Experts find it difficult to agree on a definition of a neighbourhood, but most people intuitively sense where their neighbourhood begins and ends, because it is an area centred on their home or place of work, where they meet and greet people they know on a regular basis. When people do not regularly meet and greet, a sense of neighbourhood fades. Within that neighbourhood there may be the public realm, including the local parks and streets as well as the buildings in which people live and work. The neighbourhood or precinct is the building block for the green city and this is where the greatest potential lies for local projects, initiated, supported and sustained by citizens. Buildings are often the main focus. Buildings are important and are considered later in this chapter, but a collection of buildings is not enough on its own to create a functioning or attractive neighbourhood. Small-scale neighbourhood projects are often overlooked by planning and design professionals, who tend to be assigned to (and are often entranced by) large-scale expensive schemes which feature on city-wide maps; however, thousands of small neighbourhood projects can coalesce and combine to transform districts and, ultimately, whole cities. This
chapter considers small-scale projects at neighbourhood and building scale, which will ultimately constitute the transformational change which many of us now seek.

Living Streets

Clearly the kind of social network that depends on so-called face time will be disrupted if people are in their car and not on foot or on their bike. Donald Appleyard’s pioneering study in the late 1970s found that the residents of streets with light traffic had three more friends and twice as many acquaintances as similar people on otherwise similar streets with heavy traffic. The perception of safety is also important, because children are less likely to be corralled indoors by nervous parents, and older people will feel the confidence to venture out, if motor vehicle traffic is limited and if there are parks, gardens and squares to relax in. In the 1970s, in the Netherlands, Woonerfs were first established. They are streets where pedestrians and cyclists have priority over motorists and speed limits are kept low. By the turn of the century there were more than 6000 such areas in the Netherlands and the idea had spread across much of Europe. Once it was appreciated that promoting eye contact between pedestrians and motorists is more effective than speed limit signs and regulations, the shared space concept, where all users have equal priority, became the new objective. The living streets concept takes the idea a stage further, with pedestrians given priority over motor vehicles. Paving treatments, chicanes, the absence of kerbs and the provision of seating

Figure 9.1 Brighton New Road. Street improvements by Gehl Architects, where motorists and pedestrians share space on equal terms.
are used to create streets where motorists drive slowly and tentatively. Signs and barriers, which have been shown through research by Jan Gehl and others to have no influence on safety, are kept to a minimum, so that streets can be de-cluttered and made more inviting. Although shared space or living streets projects are not primarily about greening, they do encourage a healthier lifestyle (by encouraging walking and cycling) and de-cluttering often does provide opportunities for planting trees or creating planters or rain gardens. With more people taking their time to enjoy the street, they are surely more likely to take an interest in the comfort and beauty provided by vegetation.

Standardising the Neighbourhood

In the developed world, the participation of citizens in the greening of neighbourhoods has been relegated to an indirect role, whereby people are primarily consumers of local government services. In other words you can complain to an official or politician if something irks you, and if a defect is confirmed because of a lack of conformity with official standards or guidance, and if it is affordable, action will be taken. This illustrates the importance of standards, but greening falls behind with this approach because, until recently, standards have been compiled only for streets, paving, drains and lighting, with vegetation considered an optional extra. Municipalities are good at creating and maintaining urban forests of trees in parks and streets but they are not so adept at maintaining landscapes at ground level, where mechanisation has led to the preponderance of species-poor grasslands. Coupled with these difficulties is the widespread ignorance of the various benefits of vegetation and soil and a commonly held belief that the provision of planting is a matter of aesthetics alone. When local authorities have experienced difficulties with vegetated fragments of ‘municipal landscapes’, especially small sites and traffic islands, there has been a tendency to ‘pave and forget’ in the mistaken belief that asphalt deserts save time and money. This has not gone unnoticed by the guerrilla gardeners, now operating in 30 countries, who, frustrated by the sterility of their neighbourhoods, have taken action and planted their own vegetable or flowers gardens, often under the cover of darkness to avoid official interference.

Design Your Own Park

Evolutionary biologist David Sloan Wilson studied the distribution of altruistic people in his home town of Binghampton, New York and noticed how clusters of these altruistic people occurred in various
locations. Altruistic people (Wilson calls them ‘prosocial’) seem to attract and foster more altruistic people. He wondered if areas where there appeared to be little altruism could be turned around by initiating projects where people were given an opportunity to cooperate with their neighbours; this tends to bring people together and create a positive mood. In order to test his ideas on the ground, he has initiated five Design Your Own Park initiatives where people are creating parks of their own design on neglected ground. The approach adopted in these projects is based on the ideas of Elinor Ostrom, who won the 2009 Nobel Prize for economic science. Ostrom showed that people can cooperate to manage common resources to great effect if goals are defined, costs and benefits are shared equally, decision-making is through consensus, conflict resolution is fair, the group has autonomy and outside relationships are carefully structured. For example, Ostrom found that primitive communal farmer-managed irrigation systems are more efficient and effective than equivalent engineer-designed official government projects. The lesson is that people can make a good job of managing their own common ground if the right frameworks are in place. This can bring people together to do even more.

