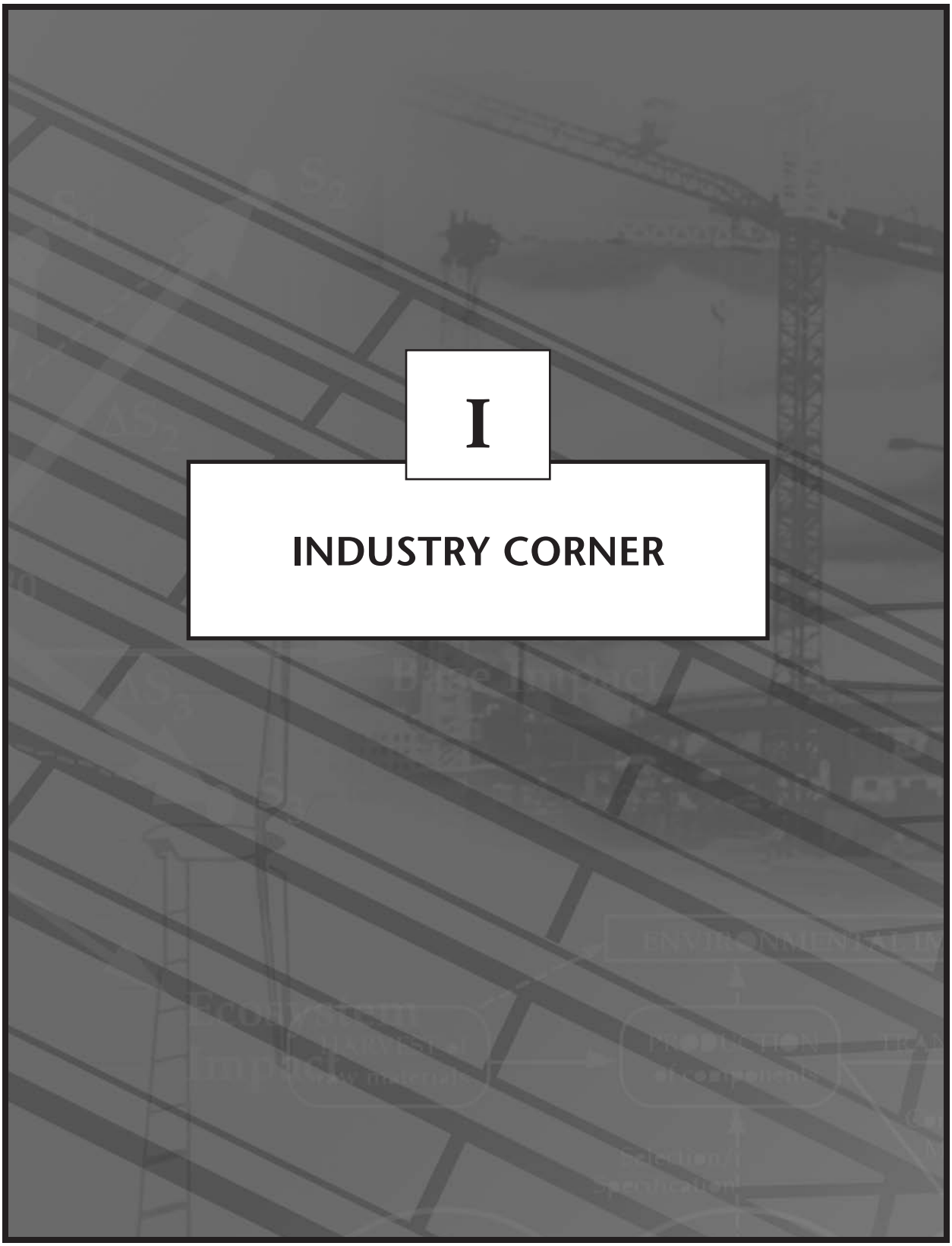

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INDUSTRY CORNER

ARE GREEN WALLS AS "GREEN" AS THEY LOOK? An Introduction to the Various Technologies and Ecological Benefits of Green Walls

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INTRODUCTION

According to a United Nations forecast seventy percent of the world population will be living in cities by 2050 (UNFPA 2007). Such a major shift away from rural and naturally vegetated areas to the polluted, noisy, and crowded concrete jungle of modern cities is and will continue to be profound. We must find new and innovative ways to better integrate nature into our ever expanding cities. Green roofs and parks are one way to do this but there are substantial amounts of vertical space that for the most part have been underutilized. Green walls not only bring nature back into city life, they do so in a way that is accessible to everyone.

