Chapter 6
A Green Building Envelope: A Crucial Contribution to Biophilic Cities

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Abstract Throughout history, greening of outside walls and roofs of buildings has taken place. Reasons for doing so were the increase of insulation (keep cool in summer and keep cold out in winter), improved esthetics, improved indoor and outdoor climate, adsorption of particulate matter (PM_x), as well as increasing ecological values by creating habitats for birds and insects. Green façades and living walls systems can improve the (local) environment in cities. They offer more surfaces with vegetation and, at the same time, contribute to the improvement of the thermal performance of buildings. Although in the past, relatively little attention has been paid to these valuable opportunities of vegetation and its interaction with buildings. More and more attention is shifted to these so-called beneficial relations in especially dense urban areas, which can be considered as deserts in biological terms. This movement from a biophilic perspective point of view includes combining nature and natural elements in the built environment to ameliorate the negative impact of climate change as for example loss of biodiversity, mitigation of urban heat, or air pollution reduction.

6.1 Introduction

Cities and urban environments contain a variety of ecological and green assets, efforts are being made to further enhance the green elements and features of these living and work environments at the building scale. Integrating the positive aspects of greenery inside urban environments is called: Biophilic urbanism (Beatley and Newman 2013). A biophilic designed city is more than a biodiverse city; it is a place that learns from nature and emulates natural systems, incorporates natural

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forms and images into its buildings and cityscapes, and designs and plans in conjunction with nature; it transform cities from gray and lifeless to green and biodiverse (Beatley 2008).

Biophilic design is an innovative way of designing urban areas where we live, work, and learn, creating healthy and productive habitats for city dwellers. It is based on the theory of "biophilia" which contends that human health and well-being has a biologically-based need to affiliate with nature.

While parks have often been a part of cities, architects and designers today are incorporating nature into their designs through a variety of innovations such as green roofs and vertical gardens, a renewed focus on local and natural materials, and reclamation or restoration of spaces (Derr and Lance 2012).

This chapter will show within an ecological engineering context the impact of green roofs and green façades in (dense) urban areas. An overview and comparison of different types of horizontal and vertical green for housing, industrial, and other commercial buildings will be given. Some concrete examples will be elaborated to show possibilities of their multifunctionality.

There is a growing body of evidence of the positive physical and mental health benefits associated with greenery and green elements in the built environment (Beatley and Newman 2013). Realization of vegetated roofs and façades finds more and more frequent application in the building sector; although for large scale application, there is in general, still hesitation among policy makers and designers. That is a great pity as financial details show that applications of green roofs are not (any) more expensive than for example traditional flat roofs (Bohemen et al. 2009; Köhler 2012).

Greening of outside walls or facades of buildings gains also more interest in recent years. Although these concepts are not new (in the eighties of the twentieth century, different reports and books have been published, research into the use of green inside cities increased substantially). In particular, the amount of publications, articles, and research focused on the use of green roofs and green façades has increased in recent years (Köhler 2008). Despite the interest (under city dwellers, architects, city planners, policy makers, and scientists) in a green building envelope with corresponding positive claims, hard data about the effect of urban green is sometimes missing or not well studied yet. However, nowadays the environmental impact of buildings on the inner and outer climate becomes more and more apparent.

Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment. Buildings in which we spend a great part of our life to protect us from nature's extremes, yet they also affect our health and environment in countless ways (EPA 2010). Green building strategies not only stand for sustainable materials in their construction (e.g., reused, recycled-content, or made from renewable resources), but also by using of natural processes (e.g., shading effect of trees, insulation capacities of green roofs and green façades, mitigation of urban heat due to evapotranspiration). The green building strategy in the presented chapter focuses on one key aspect of the "greening process" namely the use of plants on and around urban buildings.

6.2 Green Building Envelope Strategy

The resilience of cityscapes against climate change is predominantly determined by the properties of their surfaces and the spatial arrangement of the buildings. These factors induce the occurrence of urban heat islands or flooding (Scharf et al. 2013). When global radiation reaches a surface it may be reflected (Albedo) or transformed to sensible or latent heat flux. While plants are able to transform the sun energy into biomass, oxygen, and air humidity, regular building surfaces (e.g., plaster) emit sensible heat flux. Plants regulate the urban microclimate, while conventional surfaces lead to microclimatic extremes and reduce the thermal comfort within cities (Scharf et al. 2013).

To deal with problems in dense urban areas often one-sided solutions are chosen. With the increased focus on ecological impacts of human activities on our environment the attention is shifted more and more to integrated solutions. Ecological engineering principles and biophilic design, can contribute to integrated solutions as it is applied and multidisciplinary science; it is integrating human activities with the natural environment, so that both can have advantage of designing and refurbishing of constructions. Conservation and the development of biodiversity by utilization of biological processes are central in the designing process. Dense and paved cities need an appropriate development, which incorporates an ecological approach to building and landscape design with respect to link functions such as water management, air pollution reduction, energy conservation, the recycling of waste (water), and nature conservation (biodiversity).

One promising option for dense urban cities is the greening of buildings (Johnston and Newton 2004; Ottelé 2011; Perini 2012). By strategically adding a "green skin", it is possible to create a new network of vegetation as roofs, walls, courtyards, streets, and open spaces. These networks, also called stepping stones, are particularly important in the city centers where vegetation may cover only about one third of the land surface, compared with 75–95 % in the outer suburbs (Johnston and Newton 2004). In these areas, there is less biodiversity and a lack of breeding and nesting possibilities for animals, besides paved surfaces collect a lot of heat, which negatively contributes to urban heat.

Application of plants rooted in the soil at the base of façades or on roofs by many architects and landscape architects is indicative of the value placed upon their presence in the urban landscape (Laurie 1977). Structures covered with green are a symbol of building in harmony with architecture and nature (Lambertini 2007). The garden-city movement at the end of the nineteenth century may be seen as one of the first ecological reactions to industrialization in urban areas (Kaltenbach 2008).