A Phoenix Rises

When citizens do participate in neighbourhood greening, the layout of space tends to be quite different from that typically found in conventional parks. Parks become more like gardens, are more intimate and have more character, with a high diversity and high density of planting. An example of this is the Phoenix Garden in London’s West End, created by volunteers in 1984 on what had been a Second World War bombsite (see figure 9.2). The involvement of a number of hands-on volunteers (including the author) in the establishment and maintenance meant that a large number of features are included in a small area, including many trees, shrubs, trellises, planting beds and seating, as well as a pond, compost bay and shelter. Installations from the early days that didn’t work, like a sand pit, have been planted or adapted. As the garden has matured, there are minor difficulties created by perhaps a little too much shade as closely planted trees grow more quickly than people imagined they would, but the desire to increase biodiversity has given the garden a new impetus, with planting designed to attract wildlife, including bees and birds. The Phoenix Garden is little known outside of the immediate neighbourhood but is a great success with both local residents and workers, and is a venue for a number of regular community events. It achieves a great deal in a small space and has an intimate charm, which is absent from many municipal parks.
Growing Their Own

The transfer of ownership and management from government to local communities, so-called ‘asset transfer’ tends to be focused on buildings, but is likely to be increasingly used to release green space in the future. Current concern regarding the high cost of public services is encouraging officials and politicians to look closely at more widespread ownership and management of urban green space by local groups, not only for the provision of conventional parks but also to cater for the renewed interest in urban vegetable growing (known as allotments in the UK). In England and Wales, the Small Holdings and Allotments Act of 1908 obliged local authorities to provide vegetable plots to citizens at an affordable rent. A post-war decline in enthusiasm for this kind of gardening eventually led to sell-offs and redevelopment of some underused plots, but the decline has now been reversed, with

Figure 9.2 Phoenix Garden, established and maintained by the local community in London’s West End.
Ecosystem Services Come to Town

shrill demands for new plots to be created. Now, organisations like the heritage charity, the National Trust, and local associations are helping to address the demand by providing new sites.\(^9\) Within Europe there are allotment gardening federations in Austria, Belgium, Denmark, Finland, France, Germany, Luxembourg, the Netherlands, Norway, Poland, Slovakia, Sweden, Switzerland and the UK representing some 3 million people. In the USA, also, there are indications that local cooperation to encourage and foster food gardening is on the rise.\(^{10}\)

Learning from Squatter Settlements

A number of researchers have looked carefully at the self-organised social and spatial arrangements of spontaneous informal (squatter) settlements and, contrary to conventional belief, have found a number of interesting and positive aspects. Neha Goel, who has studied the Khichripur slums of Delhi, India, sees squatter settlements as a self-organising process driven by family, clan and taboo, rather than simply a chaotic collection of buildings.\(^{11}\) Although squatter settlements are characterised by poverty and inadequate infrastructure, they are remarkably efficient, flexible and resilient and provide people with attractive dwellings and workplaces with an excellent family and cultural life. People are often happier in squatter settlements than the planned and designed housing ‘projects’ into which they are moved by city authorities as slums are cleared. Architects and town planners are becoming interested in learning from the village-like urban vernacular, with its curved river-like pattern of car-free streets and hierarchies of public spaces (chowk in Hindi and Urdu), which form at junctions and often feature shade trees and water tanks (see figure 9.3). Private activities often spill over into, and animate, public spaces. Dwellings have a number of characteristics that provide adaptation to climate, including shared and thick external walls which increase shade and provide thermal mass and shaded courtyards to promote convective cooling. Rooms are multi-functional, carefully decorated and managed, and their use changes throughout the day. Owner-occupants are intimately involved in the building process – everyone knows what and how to build. The building techniques used suit everyone. Building forms are conservative and devoid of pretentious architectural styling, but there is a high level of flexibility of size, layout and decoration to suit individual families. The aim for those involved in urban renewal must surely be to take the attractive scale, organic form, flexibility, levels of participation and popularity of informal settlements and add to this the expensive – and by its nature centrally organised – infrastructure required to ensure health. There is also much to learn from the way that ordinary citizens are able to create such interesting places. Although it seems improbable that governments will ever relax their
control enough to allow people to self-build whole districts, modern easy-to-use design software has the potential to allow citizens to design and test virtual informal settlements. Such citizen-based virtual schemes could be translated into conventional drawings and documents by design professionals.

