecture (Berardi *et al*., 2014). Early Viking housing and mediaeval buildings also employed green roofs, with the technique also popular during the settling of the American west and in the vernacular tradition of Scandinavia. During the 20th century Le Corbusier also included them in his five points of modern architecture before the technology gained a real foothold in Germany (from the 1880s), then latterly in France and Switzerland (Magill *et al*., 2011; Berardi *et al*., 2014). In comparison, the UK is a relatively recent innovator in green roofs (although the

Figure 1.1 The mythical Hanging Gardens of Babylon.
Source: Wikimedia.

technology was used to camouflage airfield buildings during World War II) with some good examples in London (St James Tube Station), Manchester (Metropolitan University), Edinburgh (Royal Bank of Scotland) and Cardiff (Interpretation Centre).

1.2 Extensive and Intensive Systems

Green roofs (also known as vegetation or living roofs) are an example of a 'no regrets' adaptation measure that can serve multiple societal goals (Mees *et al.*, 2013). For example, they can offer a number of improved public ecosystem services (or benefits), such as increased biodiversity, improved air quality and mitigation of the urban heat island effect, as well as having the ability to harvest rainwater and reduce surface runoff. Similarly, they offer additional private benefits to property owners through improved energy savings, thermal comfort and aesthetics, and can potentially increase property values.

1.3 Valuing Green Infrastructure and Wider Economic Benefits

There are clearly a range of benefits that green infrastructure can bring to bear in adapting to, and mitigating for, climate change. Often these may be indirect, through reduced flooding risk, which can increase property values

Table 1.2 Potential benefits of green infrastructure in a retail centre (NRDC, 2013)

Green infrastructure improvements	40,000 sq. ft green roof with 90% green coverage 50 strategically planted medium-sized trees Bioswales and rain gardens that manage an inch of runoff from 2000 sq. ft adjacent impervious area 72,000 sq. ft permeable pavement parking lot Cisterns to capture runoff from 5000 sq. ft of roof area and use for irrigation
Building assumptions	Area: 40,000 sq. ft One storey with 40,000 sq. ft roof Lot area: 128,000 sq. ft Permeable area: 5000 sq. ft (covered in turf) Number of storeys: 15 Annual rent: $17 per sq. ft Annual retail sales: $2.182m per store
Potential benefits	Energy savings (reduced demand for heating/cooling): $3560 p.a. Avoided costs for conventional roof replacement: $607,750 NPV over 40 years Tax credit: $100,000 for installation Increased retail sales: $1.2m p.a. Stormwater fee reduction: $14,020 p.a. (with projected 6% increase) Total benefits (over 40 years) > $24,202,000
Non-quantified benefits	Water conservation (increase in net benefits) Increased property value (significant increase in net benefits) Reduced infrastructure costs (possible increase) Reduced crime (possible increase) Improved health and employee satisfaction (increase in net benefits) Reduced flooding costs (uncertain impacts)

(Molla, 2015), or perhaps contributing to, for example, a higher sustainability assessment rating through BREAAM[1] or LEED[2] (Berardi *et al.*, 2014). Perhaps key to understanding how cities could create real change in the built environment to bring about more sustainable outcomes is the commercial property sector, comprising offices, retail and industrial properties. Theoretically, at least, GI (including green roofs) could help increase property values, sales, save energy and increase workplace productivity. Research by NDRC (2013) highlights how, in an office building, the total present value of benefits can approach $2m and in a retail centre, $24m (with $23m of this in increased sales). In the case of the retail centre, present value benefits were calculated over a 40-year period using a 6% discount rate, and projected inflationary rates with the location assumed as being Philadelphia (Table 1.2).