The many systems available on the market allow combining nature and built space to improve the environmental quality in urban areas (Fig. 6.1), and to retrofit the wide building heritage (which is often unsuitable and cause of relevant energy waste and discomfort conditions) with respect to architectural, functional, and performance aspects (Novi 1999; Nuzzo and Tomasinsig 2008; Dunnett and Kingsbury 2004). It is an important field to investigate since data show that

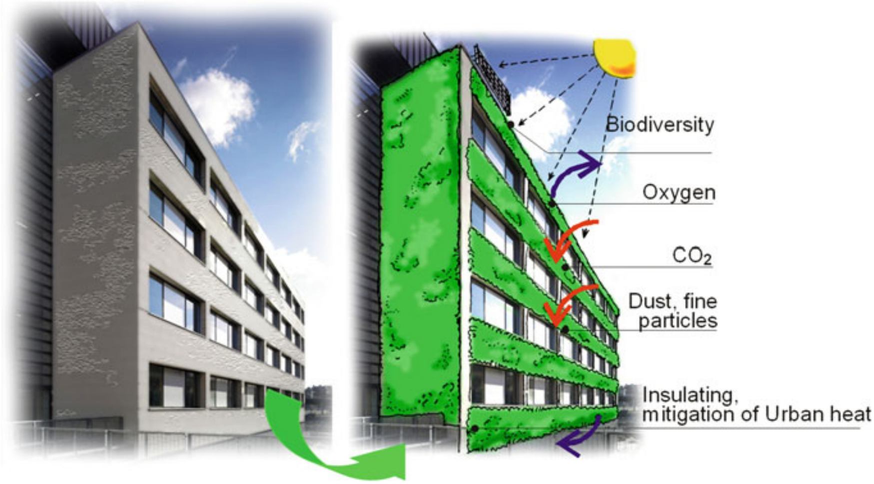

Fig. 6.1 A green building envelope strategy incorporates multidisciplinary environmental advantages for both city dwellers as nature

architecture plays an important role in the field of sustainability. In fact, the building sector has one of the greatest impacts on the environment; buildings consume a significant amount of energy over their life cycle and generate 40–50 % of the total output of greenhouse gases (Thormark 2002; Ardente et al. 2008; Prasad and Hill 2004).

A green building strategy offers the potential to learn from traditional architecture; the earliest form of vertical gardens dates from 2000 years ago in the Mediterranean region and ornamental roof gardens have been developed initially by the civilization of the Tigri and Euphrates River valleys (the most famous examples of which were the Hanging Gardens of Babylon in the seventh and eighth centuries B.C. (Köhler 2008; Dunnett and Kingsbury 2004). Several examples of green envelopes, back to eighteenth to nineteenth century, can be found in Northern European regions, such as climbing plants to shade vertical surfaces in Mediterranean regions, due to the cooling potential of vegetation and the insulation properties (thermal capacity). Nowadays, this kind of building envelope strategy also incorporates advanced materials and other technologies to promote sustainable building functions (Köhler 2008).

Greening the exterior of buildings (façades and roofs) provides numerous ecological and economic benefits, including storm water management, energy conservation, mitigation of the urban heat island effect, reducing air pollutants, increased longevity of building materials, as well as providing a more esthetically pleasing environment in which to work and live (Johnston et al. 2004; Dunnet and Kingsbury 2004; Getter and Rowe 2006; Minke and Witter1982; Krusche et al. 1982; Bohemen et al. 2009; Ottelé 2011; Perini 2012).

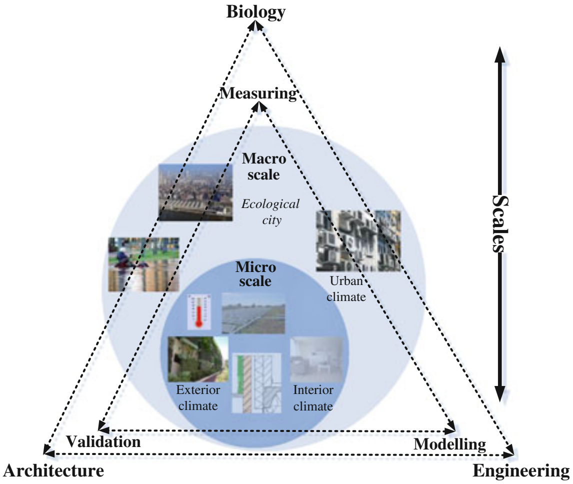

Fig. 6.2 Urban green and the application of it requires an holistic approach to encounter the negative impact of the build environment on (local) climate

The application of vegetation, especially in relation to the involved biological processes in urban areas, requires an holistic approach at different scales (Fig. 6.2), since the benefits operate at a range of different scales from the individual building, the domestic, or garden scale, to district and finally to the city scale (Beatly 2008). Different disciplines such as biology, architecture, and engineering comes together in this concept, as it should be applied, as an integral approach to optimize the efficiency of green structures and its surrounding.

Another important distinction can be made to private and public advantages. Private advantages should be found in the direction of energy savings, esthetic improvement, or for example extension of the life span of the waterproofing layer, while public advantages are associated with storm-water management, biodiversity, urban heat, and for example air pollution (Johnston and Newton 2004).

As mentioned earlier, green roofs and green facades are common techniques to implement urban greenery at the building level, and within these techniques there is a variety of concepts possible (Table 6.1).

Literature review done by Peck et al. (1999) and Köhler (2008) shows the benefit of green roofs on the inner temperature in buildings. Under a green roof

Table 6.1 Green building techniques for the urban area

Common urban green (techniques) at the building level			
Vertical green		Green roofs	
Extensive	Intensive	Living wall concepts	Green façade (traditional)
Thin substrate layer (5–15 cm). Vegetation mainly sedum, mosses, and herbs	Thicker soil layer (>25 cm). Vegetation mainly herbs, herbs, shrubs and trees	Modern technique based on grow able panels (mainly prefabricated), hydroponic system and nutrients needed	Consists out of self-adhesive creepers (tendrils)

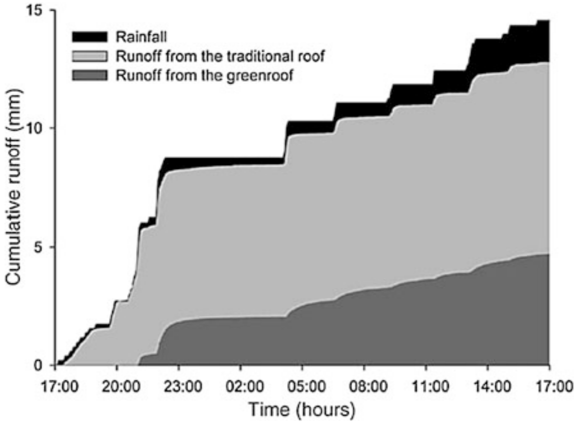

Fig. 6.3 Cumulative runoff as measured by Mentens et al. (2006) on an extensive green roof and a bare roof based on a 14.6 mm rain shower

without cooling, indoor temperatures were found at least 3–4 °C lower than the outdoor temperature, which was between 25 and 30 °C.