Rain Gardens

Community participation is definitely a resurgent force, but even where management remains with local government (as it will for most of the public realm) policy demands for the restoration of biodiversity and better storm water management are changing the way that neighbourhood green spaces work. Although watershed or catchment management provides an overarching framework for the planning of sustainable drainage, individual projects are often opportunistic and initiated at the neighbourhood level. A good example of this phenomenon is that of the rain gardens that are springing up in neighbourhoods throughout the USA. Authorities are devising clear policies, and knowledgeable and enthusiastic officers are providing excellent support in the form of technical advice; however, the invention and persistence of people is turning once overlooked and underused places into attractive and low-maintenance green spaces that are also a fully functioning parts of the drainage system. An excellent example
of partnership between the authorities responsible for catchment management and local involvement with neighbourhood greening is the Liberty Lands Park in Philadelphia, established as a community park in the 1990s. This 8000 m² park was renovated in 2009 in order to capture and store storm water from adjacent roads. Water is cleansed by a series of rain gardens before it is stored in cisterns. It can then be used for irrigation if required. Another fascinating and inspiring way that neighbourhood greening is flourishing in Portland, Oregon, is where streets are being modified to include rain gardens. Conventional traffic engineering often involves verges and islands comprised of hard materials, but in Portland, where slope and topography permits, and often in places identified by local residents, kerbs are cut through to allow surface water to feed shallow basins filled with permeable soil and planted with a range of plants to suit the various conditions. (The rain gardens do flood after heavy rain but this is temporary and there are areas around the margins that remain fairly dry.) This diversity of topography, hydrology and predominantly native planting promotes biodiversity, and any trees planted nearby thrive because of the increase in soil moisture.

They Paved Paradise

Roads lead to parking lots, big and small. It has been estimated that parking lots make up 10% of the land surface of American cities so the problem is a significant one. Parking lots are some of the most barren places, quickly shedding rainfall, making a major contribution to urban heat islands and releasing oils and other pollutants into drains. The City of Toronto, Canada, has identified this problem and in 2007 issued new guidance to assist designers, developers and reviewers of schemes to widen their objectives. This guidance makes it clear that the city will expect better consideration of the needs of pedestrians and cyclists in the future, and that existing trees and soils should be retained wherever possible. Porous paving will be used where feasible, and new landscape beds and lines of shade trees will be consolidated into adequately sized features. Importantly, the guidance indicates that rainwater and snowmelt should be directed into swales, which allow infiltration, evapo-transpiration and water reuse to take place. Similar guidance has been issued by many other North American and Australian cities, and many similar features are required by statute in Germany, Austria and Switzerland.

Clapton Park Estate

The Clapton Park Estate is a social housing scheme of about 1200 dwellings in Hackney, one of London’s toughest inner city boroughs (see Figure 9.4). Since 2002, the management of the estate has been
undertaken by a small independent contracting firm led by John Little. He has ecological knowledge and engages with residents, both on a formal level through the residents’ body and the managing agents, but also informally through open days and chats during routine working visits. This simple formula has led to a transformation of the grounds. Boundaries that were routinely treated with herbicide are now full of wild flowers and former species-poor lawns are now being used to grow vegetables. People are involved and the estate is a nicer place to live in, and the encouragement of biodiversity is not seen as a problem but a desirable goal.

People of the Trees

The planting of trees is probably the simplest and most popular way of greening streets and neighbourhoods. Trees were widely planted in cities during the 19th century for aesthetic purposes and have created
Ecosystem Services Come to Town

a legacy of magnificent avenues, which in some cases are coming to the end of their life. This has prompted debate over whether or not like should be replaced with like or whether different, less problematic species should be used. For example, the great size of some trees as they reach maturity has caused concern in some cities, and trees have been blamed for exacerbating problems with older buildings with inadequate foundations, particularly on clay soils, which can shrink in drought and swell when re-wetted. Pollution-tolerant species survived the soot and smog (for example, London plane and hybrid lime in London) and people came to realise that trees actually help to improve air quality by filtering particles and absorbing pollutants. More recently the role of trees in maintaining a pleasant microclimate, supporting wildlife, calming nerves and boosting property values has also become more widely appreciated. Information regarding the appropriate trees to plant is available from most local authorities, and urban tree planting is ably promoted by a number of non-governmental organisations such as Trees for Cities and the Tree Council in the UK, the National Tree Trust in the USA, Planet Ark in Australia and the International Tree Foundation in Africa. China leads the world in tree planting initiatives, having held an annual tree planting day for more than 30 years, with more than 540 million people involved in tree planting each year.