Currently green walls are at the cutting edge of interior and architectural design trends but they are also being integrated into sustainable building design for their numerous environmental benefits. This article aims to clarify what green walls are, going into detail about the various technologies available; the pros and cons of each; and the ecological, social, and economic benefits of these living works of art.

GREEN WALLS DEFINED

The terms green wall, living wall, plant wall, or vertical garden are used interchangeably but appertain to the same general concept. From here on they will be referred to simply as green walls.

Numerous green wall technologies have appeared in the last few years but can be broken down into two main categories: hydroponic systems and modular boxes. Some also put green facades (e.g., ivy walls) into this group; however, they should be in a class of their own as the technology is vastly different.

Green walls are self-sufficient vertical gardens that are attached to the exterior or interior of a building. They differ from green facades in that the plants root in a structural support, which is fastened to the wall itself (Green over Grey 2009). The plants receive water and nutrients from within the vertical support instead of from the ground. This fundamental denotation includes many different methods; these will be covered extensively in the coming sections.

Exterior green wall. Image provided courtesy of Green over Grey—Living Walls and Design Inc.

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NATURAL GREEN WALLS

Species that grow vertically can be found all throughout nature. Vines and climbers are an obvious example. However, it is a common misconception that plants need soil in order to survive. Although it does offer the structural support required by some, countless others have evolved to grow in little or no soil at all.

The edges of riverbanks, beside waterfalls, around cave openings, on cliffs or the sides of trees are some examples of the diverse environments in which natural living walls occur. As long as plants receive light, moisture, and nutrients they can thrive. This is why plants that grow vertically are found more frequently where there is a relatively high and constant source of moisture, either from spray, seepage, humidity, rain, etc. Most natural sources of water contain enough dissolved nutrients to sustain vegetation, including rain water. Certain epiphytic species in the genus *Tillandsia,* also known as air plants, derive all of their moisture needs from the air (Brickell and Cole 2004).

Natural green wall found alongside a waterfall; a diversity of plants thriving in little to no soil.

HISTORY OF GREEN WALLS IN CITIES

Humans and plants have always co-existed but it wasn't until about 10,000 years ago that true agriculture was developed (Hamilton 2009). At this point humans realized that they could benefit from growing and tending to plants. It is unknown when people started to keep plants in cities for their beauty alone but over 2500 years ago the famous Hanging Gardens of Babylon were constructed for this reason. It is said that the Gardens were built by a husband to please his wife because she had a passion for mountain surroundings and missed this while living in the city (Ashmawy 2006). Ancient Greek sources described the Garden like this:

> The Hanging Garden has plants cultivated above ground level, and the roots of the trees are embedded in an upper terrace rather than in the earth. The whole mass is supported on stone columns. . . . Streams of water emerging from elevated sources flow down sloping channels. . . . These waters irrigate the whole garden saturating the roots of plants and keeping the whole area moist. Hence the grass is permanently green and the leaves of trees grow firmly attached to supple branches. . . . This is a work of art of royal luxury and its most striking feature is that the labour of cultivation is suspended above the heads of the spectators (Ashmawy 2006).

Green facades (i.e., ivy, vines, cascading groundcovers) have been used in urban areas for centuries. However, it was only about 30 years ago that the first true green walls were invented. Their popularity in Europe has been growing steadily ever since. North America is quite behind and just catching up now; it is currently in the middle of a green wall revolution especially among environmentally aware designers, architects, and developers.

TECHNOLOGIES

Hydroponic Systems

Background

The French botanist Patrick Blanc is the grandfather of green walls. He is accredited for inventing the first hydroponic system and for introducing green walls to the public realm over twenty years ago. "Mur végétal" translates roughly to vertical garden and this is the term coined by Blanc. Today, his vertical gardens can be seen all over the world, some covering buildings up to 10 stories high! They didn't start this way, and as with any invention there were major elements of trial and error.