Green roofs can be used for the retention of water, and as a consequence, the sewer system can be tailored to lower the peak concentrations and to improve the water quality in the period of heavy rain. This subsequently can lead to savings on investments in sewer and water purification installations (Heidt and Neef 2008). The retention capacity can be between 60 and 100 % depending on the construction details of the green roof. According to Mentens et al. (2006) the reduction of the runoff consist in: delayment of the initial time of runoff due to adsorption of rainwater in the green roof system, reducement of the total runoff by retaining part of the rainfall, and by distributing the runoff over a longer period of time through a relative slow release of the excess water that is temporarily stored in the pores of the substrate. The effect of a green roof on the runoff compared to a traditional flat (bare) roof can be seen in Fig. 6.3. Green offers furthermore a variety of plants and animals; as a result of this many species can establish or maintain themselves in an urban environment. The biodiversity in cities is generally higher than in agricultural areas, but lower than in the rural area (Natuur balans 1999). The urban area offers a unique lodging to some specific types by the substrate (mostly brick, limestone, and masonry (Darlington 1981)) and the urban microclimate, such as wall vegetation and mosses. One of the characteristics that set a city apart from its rural surroundings is the altered climate that prevails over urban environments. Comparing rural areas with the urban areas differences can be found in solar input, rainfall patterns, and temperature.

The integration of buildings with vegetation, i.e., green roofs and vertical greening systems, is a constantly evolving research field and especially in the last decade a lot of technical developments are done. However, green envelopes (especially the most innovative vertical greening systems) are not yet fully accepted as an environmental quality restoration and energy saving method for the built environment, mainly due to the lack of data needed to quantify their effects, and to evaluate the real sustainability (environmental and economic) of these (Perini et al. 2012). The many greening systems available on the market allows combining nature and the built environment to improve the environmental quality in urban areas; for example, green façades and living wall systems offer more surfaces with vegetation and, at the same time, contributes to the improvement of the thermal performance of buildings.

As earlier stated, the largest uncovered surfaces in cities are rooftops, as these surfaces offer a great potential for urban agriculture. New York is an example where already many projects are established. The Brooklyn Grange, a rooftop farm business in Long Island (United States) is one of the largest of these projects. Also in the Netherlands a few projects exist. De Dakakker in Rotterdam and Zuidpark in Amsterdam are the most successful examples. Urban agriculture is a nice example to educate city dwellers and to connect them again with the whole food production chain (Dakakkers 2013). Urban agricultural projects are also a tool to stimulate social cohesion between citizens (Farming the city 2013).

6.3 Air Quality Improvement with Vegetation

All plants will help to ameliorate the effects of air pollution. This can be done at the microclimatic scale, but in the case of many green structures also at larger scale. Leaves of plants provide a large surface area (Fig. 6.4a, b), which is capable of filtering out particulate matter (PM_x) and other pollutants such as NO_x (conversion to nitrate (NO_3) and nitrite (NO_2)) and CO_2 in daytime. A green façade will block the movement of particulate matter particles along the side of a building and filter them (Minke and Witter 1982). Vegetation has a large collecting surface area and promotes also vertical transport by enhancing turbulence (Fowler et al. 2001;

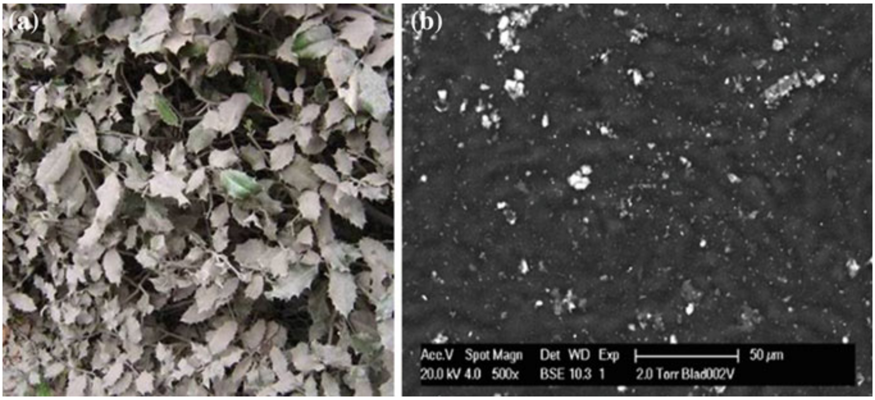

Fig. 6.4 **a** Dust on European Holly (*Ilex aquifolium*) leaves near an unpaved road. **b** Micrograph (ESEM) of fine dust on common ivy (*Hedera helix*) leaf

Beckett et al. 2004). When concrete, brick, stone, glass, and asphalt surfaces are heated during the summer period, vertical thermal air movements (upward) are created and dust particles found on the ground are carried and spread into the air (Minke and Witter 1982). Particulate matter is adsorbed by the leaves, trunks, and twigs (Fig. 6.3a, b), and is an efficient sink for particulate matter (Fowler et al. 1989).

According to Hosker and Lindberg (1982) fine dust ($PM_{2.5}$ and PM_{10}) concentrations are reduced when particles are adhered to the leaves and stems of plants. Literature claims that by rainfall the adsorbed particulate matter is washed off into the soil or substrate below. However, results from a conducted simulated rainfall experiment (Ottelé 2011), shows that especially the fine and ultrafine particles are fixed on the leaf surface. Also falling of leaves in autumn contributes to particle binding. Research shows for example that plant barriers immediately along a roadside (daily traffic level 20.000–50.000 vehicles) are more beneficial in capturing lead (Pb) and cadmium (Cd) particles than plants investigated in the rural area (Bussotti et al. 1995).

Also Thönnessen (2002) found heavy metal concentrations and fine particles on leaves of a green façade (*Parthenocissus tricuspidata*) in the inner city of Düsseldorf (daily traffic level 12.500 vehicles). Sternberg (2010) found the same results by comparing *ivy* leaves from different sites (by counting particles on ivy leaves), the leaves from the sites exposed to a high daily traffic level, had collected a significant number of particles compared to the sites that are less exposed.

Research at the university of Bonn shows that mosses for example are excellent fine dust absorbers (Frahm and Sabovljevic 2007). One square meter of moss can "consume" 20 g of fine dust each year. Since moss is one of the easiest plants to use, for example, on a green roof, is an enormous advantage and cheap method against (local) air pollution.

Besides particle binding plants are also known to absorb gaseous pollutants through the stomata (CO_2 and NO_x). Via photosynthesis CO_2 is sequestered in the leaves (Minke and Witter 1982). The negative health effects of particulate matter pollution for human's stands for decreasing lung functions, increased respiratory problems, and other health care visits for respiratory and cardiovascular diseases (Pope et al. 2009).