Tree Pits

Finding the space to plant trees in the inner city can be a real challenge, and there are whole districts where tree planting is not feasible. Trees can hinder access, block light and interfere with tall vehicles and lighting poles, signposts and overhead utilities, but it is the plethora of underground services that take up space under the street, which causes probably the most difficulty. The average modern city street has underground electricity, gas and telecommunication cables, potable water pipes and sewers, backfilled with aggregate, leaving little natural soil – inadequate and often unsuitable conditions for tree roots. Although the volume of a tree pit will vary according to species, climate and soil conditions, a typical tree requires 20 m$^3$ of soil at maturity. At the point of planting, an excavation for a tree pit will normally be 900 mm by 900 mm wide and 750 mm deep (a volume of only 0.6 m$^3$), but of course the roots will spread beyond this as the tree grows. In the recent past, common practice has been to keep tree pits separated from drainage systems, but there is increasing interest in incorporating tree pits into sustainable drainage systems, to the benefit of the drainage system, but also the tree. In the past decade in Australia so-called bio-retention tree pits have been used to receive surface water runoff, with excess water overflowing into conventional
The idea is not entirely new: for example, the patio of the oranges by the Grand Mosque in Cordoba, Spain was created in the 10th century (see Figure 9.5). Each tree pit receives surface runoff, and when they are full a channel in the surface paving sends water to the adjacent pit and so on.

Tree Trenches

Given the congestion and complexity of the underground environment of the modern street, the difficulties of finding space for trees and the urgent need to plant more trees in the face of climate change, efforts are underway to routinely provide purpose-made trenches for trees. ‘Tree trenches’ are a useful way of protecting underground services from roots but can also become a fully integrated component of the surface drainage system, being interconnected with...
underground water storage systems (storm cells) and with outlets that enter other downstream components or conventional drains. Examples of this approach can be seen in cities such as Nijmegen in the Netherlands and Philadelphia in the USA\textsuperscript{23} (see figure 9.6).

**No Space?**

Sometimes, however, despite our best efforts, no room can be found for street trees, and a different approach is required. For example, in the City of London (the historic core of London) a combination of narrow, often medieval streets and modern underground services means that frequently the only opportunities for greening are on walls and roofs, and there is often an expectation that when a site is redeveloped, new space is provided at street level in the form of new piazzas or passageways under buildings. This approach leads to a blurring between the public and private realms, especially at street level, and an increasing reliance on the buildings as the platform for urban greening. With the heavy structures that predominate in city centres, there are many opportunities for retrofitting soil and vegetation, as is being demonstrated for instance at The Museum of London, in the Barbican, where the author’s firm, the Green Roof Consultancy, is advising on the installation of roof gardens, extensive green roofs and living walls.\textsuperscript{24}
Energy Efficient Buildings

For many, the greening of buildings and the built environment begins and ends with the reduction in energy consumption through intelligent design, high levels of insulation and the installation of efficient appliances. This approach is exemplified by the Passivhaus approach, conceived by Bo Adamson of Sweden and Wolfgang Feist of Germany in 1988. This meeting of minds led to the foundation of the Passivhaus-Institut in Darmstadt, Germany in 1996, and by 2003 the idea had gained a foothold in the USA. In Europe, the target of the Passivhaus approach is to reduce energy demand for space heating and cooling to less than 15 kWh/m²/year, which represents a reduction of more than 75% of the energy consumed by equivalent buildings meeting current US or UK standards. Clearly this approach sets new standards that, once adopted, will result in huge reductions in energy use and associated CO₂ emissions. Of course, I commend energy conservation, but argue that greening should go far beyond this.

Water Efficiency

A similar approach, of increasing efficiency, can be applied to water consumption. The collection, cleaning and pumping of potable water is achieved through the consumption of surprisingly large quantities of electrical energy, which has a carbon footprint – water is said to have ‘embodied carbon’. In developed countries this usually exceeds 1 tonne CO₂-equivalent per million litres (tCO₂e/Ml) and may even exceed 3 tCO₂e/Ml if desalination is used. Water itself can be in short supply, and even where supplies appear to be secure, water that has been removed from rivers and aquifers may often cause the decline of ecosystems and the drying of the landscape. Water saving strategies include: metering (so as to be able to monitor consumption), prompt repair of leaks, having showers instead of baths and the use of water-efficient appliances.

Autonomy

Beyond efficiency and conservation, however, there is the move towards more autonomy. A building can generate electricity through the use of photovoltaic (PV) cells or wind turbines. A typical domestic PV installation can generate around 40% of the electricity an average household uses on an annual basis. Heat can be collected from the sun using solar hot water or from the ground using ground source heat pumps. Rainwater can be harvested from roofs and stored for reuse in toilet flushing or irrigation, and grey water (wastewater from washing)
can also be treated and reused (although care is required in the use of grey water because it can contain pathogens).²⁸,²⁹

Building-integrated Vegetation

So the building is efficient in energy and water consumption. It may generate some or all of the energy it consumes. It may collect some of the water that it consumes. It will have the necessary systems in place to reduce and manage waste. Materials used in construction will have been chosen in order to minimise embodied carbon and to be locally appropriate. Now there is more that can be done. By bringing soil (growing media) and vegetation onto and around the building, biodiversity can be increased, but there will be additional benefits in terms of the thermal performance of the building, improvements to the local microclimate and reductions in surface water runoff.