GI can, in a general sense, also reduce lifecycle costs associated with private property improvements. Green roofs do not need to be replaced as

[1] Building Research Establishment Environmental Assessment Methodology.
[2] Leadership in Energy and Environmental Design.

frequently as conventional roofs – they are typically considered to have a life expectancy of at least 40 years, compared with 20 years for a conventional roof. For example, in a midsize retail building (with a 40,000 sq. ft roof), a green roof could avoid a net present value of over $600,000 in roof replacement costs over 40 years; a medium-sized office building, with a roof half that size, could save over $270,000. In some instances, green roofs can also reduce air conditioning system capital costs by allowing for use of a smaller heating, ventilation and air conditioning (HVAC) system.

1.4 Measures of Greenness in Cities and the Growing Market for Green Roofs

The Inter-American Development Bank (2014) suggest that Latin American and Caribbean cities need to measure and benchmark the amount of green space within their boundaries. A key indicator is suggested as being the amount of green space (in hectares) per 100,000 inhabitants, with a green rating as >50 ha, orange as 20–50 ha and red as <20 ha. Similarly, the World Health Organisation (WHO) has suggested that every city should have a minimum of 9 m^2 of green space per person. An 'optimal' amount would sit between 10 and 15 m^2 per person. Indeed, one of the greenest cities in the world is thought to be Curitiba in Brazil, with 52 m^2 per person, followed by Rotterdam and New York (Karayannis, 2014).

This increasing focus on green space and its role within a specific measure of urban sustainability has come at a time when there has also been an increasing focus on how cities can become more self-sufficient in terms of food production. Urban agriculture, which focuses on the development of localised food systems within and close to urban areas, has been a frequent feature of sustainable thinking in many cities (Hui, 2011). This is not surprising, given that cities occupy only 2% of the global land surface but consume 75% of the world's resources (Giradet, 2008), although by the same token cities can also be relatively efficient in terms of per capita consumption and emissions. There are many examples of what has been termed 'zero acreage farming' (Z farming), which implies the non-use of land/acreage, and which is a subset of the wider term 'urban agriculture' (Specht *et al.*, 2013; Thomaier *et al.*, 2014). Examples include open rooftop farms, rooftop greenhouses, productive façades and indoor farming. Clearly, green roofs which produce food are a key example of this growing phenomenon.

1.5 A Growing Global Market for Green Roofs

In contrast to other markets such as photovoltaics (PVs) or biofuels, the growth of green roofs and green walls (building-integrated vegetation, BIV) is often driven by city-level actions rather than national policies. Green roofs tend therefore to be driven by building code requirements and mandates or financial incentives (or both).

Previous estimates (Ranade, 2013) suggest that the green roof market globally will be $7bn, comprising a $2bn market for suppliers of polymetric materials and the balance for vegetation, installation and operations. This reflects falling costs, and also the use of incentives and regulation. By 2017, costs for green roof installation are expected to be cut by 28%, from an average of $38 per sq. ft in 2012 to $23 per sq. ft in 2017. Green wall growth is expected to be $680m by 2017. Europe has led the growth of the green roof market over the last 20 years: for example, Germany has 86 million m^2 of green roofs out of a total of 104 million m^2 and already 10% of flat roofs are green. Similar growth levels have occurred in Switzerland, where for example in Basel 70% of its green roof target has been met. Despite this, there is considerable opportunity for green roof growth in other European cities, such as London and Copenhagen. Wilkinson and Reed (2009) estimated that 15% of commercial office roofs in the Melbourne CBD could be retrofitted as green roofs. Despite this growth, the sector faces key challenges. Generally speaking, most green roofs globally have used sedum or drought-friendly irrigation, but green thinking is moving towards greater diversity in species – with payback periods of 30 years.

1.6 Overview of the Structure of the Book

As this chapter and the book as a whole emphasises, roofs can fulfil a multitude of objectives: attracting biodiversity, improving thermal performance, attenuating stormwater runoff, mitigating the urban heat island, providing space for urban food production, providing space for social interaction and engagement, and possibly space for the reintroduction of endangered species of flora and fauna. In most climates, therefore, green roofs can make a positive contribution to building resilience to climate change and help to arrest the speed of that change.