Besides these effects also durability problems are involved and include accelerated corrosion of metals, as well as damage to paints, sculptures, and soil-exposed surfaces on man-made structures (United Nations 2007). The improved air quality by a green envelope has direct benefits for people who suffer a long disease. A decrease of smog formation will occur, and also durability or corrosion problems are reduced of urban infrastructure that is susceptible to damage from air pollution (United Nations 2007).

A study carried out by the University of Dresden (Schröder 2009) with regard to the organic balance of a greened façade with 1,000 m^2 *Hedera helix* pointed out that in one year: 1,019 kg of water and 2,351 kg of CO_2 is consumed and bound, respectively. In this reaction, 5,854 kg of organic mass (water content 4,409 kg and dry mass 1,415 kg) and 1,712 kg of O_2 is produced. With the assumption of an leaf area index (ratio between leaf surface in m^2 and covered wall surface in m^2)

for *Hedera helix* of 2.6 up to 7.7 m^2 leaf/m^2 wall (Bartfelder and Kohler 1987a, b), a leaf surface area of 2,600 up to 7,700 can be calculated.

Measurements carried out by Rath and Kießl (1989) on the effect of green façades on the SO_2 concentration show that the concentration of SO_2 was clearly lower between the foliage than in front of a non-greened façade.

Field measurements conducted by a national research program in the Netherlands (IPL 2006) to investigate the effect of a vegetation corridor on the reduction of PM_{10} levels near a highway (A50), show a minor contribution of the vegetation corridor on the concentration levels measured in the ambient air. They estimated the effect of vegetation smaller than 10–31 % on the traffic contribution of particulate matter, due to the high uncertainty of the used measuring equipment.

6.4 Temperature Regulation and Insulating Properties Due to a Vegetation Layer

Buildings consume roughly 36 % of total energy use and 65 % of the total electricity consumption. Kula (2005) suggests that a wide scale green roof implementation could significantly impact energy savings. According to Dunnet and Kingsbury (2004) every decrease of the internal building temperature with 0.5 °C may reduce the electricity use with 8 % for air conditioning in summer periods. Akabari et al. (2001) concluded that since 1940 the temperatures in urban areas have been increased by 0.5–3 °C. Akabari et al. (2001) also estimated that 5–10 % of the current electricity demand of cities is used to cool buildings just to compensate the 0.5–3 °C increased temperature.

Green roofs, living walls (LWS), and green façades create their own specific microclimate, quite different from surrounding conditions. Due to this specific microclimate, both around the building and at grade are affected. Depending on height, orientation, and the location of surrounding buildings, the façade is subjected to extreme temperature fluctuations (hot during the day and cool at night), with constant exposure to sunlight and wind. The climate on a roof or at a façade is comparable with an arid or alpine climate, and only suitable to specific types of plants. Most of the Sun's radiation that is adsorbed by concrete, bituminous materials, or masonry is reradiated as sensible heat. Asphalt, concrete, and masonry will reflect 15–50 % of the received radiation (Laurie 1977), greening paved surfaces with vegetation to intercept the radiation before it can hit hard surfaces can reduce the warming up of hard surfaces, especially in dense urban areas.

A study in Toronto carried out by Liu and Baskaran (2003) shows clearly the temperature difference between a bare and green roof. Temperatures up to 70 °C were measured for the bare roof, whereas the temperature on the green roof remains around 25 °C. The consequence of this is that the roof membrane (bituminous material) of the bare roof ages must faster due to UV light compared to a green roof, which is protected by the substrate and plant layer. Since UV light deteriorates material and mechanical properties of coatings, paints, plastics, etc., plants will also have an effect on durability aspects. This is a beneficial side effect, which will have a cost-effective effect on maintenance costs of buildings. The denser and thicker the plant layer on the green façade, the more beneficial these effects are. As for example, life expectancy of bare roofs is in general 15 years, whereas for green roofs this is up to 40 years.

Finally, due to the adsorption of heat during the day, the bare roof will reradiate the adsorbed heat during night contributing to the urban heat island effect(Eumorfopoulou and Aravantinos 1998). In an urban heat island effect situation, even night air temperatures are warmer because of built surfaces adsorb heat and radiate it back during the evening hours (Getter and Rowe 2006). Covering a building with vegetation prevents solar radiation from reaching the building skin (shading effect of leaves), and in the winter, the internal heat is prevented from escaping. By constructing green façades and green roofs, great quantities of solar radiation will be adsorbed for the growth of plants and their biological functions. Between façade and a dense vertical green layer (for both rooted in the subsoil as rooted in artificial soil-based systems) a stagnant air layer exist. Stagnant air has an insulating effect; green façades can therefore serve as an “extra insulation” of the building façade (Minke and Witter 1982; Krusche et al. 1982; Ottelé 2011). Also direct sunlight on the façade is blocked by the vegetation. This blocking of the sunlight ensures that the temperature will be less high inside a house. In winter, the system works the other way round, and heat radiation of the exterior walls is insulated by evergreen vegetation. In addition a dense foliage will reduce the wind speed along the façade, and thus also helps to prevent that the walls will cool.

The insulation value of vertical greened surfaces can be increased basically by different mechanisms (Peck et al. 1999; Rath and Kießl 1989; Pérez et al. 2011):

- by covering the building with vegetation, the summer heat is prevented from reaching the building skin (shadow), and in the winter, the internal heat is prevented from escaping, reflected, or absorbed.
- thermal insulation provided by vegetation, substrates, and configuration (mostly related to living wall concepts).
- by trapping an air layer within the plant foliage, since wind decreases the energy efficiency of a building by 50 %, a plant layer will act as a buffer that keeps wind from moving along a building surface.
- cooling of air due to evapotranspiration of plants and substrates (if used).

Green façades and roofs will cool local air temperatures in two different ways. As explained, first of all, walls behind greened surfaces absorb less heat energy from the sun (traditional façade and roof surfaces will heat up the air around them). This effect is clearly visible in Fig. 6.5a, b where uncovered parts of the façade are heated up (color red) and the parts covered with leaves considerable lower (color blue and green). Secondly, green façades and roofs will cool the heated air through evaporation of water (Wong et al. 2009) (for evaporation of 1 kg water, 2.5 MJ of energy is necessary); this process is also known as evapo-transpiration. Besides, hard surfaces encourage the runoff of rainwater into the sewage system. In urban