A Coat for Buildings

Unlike most animals, which, if they are living in the open, have fur or hair to protect them, most buildings are ‘naked’, with building materials exposed to damaging ultraviolet light and extremes of temperature. By shielding these materials with soil and/or plants, their life can be extended by decades, and if the soil is deep enough, centuries. The
asphalt-covered reinforced concrete roofs of the Moos Lake water filtration plant, constructed in Wollishofen, Zurich, Switzerland, in 1914, were exposed to the sun in their first summer of operation, causing the water within the buildings to overheat. Warm water can promote the growth of pathogenic bacteria so action was required. The solution was to cover the roofs with layers of gravel and local soil (see figure 9.8) in order to shade the structure and promote evapo-transpirative cooling. In 2005, more than ninety years after construction, the waterproofing under the gravel and soil was inspected in a few locations and found to be in excellent condition. Exposed asphalt would not normally be expected to last more than 25 years before requiring repair and it can therefore be seen from the experience in Zurich that a green roof may more than quadruple the life of the waterproofing layer.

Value of Shade

Leaves may protect a building from the sun, intercepting up to 90% of the sunlight, using some of the energy in photosynthesis and reflecting the remainder. The reflectivity, or albedo, of leaves varies from a factor of 0.7 to 0.85, which is comparable to that of ‘cool’ roofs, which are painted white to reflect the sun’s heat. This protection can be in the form of an overshadowing tree, or scrambling, trailing or climbing plants closer to the structure. Vines have been shown to reduce the surface temperatures of walls by up to 20°C on hot summer days and to reduce interior temperatures by more than 5°C in similar
Deciduous plants may be particularly useful in temperate climates, shielding the building from the summer heat but allowing welcome winter sun to flood in. Evergreen climbing plants like common ivy can also have a beneficial effect in winter, reducing wind chill and creating a blanket of air on an outside wall. It is a widely held misconception that climbing plants, like common ivy, damage buildings. Research at Oxford University has shown that ivy provides a protective blanket around buildings, which extends the life of the building fabric. If you are still not convinced and have concerns about plants clinging directly to buildings you can grow climbing plants on wires or frames, which can be removed for maintenance purposes (see figure 9.9).

Living Walls

Using climbing plants is an ancient and simple way of vegetating facades (or even roofs); however, during the last decade or so a number of new techniques have emerged. Inspired by the way tropical
epiphytes thrive on tree trunks with no soil, the French botanist Patrick Blanc has pioneered the practical use of hydroponic living walls, where several species of plant of varying size and form grow from a thin layer of textiles attached to a backing board (see figure 9.10). His installations adorn a number of high-profile buildings throughout the world and have encouraged others to follow. Modular, scalable living wall systems have now appeared on the market and the competition is growing. Some systems are hydroponic (without soil) and rely on mineral wool, like the Biotecture system, whilst others consist of high-density polyethylene (HDPE) modules, which have cells that can be filled with growing medium and planted with a wide range of species. Other systems are based on plastic containers held in frames and fabric pockets. Living walls are irrigated, usually by means of pipes and emitters with varying levels of sophistication in terms of control. Some walls are periodically soaked, whilst others have a high level of automation, with sensors, which can trigger alarms or text messages if the wall dries because of component failure of the water being
Living walls are reliant on irrigation and in most climates most species currently used will die if the water supply is interrupted. Wherever possible, captured rainwater or treated grey water should be used to irrigate living walls. Look at a broken downpipe on a shady wall and in most cities you will see wild ferns, mosses and other plants that grow from the brickwork and masonry. This suggests that it would be possible to load a modular wall with substrate and direct rainfall through it in order to create a low maintenance living wall that does not require irrigation. For the time being, however, living walls are planted with a range of popular horticultural plants. Invention and creativity is possible, but for success good horticultural knowledge is required, with planting carefully matched to aspect, local microclimate and the region in which the wall is created. Even with the benefit of irrigation, highly exposed walls that receive more sunshine are more difficult to cultivate than shady walls because of the high levels of evapo-transpiration, high exposure to sunlight and higher fluctuations in temperature that occur. The irrigation of living walls can be turned to good effect. Irrigation water can be passed through heat exchangers inside a building and the heat lost from the living wall. This has already been achieved in Hatton Wall in London, where heat from the computer servers in an office is being pumped to a Biotecture living wall in an outside courtyard. Even where heat exchangers are not used, however, living walls can create much cooler exterior microclimates and can shield what would otherwise be overheated high-density building materials from the sun’s rays.