Furthermore, in addition to the primary reason for the retrofit, other benefits co-exist. For example, a green roof retrofit in northern Europe for improving thermal performance and saving energy not only results in less GHG emissions but also attracts biodiversity, reduces stormwater runoff, mitigates the urban heat island, and could provide space for the reintroduction of endangered species of local flora and fauna. Where access is provided, the roof could also provide space for urban food production and/or space for social interaction and engagement. These multiple benefits make it an attractive option.

In Chapter 2, structural issues are taken into account by Renato Castiglia Feitosa and Sara Wilkinson. Retrofit of the existing stock of buildings is vital, as only 1–2% is added annually to the total stock of buildings, and around 87% of the buildings that we will have by 2050 are already built (Kelly, 2009). With regard to green roofs, the overriding issue is one of structural capacity to accommodate the additional loads that a retrofit brings. This chapter considers the technical and engineering considerations that stakeholders need to consider when evaluating green roof retrofit potential. For example, existing structure, load-bearing capacity, access, power and water supply, orientation, exposure to sunlight and overshadowing, and occupational health and safety. In short, how to determine what type of green roof is suited to the structure.

Issues of urban heat islands are raised in Chapter 3 by Paul Osmond and Matthias Irger. The global climate change and the urban heat island (UHI) phenomenon – whereby cities absorb and release more heat than the surrounding countryside – carry growing potential to make urban life at particular times and places an exercise in low-grade misery. The mitigating role of urban vegetation and green spaces, reflective materials and strategies for reducing the release of heat from human activities like transport and air conditioning are increasingly well understood. Green roofs have also been widely recognised as playing a part in UHI mitigation. This chapter reviews the literature around the microclimatic effects of green roof retrofitting and presents a model based on detailed remote-sensing data for metropolitan Sydney, Australia. We apply this model to explore the effects of installing extensive green roofs on 100% and 50% of rooftops across the variety of urban form typologies which characterise Sydney's built environment. The results suggest a modest but real reduction in heat island effects.

Thermal performance is the focus of Sara Wilkinson and Renato Castiglia Feitosa in Chapter 4. Green areas have diminished in big cities and with increasing temperatures, deterioration of air quality is a common result. Consequently, there is a rise in air pollution and GHG emissions, the costs of air conditioning, and mortality and heat-related illness. Due to the lack of space in urban areas, green roof retrofit is a feasible alternative to this problem. Green roofs improve the insulating qualities of buildings, attenuating heat exchange through inadequately insulated and poorly sealed roof structures. After a review of the literature, this chapter reports an experiment on two small-scale metal roofs in Sydney (Australia) and Rio de Janeiro (Brazil) to assess the thermal performance of portable green roof modules. In each site, two identical roofs, one covered with modular lightweight trays planted with succulents and the other not, had their internal temperature recorded simultaneously and compared. Green roofs were showed to attenuate housing temperatures, indicating that green roof retrofitting could lower the cooling energy demand considerably.

In Chapter 5, Jessica Lamond, David Proverbs and Sara Wilkinson describe research demonstrating the assessment of whether to retrofit with green roofs as a means of attenuating stormwater runoff. The problem of pluvial flooding in terms of financial costs and the impact on our urban settlements is the starting point for a discussion on the potential of retrofitted green roofs as a mitigating measure. A range of technical specifications for stormwater roofs, and critical issues to consider in retrofit of existing buildings, are evaluated. Theoretical frameworks of the distributed benefits of green roofs are presented, and a methodology to estimate the potential for stormwater attenuation of green roof retrofit at the city-scale level is described in detail. The chapter reports on recent empirical research undertaken in two cities with very different climatic conditions: Melbourne, Australia and Newcastle, UK, at city-scale level. Having examined the city-scale level, a second illustrative case study at an individual building