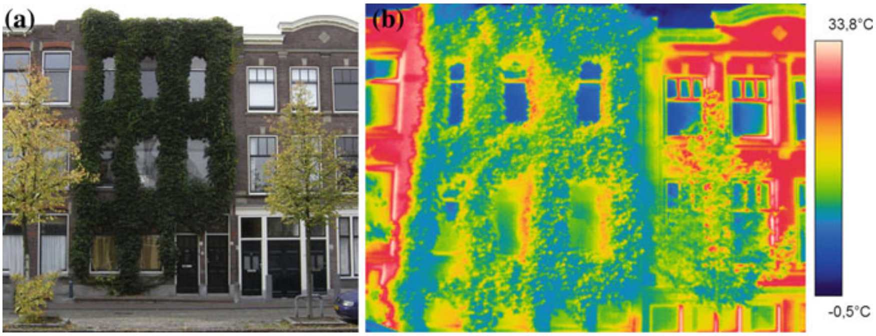

Fig. 6.5 **a** Boston ivy (*Parthenocissus*) rooted in the soil and applied directly against the façade in Delft summer 2009. **b** Photograph taken of the same façade with an infrared camera (FLIR) with ambient air temperature 21 °C

areas, the impact of evapotranspiration and shading of plants can significantly reduce the amount of heat that would be reradiated by façades and other hard surfaces. Plants buffer water on their leaf surfaces longer than building materials, and the processes of transpiration and evaporation, can add more water into the air. The result of this is a more pleasant (micro)climate in the urban area.

Field measurements performed by Bartfelder and Köhler (1987a, b) show a temperature reduction at the green façade in a range of 2–6 °C compared with a bare wall. Holm (1989) shows with field measurements and his DEROB computer model the thermal improvement potential of leaf covered walls. Also Eumorfopoulou and Kontoleon (2009) reported the temperature cooling potential of plant covered roofs and walls in a Mediterranean climate; the effect was up to 10.8 °C. Another study by Wong et al. (2009) on free standing walls in Hortpark (Singapore) with vertical greening types shows a maximum reduction of 11.6 °C. Also Ottelé (2011) shows that especially with living wall concepts high temperature reduction can be achieved, resulting in better insulation values.

Perini et al. (2011) show the influence of a green layer on the reduction of the wind velocity along the surface of a building. An extra stagnant air layer in optimal situations can be created inside the foliage, so that when the wind speed outside is the same as inside R_{exterior} can be equalized to R_{interior}. In this way, the building's thermal resistance can be increased by 0.09 $\text{m}^2\ \text{K}\ \text{W}^{-1}$.

These results refer to the wind speed measured at a façade covered by a well grown direct greening system and a living wall system based on planter boxes; in the case of living wall systems the insulation properties change according to the materials used. The thermal resistance of a living wall system based on planter boxes is also influenced by the wind reduction, besides the thermal resistance of the system itself contributes to the thermal resistance and is estimated up to $R = 0.52\ \text{m}^2\ \text{K}\ \text{W}^{-1}$.

For both green façades and living wall systems these results imply potential energy savings for building envelopes in warmer and colder climates (Perini et al. 2011; Ottelé 2011). This “technical/thermal green” strategy of increasing exterior insulation properties of vertical surfaces stimulates upgrading or retrofitting of existing (under-insulated) façades without the added cost of interior or traditional exterior insulation systems.

An experimental research conducted by Ottelé (2011) was set up to in order to classify the thermal benefits of green façades or plant covered cladding systems under boundary conditions in a so-called hotbox testing facility. For this reason, an insulated (mineral wool) cavity wall with different (attached) vertical greening systems was built and tested in order to distinguish the thermal effect of the green systems. In total, there were two measurements performed with *Hedera helix* (direct and indirect to the wall) and four measurements were carried out with living wall systems (based on felt layers, planter boxes, mineral wool, and foam substrate.

In the study, it was found that, both for the direct and indirect greening principle lower surface temperatures of the exterior masonry were measured during summer conditions compared to the bare wall situation. The difference of temperature for the systems is reaching 1.7 and 1.9 °C, respectively, after 8 h of heating. The insulation material inside the bare wall moderates the prevailing temperature difference between the outside and inside climate chamber, resulting in no temperature difference for the inside climate chamber. The winter measurement after 72 h shows that the wall surface covered directly with *Hedera helix* is warmer compared to the bare wall, with a temperature difference of 1.7 °C. The air temperature of the inside climate chamber is lowered with 0.7 °C in the case of the bare wall, which means that the vegetation layer slows down the rate of heat flow through the façade, resulting in an improved *R*-value of the system. In the case of the indirect facade greening system the same trend was found; a temperature difference of 1.9 °C, compared with the bare wall was found and the interior air temperature is lowered with 1 °C in the case of the bare wall.

According to this measurement some conclusions can be drawn, namely, that the insulation material is superior compared with the green layer, and thus minimizes the effect indoor. However, since the green layer protects the heat accumulation in the outer layer of the masonry, less heat will be reradiated during the evening and night, which has a positive effect on the urban heat phenomena (lowering the urban temperature).

A stronger relation between temperature reduction and greenery was found for the living wall systems tested, a surface temperature reduction that can be achieved with the investigated living wall systems was between 7.2 and 10.3 °C during summer conditions. It can be noticed that the effect on the interior temperature is also higher as well as the relation between mitigation of the urban heat island effect.

For the winter measurements it was found that compared with the bare wall all the greening systems contributes to a better thermal resistance of the facade. Especially, in the case of the living wall systems higher interior room temperatures were measured up to 4 °C compared with the bare facade. Which means that the thermal resistance of the greened facades increased due to the extra material properties, air cavity, and plant tissue. Field measurements conducted by Mazzali et al. (2012) in a Mediterranean climate show comparable findings with laboratory tests and calculations conducted by Ottelé (2011). The facade covered with a living wall consisting an insulation layer (external side of the wall) shows a significant (66 %) reduction in cooling energy than a system where the insulation material is on the internal side (more heat accumulation in the massive facade); furthermore, they concluded that the most effective orientation of the (green) cladding, regardless the type of wall and the latitude, was the south side.

6.5 Utilization of Green Buildings

6.5.1 Green Roofs

Realization of green roofs is becoming a good construction practice in a lot of countries in Europe, especially in Germany, as well as in the USA (Osmundson 1999; Köhler et al. 2012); however, large scale implementation takes much more time and effort. In a report published by the municipality of Rotterdam (Anonymous 2007) a survey is given about the different types of green roofs with full financial details. Comparison of different types was needed to stimulate large scale application including suggestions for a system of subsidies (Anonymous 2007).

The advantages for the built environment as stated earlier by using vegetation on roofs are clear:

- increase of water buffering capacity (water management) instead off peak runoff to sewage system due to delayed runoff, transpiration, and evaporation.
- improvement of air quality (deposition of particulate matter on leaves for example).
- reduction of the heat island effect in urban areas. Energy savings (increase of insulation capacity—keep building cool in summer and keep cold out in winter).
- noise level reduction up to 10 dB(A).
- increase of lifetime of roofing material.
- increase of esthetic values.
- increase of ecological value and biodiversity.