Cooling Effect of Green Roofs

Exposed building materials are usually dense and often dark, absorbing and storing the sun’s radiation and reradiating some of this energy at night (the primary cause of the urban heat island effect). Where soil (or artificial growing medium, also known as substrate) occurs, this stores water, which may be evaporated from the soil and lost through the stomata of plants as transpiration. This evapo-transpiration provides cooling, which immediately reduces the transfer of heat into the building. This effect has been clearly demonstrated in Chicago, where the thermal performances of City Hall (which has a green roof) and Cook County Hall (with a conventional roof) are continuously monitored. On hot summer days, the effect of the green roof is to slow down the warming of the building in the morning, to reduce peak temperatures and to accelerate cooling in the late afternoon. The maximum air temperature difference above the green roof and the conventional roof is 9 °C. This cooling has a significant effect on the interior temperature on the upper floors of City Hall and savings in air-conditioning costs are reported to be $5000 per annum. The National
Research Council in Canada has compared a 150 mm deep green roof with a conventional roof and found that the green roof reduced the energy demand for cooling by 75% – equivalent to 6.0 kWh/m²/day. In various studies the reduction in summer midday temperature in rooms beneath green roofs, when compared with similar rooms without green roofs, has been shown to be between 5 °C and 7 °C. It seems that green roofs really do work in terms of keeping buildings cooler in summer.

Green Roofs, Rainwater Attenuation and Cooling

For any given green roof substrate (growing medium), the greater the depth, the greater its water holding capacity. An extensive green roof is a low-maintenance roof where low growing vegetation is usually left to reach its own equilibrium. A typical extensive green roof with 100 mm of substrate absorbs about 50% of the rainfall that falls upon it each year and this water provides valuable evaporative cooling (see figure 9.11). The deeper substrates of intensive green roofs (roof gardens) absorb even more rain and provide even more evaporative cooling. Thermal imaging and detailed studies by Marco Schmidt and his colleagues at the Technical University of Berlin, shows how temperatures soar on exposed roofs and walls, but stay close to ambient temperature where substrate and vegetation facilitate cooling. The ability of green roofs to absorb rainwater is not only useful in terms of providing evapo-transpirative cooling but is also a useful source

<table>
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<tr>
<th>Type of green roof</th>
<th>Substrate depth (mm)</th>
<th>Typical vegetation</th>
<th>Water retention as % of annual rainfall</th>
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<td>Sedum</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>Sedum</td>
<td>45</td>
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<td>60-100</td>
<td>Sedum, herbs</td>
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<td>100-150</td>
<td>Sedum, herbs, grass</td>
<td>55</td>
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<tr>
<td></td>
<td>150-200</td>
<td>Herbs, grass</td>
<td>60</td>
</tr>
<tr>
<td>Intensive</td>
<td>200-250</td>
<td>Lawns, shrubs</td>
<td>60</td>
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<td>Lawns, shrubs</td>
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<td></td>
<td>&gt;500</td>
<td>Lawns, shrubs, trees</td>
<td>90+</td>
</tr>
</tbody>
</table>

Figure 9.11 Annual rainwater absorption of various green roofs.
control mechanism in sustainable drainage systems, where the purpose is to reduce the speed and volume of surface water runoff following heavy rainfall. In the absence of green roofs, rainfall quickly enters drains and can overwhelm drainage systems, causing localised flooding. Even when local drains and streams can cope, the sudden pulse of water can cause scouring or erosion and result in losses of biodiversity or flooding downstream. Green roofs can combine with rainwater harvesting and other sustainable drainage techniques to reduce or eliminate these problems; indeed, they can be so effective that it is possible to build zero-discharge developments, where for all but the most extreme weather events no surface water flows from the site, reducing the need for investment in expensive conventional drainage.

Green Roofs Need the Right Substrate

For a wide range of benefits to be realised from the use of green roofs – increased comfort, improved microclimate, better thermal performance and slower drainage – it is recommended that sufficient quantity of substrate is used to absorb water. In practice, ultra-lightweight green roof systems tend to dry out rapidly in summer and therefore a minimum substrate depth of 100 mm is recommended in temperate climates and an even greater depth in arid places. In addition, it is advantageous to use special green roof substrate mixtures that have been devised to be lightweight, but have a high capacity to absorb water and are also free draining. Organic materials do absorb water well, but they should also be limited at roof level, where irrigation is not provided, because they dry and decay and are easily blown away. German guidance recommends that organic material in green roof substrates does not exceed 20% by weight, because large quantities of organic material also constitute a fire risk when dry.41