In Scandinavia in the past, roofs were covered with a soil layer (sod) that was stripped from surrounding grass meadows (Donnelly 1992). Underneath the sod structurally heavy timber beams were interspaced with birch bark to act as a waterproofing layer.

Fig. 6.6 Modern version of a (Sedum planted) green roof (Texel, The Netherlands)

A range of different types of designs are now available on the market and realized: from very extensive (ecological roof and Sedum roof) to intensive roofs (gardens and parks) (Figs. 6.6, 6.7 and 6.8).

6.5.2 *Intensive and Extensive Green Roofs*

Vegetated roofs can, among other things, be categorized by the type of drainage system and their nominal thickness. These two properties determine the structural load, the maximum possible slope, the type of vegetation, and the water retention capacity (Köhler et al. 2012). Basically, we distinguish green roofs with a thin subtrate layer (extensive) and with a thicker substrate layer (intensive) see Fig. 6.9.

The surface layer thickness of an extensive green roof is typically 5 cm up to 15 cm (Table 6.2). The exact growing depth of plants differs per species, but in

Fig. 6.7 Extensive flat roof planted with sedum. After 5 years the first establishment of native Orchids (*Orchis praetermissa*) occurred (*photo* H. van Bohemen, The Netherlands)

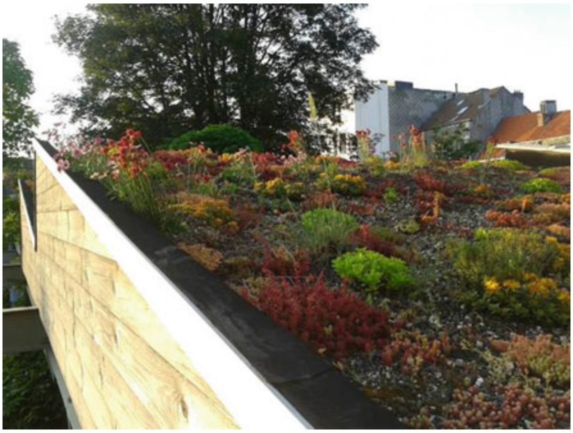

Fig. 6.8 Extensive sloped green roof (Berghem, Belgium)

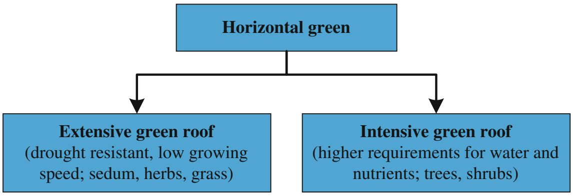

Fig. 6.9 Basic principles for a green roof strategy

general moss and sedum plants need the thinnest substrate thickness, and grasses and herbs need the upper limit of 15 cm. The growing medium should provide the vegetation of sufficient water, nutrients, and oxygen. Maintenance of extensive green roofs is low, since normally only mosses, sedum, or herbs are growing. Extensive roofs are limited accessible for people (only for maintenance purposes) and are less heavy (up to 170 kg/m^2) due to the low substrate thickness.

Intensive green roofs can be compared with parks or gardens in terms of plant diversity and application. They require deeper soil than extensive roofs and regular maintenance (Kadas 2006). This type of green roof, often accessible for people, requires a high carrying capacity of the structure of the building. The substrate layer varies from 25 cm or thicker, and must provide sufficient water, nutrients, and oxygen. The weight of intensive green roofs is usually more than 300 kg/m^2 (Table 6.2).

The boundary between intensive and extensive green roofs is vague and depends on perception. But a common rule of thumb is: non-accessible roofs with low vegetation are extensive roofs and accessible roof gardens with high vegetation are intensive green roofs.

Table 6.2 Overview of differences between extensive and intensive green roofs

Criteria	Extensive	Intensive
Field of application	Flat or sloped roof up to 45° (1–7 %)	Flat roof
Substrate height (cm)	5–15	>25
Layers	Multi-layered	Multi-layered
Weight of substrate (kg/m^2)	50–170	>300
Vegetation	Drought resistant, low growing speed, sedum, herbs, grass	Species with higher requirements for water and nutrients, grasses, trees, shrubs
Use	Habitat for animals	Additional living space for people
	Ecological compensation	Recreation area
	Rain water management	Meeting area
	Protection of roof material	Local food production
	Insulating capacity	Insulating capacity
Water retaining capacity	ca. 30–70 % of the annual precipitation	ca. 30–99 % of the annual precipitation
Maintenance	Low	High
Indication of costs (€/m^2)	20–30	>60

A green roof consists in essence of five different layers. The first layer on top of the regular roof construction is the waterproofing layer or membrane (1). This layer protects the roof against water leakages. Then there is a protection and storage layer (2), which prevents plant roots from growing through the roof package. This layer also keeps the whole green roof construction in place. The drainage and capillarity layer (3) buffers rainwater and drains surplus water. The root permeable filter layer (4) filters small particles out of the rainwater, to prevent them from ending up in the water drainage system where they might lead to blockages in the system. The final layer of the green roof is the growing media or substrate layer (5), in which plants can root. The thickness of this layer partly depends on the type of plants on the roof (Köhler et al. 2012). Table 6.2 gives an overview of the general differences between green roofs and is adapted from Köhler et al. (2012).

Brenneisen (2003) and Kadas (2006) conclude from their researches that green roofs contributes to preserving the local habitat. Green roofs are mainly inhabited by insects like beetles, ants, bees, and spiders. However, on some roofs uncommon and even rare species of spiders and beetles have been discovered (Brenneisen 2005). Furthermore, Brenneisen (2007) found also differences between extensive and intensive green roofs, as research done in Basel (Switzerland), shows that mainly because of the thin substrate layer (extensive green roof) less species can develop. A thin substrate layer is beneficial from a cost perspective, but for biodiversity it is harder to establish on an extensive roof than on an intensive roof (Brenneisen 2006). A variety of substrate thicknesses leads to different microclimates, and provides a wider potential for different species to establish. But in general can be stated that creating a green roof to foster biodiversity is a difficult task. Construction method, selection, and storage of local soil to create suitable substrate is crucial (Brenneisen 2006). Koster (2013) also emphasizes the importance of the substrate layer for the establishment of bees and in particular wild bees on green roofs. The composition of the substrate, the amount of nutrients in the soils, and the humidity of the soil determine which plants can grow there. For wild bees is the soil also directly important as nesting space, they especially like to nest in sandy soils (Koster 2013).

6.5.3 Greening of Outside Walls of Buildings

The same advantages of vegetation on roofs can be described for greening systems on walls. In recent years, different systems (Fig. 6.1) have been developed, like greening direct on the wall, greening systems before the wall, and greening possibilities incorporated within the construction of the wall (Hendriks 2000). Despite the range of possibilities there is still great hesitation in the building sector (from the originator, designer, architect, to the builder and the user) to increase the amount of outdoor wall greening. Probably mainly due to the possible disadvantages: the need for extra maintenance, falling of leaves, chance of damaging the wall structure, increase of the amount of insect and spiders in the house, and the expected extra costs involved.

By allowing and encouraging plants to grow on walls the natural environment is being extended into urban areas; the natural habitats of cliff and rock slopes are simulated by brick and concrete. There is a widespread belief that plants are harmful to building structures, ripping out mortar and prising apart joints with their roots (Johnston et al. 2004). The evidence suggests that these problems have been greatly exaggerated, except where decay has already set in and plants can accelerate the process of deterioration by the growing process. Certainly, there is little evidence that plants damage walls. In most cases the exact of opposite is true, with plant cover protecting the wall from the elements. Ancient walls still stand, despite centuries of plant growth (Johnston et al. 2004).

The leaves of climbing plants on walls provide a large surface area, which is capable of filtering out a lot of dust particles (particulate matter PM_x) and other pollutants such as NO_x and taking up CO_2 in daytime. Hard surfaces of concrete and glass encourage runoff of rainwater into the sewage system. Many plants hold water on their leaf surfaces longer than materials and processes of transpiration, and evaporation can add more water into the air. The result of this is a more pleasant climate in the urban area. Vegetation provides also nesting places for birds such as, blackbirds, song thrushes, and house sparrows.

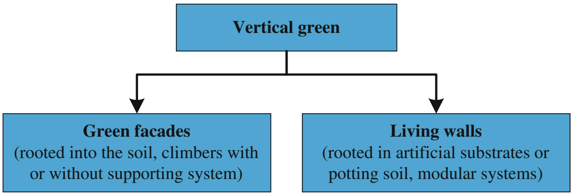

Fig. 6.10 Basic distinctions between greening principles

Table 6.3 Overview of differences between green facades and living wall concepts

Criteria	Green façade	Living wall concepts
Field of application	Sound barriers, facades (of typically older structures)	Every façade or vertical surface to create an "extra value"
Rooting medium/ substrate	Subsoil	Planter boxes, mineral wool, foam or felt layers
Layers	–	Multi-layered
Weight of substrate	–	>50 kg/m^2
Vegetation	Self-climbers (common ivy, boston ivy, etc.)	Climbers, shrubs, grasses, herbs, etc.
Use	Aesthetical reasons habitat for animals	Aesthetical reasons habitat for animals local food production insulating capacity ecological measure
Maintenance	Regular/low	High
Costs (€/m^2)	30–45	250–1,000

6.5.4 Overview of Vertical Green: Green Facades and Living Walls

Green façades, green walls, living walls, vertical green, and vertical gardens are descriptive terms, which are used to refer to all forms of vegetated wall surfaces. From the ground rooted traditional green façades and modern techniques to create green walls ensure that fundamental differences arise in vegetation types. Basically, one can understand systems rooted into the ground and based on hydroponic systems (not rooted into the ground). Green wall technologies may be divided therefore into two major categories (Fig. 6.10), namely: rooted into the ground and rooted in artificial substrates or potting soil.

Both basic principles can be classified according to their application form in practice (Table 6.3). Within the categories a distinction is made between whether if the greening system uses the façade as guide to grow upward (direct greening) or if the greening system and the façade are separated with an air cavity (indirect greening). The air space (cavity) between façade and greening system can be

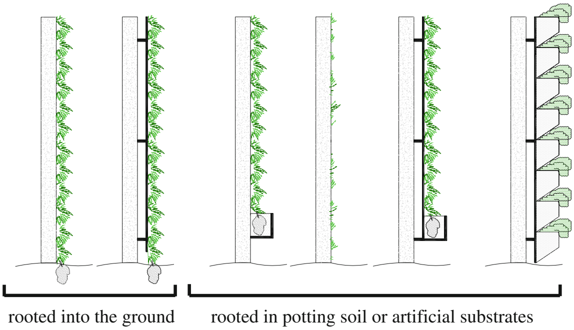

Fig. 6.11 Basic distinction between vertical green concepts, either rooted into the ground or rooted in artificial substrates (like mineral wool, foam, etc.) or potting soil

created by supporting systems, spacers, planter boxes, or by modular substrate systems. Figure 6.11 shows differences between direct and indirect façade greening and possible forms of their application.

The systems that are based on "artificial substrates and potting soil" principles are dependent on irrigation systems and adding nutrients to the substrate. These systems are known as living wall (LWS) concepts. Characteristic for this greening principle is the use of planter boxes filled with artificial substrate/potting soil or modular prefabricated panels equipped with artificial substrate. Additionally, an irrigation system is needed to keep the green system in the right condition. The used substrates and composition of living wall concepts can vary by manufacturer of the product. In general, one can distinguish systems based on (Fig. 6.12). The plants used for LWS are different type of evergreen small shrubs, offering much more creative, and aesthetical potential (Figs. 6.13, 6.14, 6.15, 6.16 and 6.17).

From a functional point of view, most of the living walls systems demand a more complex design compared to green façades; as a greater number of variables

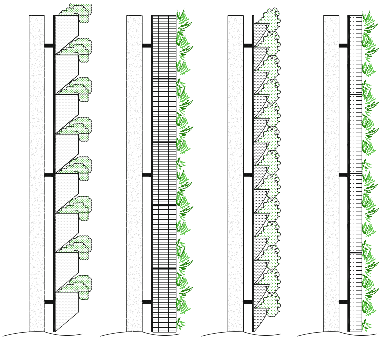

Fig. 6.12 Typical configurations of LWS concepts (based on planter boxes, foams, laminar layers of felt and mineral wool as substrate)

Fig. 6.13 Examples of green facades (rooted into the ground) *left photo* Dordrecht (The Netherlands), *right photo* Frederikshaven (Denmark)

Fig. 6.14 *Left* indirect greening system based on climbing plants attached to the façade in planter boxes. *Right* planterboxes system filled with small shrubs

must be considered, several layers are involved, and there are more supporting materials, and control of water and nutrients must be carried out. Living wall systems in fact are often very expensive, energy consuming, and difficult to maintain (Ottelé et al. 2011a, b). Furthermore, it is also important to take also the durability aspects of the systems into account. The durability of living wall