Green Roofs for Biodiversity

The most important objective in the management of the environment must be the maintenance of biodiversity and the habitats that support it, because without this we cannot survive. Buildings, and in particular green roofs, can play a valuable role in providing habitat, especially for invertebrates and birds. Buildings are also important as roost and hibernation sites for bats. Where the strength of the building structure is adequate and the soil depth is sufficient, a wide range of vegetation can be grown, including trees and shrubs and it is even possible to establish ponds and other wetland features on roofs. Ayako Nagase and her colleagues at the Chiba University in Japan have described how green roofs are increasingly being used to provide wildlife habitat
in their country. Buildings strengthened to withstand earthquakes have the necessary strength to bear the weight of substrates that may be 500 mm or more in depth. At her 10th floor study site, which received no maintenance for eight years, a wide range of predominantly native trees and shrubs have been planted. Although not all trees thrive in 500 mm of substrate, some do, and the extra habitat provided by shaded leaf litter complements pond features and other wildflower areas more typical of green roofs. The creation of extensive roofs designed for biodiversity was pioneered in Switzerland by Stephan Brenneisen. In the 1990s he had become concerned with the loss of Rhineland alluvial grassland habitat and was aware that the invertebrate fauna associated with such grassland was finding refuge on brownfield sites in the city of Basel. Green roofs were already a statutory requirement in new developments in Switzerland at that time, but Brenneisen began to investigate how green roofs could be modified or designed to provide suitable habitat for invertebrates. His concern was that where new development was to proceed on brownfield sites, invertebrate populations would be lost. Brenneisen sought to determine whether or not green roofs could provide appropriate and meaningful mitigation for such impacts. He therefore undertook surveys of beetles and spiders on 16 green roofs in Basel, with the results published in 2002. He recorded 172 species of beetles, 10% of which were listed in the national Red Data Book. His study on spiders revealed that 40% of the collected species were of ‘faunistic interest’ (a term used in the German speaking countries to indicate rarity). His study concluded that there were a number of factors that influenced the composition of invertebrate assemblages on green roofs, the most important of which was variation in substrate depth. Areas of thin substrate, which tend to be bare or sparsely vegetated, were found to provide suitable habitat for a number of drought-tolerant invertebrates. Deeper areas of substrate, however, retained more moisture and supported more vegetation, which had the effect of creating habitat mosaics that were able to support other invertebrate assemblages. The results of his research have led to changes in Cantonal Law in Basel, which requires roofs to be topographically varied in order to promote invertebrate diversity (see figure 9.12). Wherever possible, seeding with a mixture of local drought-tolerant wildflowers is used to accelerate colonisation by invertebrates.

London’s Black Redstart Roofs

Brenneisen’s work in Switzerland was an inspiration for Dusty Gedge in London, who was similarly concerned with the lost of brownfield habitats, but in his case the main species of concern was the black redstart. This bird, which is rare in England, colonised the rubble of
Ecosystem Services Come to Town

bombsites after World War II and still persists on derelict post-industrial sites. Gedge successfully campaigned for the creation of biodiverse roofs in London for the black redstart and other wildlife – named as ‘brown roofs’ because they replicated conditions on brownfield sites. Gedge’s efforts encouraged Richard Jones, Gyongyver Kadas and others to undertake research over a period of several years, which confirmed the importance of green roofs in London for the conservation of invertebrates and also confirmed the value of varying substrate depth, using a range of wildflowers and including habitat features such as logs. This is the reason why roofs should not, as a matter of course, be covered with uniform swards of sedum, the predominant extensive green roof type.

Biodiverse Green Roofs in North America

In North America, green roof experts are also applying their knowledge of ecological restoration and permaculture to the establishment of vegetation on buildings, using locally appropriate palettes of native species. Examples of this approach may be seen on the California Academy of Sciences in San Francisco, which has achieved LEED Platinum. (LEED, or Leadership in Energy and Environmental Design, is the internationally recognised green building certification system,
equivalent to BREEAM\textsuperscript{45} or the Code for Sustainable Homes in the UK). Paul Kephart and colleagues at Rana Creek have advised on the Vancouver Convention Centre Extension, where the intention is to attract butterflies and hummingbirds to a 2.4 hectares living roof. \textsuperscript{46}

### Roof Gardens for People

Where inaccessible extensive green roofs are created, with the necessary guidance it is relatively straightforward to create wildlife habitat; however, on roof gardens (intensive green roofs), where there is an emphasis on access and enjoyment and where regular maintenance is expected and is easy to arrange, there may be different expectations. Aesthetic considerations may come to the fore, and on large commercial residential or institutional buildings, like architect Emilio Ambasz’s ACROS Building in Fukuoka, Japan (see figure 9.13), the plantings may resemble those of a park or garden more than a nature reserve. The terraces on the roof of the ACROS Building are fully accessible and in effect extend the adjacent public park without compromising the function of the building as a conference hall and performance centre. No matter how formal or busy a roof garden is, however, the thermal, drainage and biodiversity functions should not be forgotten. It is possible to provide formality and to combine the requirements of visitors with those of wildlife by using the principles of ecological restoration and referring to the experience gained in places like Chibu, Basel and Vancouver.