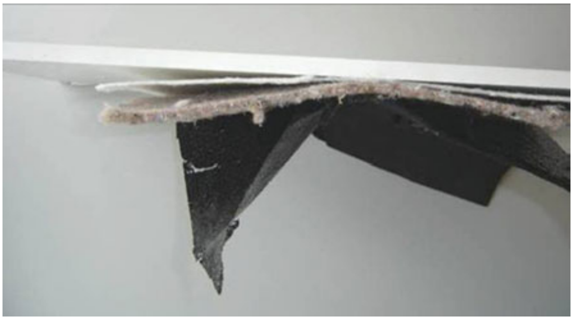

Fig. 6.15 Cross section of a living wall system based on felt layers. Due to the minimum rooting thickness very vulnerable for dehydration. Irrigation and nutrient system necessary

Fig. 6.16 Cross section of a living wall system based on mineral wool. Thicker rooting medium resulting in more redundancy against dehydration. Irrigation and nutrient system necessary

systems varies according to the type of system available. Living wall systems with panels based on felt layers have an average life expectancy of 10 years, and living wall systems based on planter boxes last more than 50 years. A thorough design (details of window ledges, doors, etc.) is always necessary to avoid damages, as corrosion or rot, caused by leakage of water and nutrients (Ottelé et al. 2011a, b). The green layer also results in a shading effect, which reduces the amount of UV light that will fall on building materials; since UV light deteriorates the material and mechanical properties of coatings, paints, plastics, etc., plants will also have an effect on durability aspects (Wong et al. 2009). Greening the building envelope with living wall systems is a suitable construction practice for new building and retrofitting (Ottelé 2011; Perini 2012). In both situations, it is possible to have a higher integration within the building envelope by combining functionalities. For example, in the case of the conventional bare walls constructed by several layers it is possible to avoid building the outer façade element since the protection against the environmental parameters is ensured by a living wall system. For retrofitting projects an external insulation material can be easily covered with LWS panels (Ottelé et al. 2011a, b).

Fig. 6.17 *Left photo* example of a living wall (felt layers) attached to a façade in the inner city of Antwerp (Belgium). *Right photo* living wall system in the inner city of Madrid (Spain)

6.6 Conclusions and Reflection

In the previous article, the author attempted to demonstrate the value of reintroducing vegetation to the surfaces of urban buildings and their related spaces. The ecological and environmental benefits of a green building envelope include the improvement of air quality and the reduction of pollution. The advantages are mainly related to the reduction of fine dust levels (Ottelé et al. 2011a), increased biodiversity (Köhler 1993), and reduction of the heat island effect in urban areas (Taha 1997; Onishi et al. 2010). This occurs thanks to the lower amount of heat reradiated by greened surfaces and humidity affected by the evapotranspiration caused by plants (Scudo and Ochoa De La Torre 2003). This process also allows indirectly to save considerable energy supplied to the building (Dunnett and Kingsbury 2004; Köhler 1993) as the plants and the growing medium provide insulation and shade, which can reduce, especially in the Mediterranean area, energy needed for cooling (Wong et al. 2009). Besides these benefits, social and economical advantages of greening systems are also involved, including: the real estate market, greater durability of buildings, and the better psychological state of citizens (Köhler 1993; Dunnett and Kingsbury 2004; Johnston and Newton 2004).

We have suggested that, far from being a radical or fashionable solution, this is simply the reinterpretation of an approach with a long and distinguished history.

Before the full benefits of green buildings could be scientifically proven, the principle was already accepted and practiced in cities all over the world. Green building is most effective as part of an integrated green approach to cities. Such an approach demands a much closer cooperation between architects, ecologists, developers, and green planners than has so far taken place. The integration of vegetation in the built space can be an opportunity to improve the environmental conditions of dense urban areas and to reduce the energy demand of buildings, especially in Mediterranean area due to its cooling capacity. This is an important field to investigate considering the growing interest on these systems, which is not only connected to a more sustainable approach to construction, but also to esthetic intentions (Perini 2012).

To guarantee sustainable practices, benefits, and performances obtainable thanks to greening systems, have to be considered along with the environmental burden produced during the life span of greening systems, and with the possible problems connected to maintenance demand. Also costs have to be considered for a wider diffusion of these systems. Measurements carried out in the field by many researchers show not only the potential of vertical green on the thermal performance, but also under laboratory conditions (Ottelé 2011). The positive effect on the thermal resistance (i.e., summer and winter) is mainly caused by the materials used, extra cavity, water availability, and metabolism of the plant tissue. Through (significant) less heat accumulation by the masonry in combination with evapotranspiration caused by the plant material, a positive effect to lower/mitigate the urban heat island effect can be taken into account.

As discussed throughout the article, many aspects have to be considered to avoid that green only plays an esthetic role with respect to sustainability. Characteristics, components, and materials of vertical and horizontal greening systems can have an influence on the environmental burden and environmental benefits, etc. Some systems, as the living wall ones described, offer much more creative and aesthetical potential, but due to the material used and durability in some cases cannot be considered as sustainable. Material choice and durability aspects are important (environmental impact) when the energy demand of a building can be reduced or when the multifunctionality of the construction due to the integration of vegetation can be increased. These aspects have been considered also through a life cycle analysis (Ottelé et al. 2011a, b). As suggested by Henry and Frascaria-Lacoste (2012) the adoption of LCA analysis for the labeling of green products could increase their use since it has the potential to boost the confidence of consumers. Therefore, this could lead to particular focus being placed on specific green elements, which could potentially further homogenize natural features within cities, with possible negative impact on other benefits of green, such as biodiversity (Henry and Frascaria-Lacoste 2012). However, a LCA could lead to deeper consideration by manufacturers of the environmental burden produced by their systems to improve the balance between benefits and burden for a more sustainable built environment.

To stimulate biophilic design in architecture modern greening concepts as vertical gardens and green roofs, should be considered as a “building material” with multifunctional properties (ecological, social, mitigation of urban heat, etc.) compared to our traditional cladding and roofing materials (masonry, concrete, marble, glass, bitumen, etc.). Material choices are often underestimated by designers, manufacturers of greening systems, and architects. An optimal balance have to be found between durability aspects, materials really needed (also by mass, i.e., in this case less is more!) service life, and lifespan. In the case of a new design, try to integrate a greening concept into the building envelope instead to add an “extra” green layer to a conventional solution. Besides, it is mandatory to be aware of the cooling and insulation potential of green structures related to energy savings, it contributes to a lower energy demand at the building level, and must not be underestimated. This “total” awareness, which is related to a wider research in this field, will lead to a more eco-friendly and sustainable design of cities.

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