### Worldwide Applications

Roof gardens have a long history, having been included on palaces and citadels in the Renaissance (like those created by the Gonzaga family in Mantua, Italy) and probably long before that. In Europe, modern
green roofs also have a long history, with guidance promulgated by the German Landscape Research Development and Construction Society (FLL) as long ago as 1984, so there is confidence in Europe, and increasingly in North America in industry-standard technology and methods, but as the idea spreads across the globe there is a need to develop new methods of vegetating buildings. Basic components such as waterproofing may be suitable all over the globe, but each climate and bioregion should develop locally appropriate substrates and planting strategies so that the performance of each green roof is tuned to suit its setting and so that benefits for local biodiversity are maximised. This means that research on locally appropriate green roof substrates and plants will be undertaken all over the globe as the technology spreads. There is already evidence of this happening, with research underway in universities and other institutions in several countries representing a wide range of climates including Australia, Brazil, China, Greece, Iran, New Zealand, Singapore and Turkey. In China, for example, the green roof and living wall industries are already thriving. Living walls were particularly visible at the World Expo in Shanghai in 2010.\(^{47}\) Singapore is leading the way in developing tropical building-integrated vegetation and celebrates this with the term ‘skyrise greenery’.\(^{48}\)

**Wildlife and Buildings**

Some wildlife has learnt to live in close association with people and their homes and places of work in the last few millennia. There are pests like rats and mice, of course, but also harmless creatures, including several species of bat and birds such as the swift, swallow and house martin. In recent decades as older buildings have been demolished or refurbished, there has been a tendency to close off openings and voids, thus depriving wildlife of nesting and roosting sites. Building standards have improved and there is a desire to make buildings airtight, which means that new buildings have usually lacked the beneficial nooks and crannies found in older buildings (although they do often include ledges, which act as perches for pests such as feral pigeons). In concert with the loss of roosting and nesting sites, modern cities have become tidier, with fewer wild plants and less insect prey for birds and bats. This has caused a decline in numbers – with some species such as the house sparrow suffering a huge decline – a 66% fall in London between 1995 and 2007.\(^{49}\) More than 60 species of bird are known to use artificial nest boxes, which can, and should, be included on, or even in the fabric of, buildings. Bird boxes for particular species can be manufactured to designs provided by various expert groups, or even purchased from specialist manufacturers like Schwegeler.\(^{50,51}\) Advice should be sought on suitable locations for
boxes – some birds prefer certain heights and aspects, and exposed boxes may put the young at risk from high temperatures or predators. Purpose-made boxes manufactured from untreated timber or a cement and woodchip mixture are available for bats. Several species are known to use them both for roosting and breeding. Roosting boxes should be placed in sunny locations out of the reach of predators. Other, normally larger, well-insulated boxes, which can help create conditions of stable temperatures and humidity, are also available for use as hibernation sites. Experts caution that boxes are not able to substitute for all kinds of natural tree holes or voids in buildings but they do have a role in helping to replace roosts and hibernation sites lost through development and refurbishment. For those who require further detailed information on how to attract wildlife to buildings, excellent guidance is available from nature conservation and green building bodies. Ground-nesting birds are also attracted to large extensive green roofs. Most extensive green roofs are free from human disturbance and inaccessible to predators such as cats and foxes. They also have a wide horizon, which makes them ideal for ground-nesting birds, which avoid sites with overlooking trees, which could provide perches for birds of prey. Examples of extensive green roofs with nesting birds include the Rolls Royce factory near Goodwood, Sussex, which has supported three pairs of skylarks, and roofs on distribution centres at Emmen in Luzern, Switzerland where lapwing are a regular feature. In Emmen, initial problems with chick mortality have been solved by expert Natalie Baumann, who has added shelters, shallow pools and other habitat features.

Figure 9.14 Rooftop permaculture, Florida, USA.
Rooftop Harvests

Sir Benjamin Ward Richardson, a prominent physician, anaesthetist and sanitarian, founded the Journal of Public Health in 1855 and was an early advocate of the benefits of cycling. Writing in 1876, he argued that in all large towns the roof of each house should be a garden. He believed that widespread creation of roof gardens would result in a vast increase in the health and the happiness of the population. Now nearly 140 years later, in Brooklyn, New York, Ben Flanner is making rooftop gardening his livelihood by growing 30 or more varieties of fresh vegetables, herbs and fruit for the many restaurants in the neighbourhood. The advantage of this kind of enterprise is that fresh, high-quality produce can be delivered to the customer within minutes of harvest. This kind of initiative brings the usual benefits of roof greening to the building – intercepting rainfall and providing summer cooling, but the installation pays for itself and there is no maintenance bill as there would be for an ornamental garden. Pioneers like Kevin Songer in Florida are also demonstrating that rooftop vegetable gardening is feasible in sub-tropical locations (see figure 9.14). Clearly there is a future for rooftop farming along with the whole range of other possibilities that I have described. Building exteriors should not ordinarily be naked, but should be made to work harder for interior comfort, for the benefit of people and wildlife and to conserve the wider environment.