Blanc was always fascinated by plants and started his research in the tropical rainforests of Asia. He wanted to recreate the ecosystems he found in these forests inside his apartment in France. He looked to nature for inspiration and realized that many plants can grow without soil. Their roots instead develop throughout a substrate, such as moss or algae growing on rocks or tree trunks. He took this idea and started to toy with it.

He found that certain textiles could provide similar properties to moss or algae because they gave structural support, held moisture, and allowed the roots to move freely throughout. Natural fibres such as wool or cotton did not work because they would break down. However, recycled synthetic fibres such as nylon and polyester did not have any problems and lasted indefinitely, even under constant moisture.

The support structure was another issue; he started by using wooden boards, which imitated tree trunks. After a few years the wood started to decay and fall apart obviously destroying the vertical garden in the process. He finally found a type of waterproof plastic board that did not break down yet provided structural support for the plants to grow.

This is the system that he still uses, and it can be seen on hundreds of buildings around the globe. Over the years Blanc has experimented with thousands of plant species and found that even bushes and trees were able to thrive. The longevity of the system has been tested, with the oldest vertical garden almost thirty years old. If the gardens ever have to be removed the plastic panels can be reused or recycled.

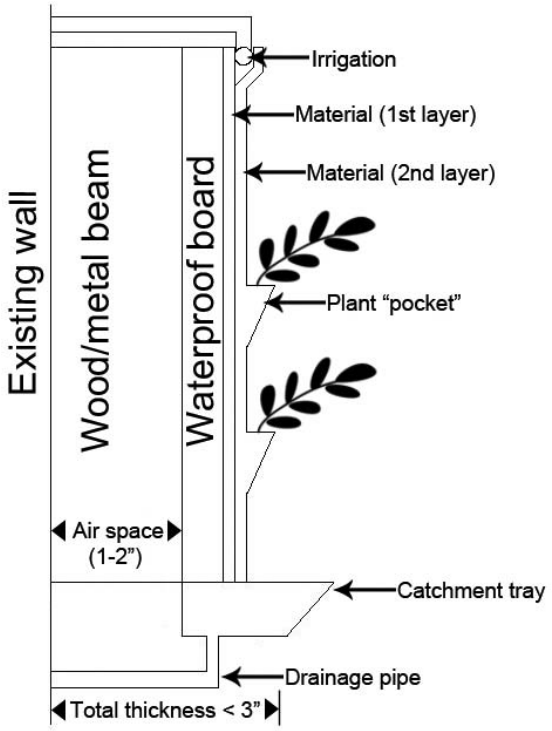
Technical Details

A frame is erected, simply as vertical beams or, for larger projects, as a lattice work. For exterior green walls that are exposed to the elements it is possible to use either aluminum, galvanized steel, stainless steel, or some other non-rusting metal. It is firmly attached to the building or structure. Waterproof

Hydroponic green wall creation by Patrick Blanc; hotel restaurant, Paris France. Photo: Mike Weinmaster.

Portable hydroponic green wall. © *Greenwall Australia.*

FIGURE 1. Side view of a hydroponic green wall system.



panels are then fastened to it (see Figure 1). For interior green walls wood beams are used for framing as no moisture is able to go behind the waterproof panels. Wood is cheaper and also more sustainable than metal.

Both exterior and interior walls have an air space between the panels and the existing wall. This space is approximately 1.5 to 2 inches wide running the whole height and length of the garden. It enables air to circulate freely behind the wall.

Two layers of material are stapled to the waterproof panels. The material is generally made up of recycled synthetic fibres that are spun into a nonwoven matrix. Plants are placed between the two layers of material in hand cut pockets. Soil is removed from around the roots, and some companies use an inert substrate, such as perlite or vermiculite, in its place. The substrate holds the water longer thus reducing the amount of irrigation required. The roots of the plants are free to grow throughout the whole vertical garden resulting in no space limitations (Green over Grey 2009).

A drip irrigation system is placed between the two layers of material allowing the water to slowly percolate downward. This supplies the plants with an ideal amount of moisture and nutrients. The nutrients are distributed with a fertilizer injector that puts minute amounts into the water stream at only 0.2 to 0.3 gram per litre (Blanc 2008). Harvesting and irrigating with rainwater is recommended and when used diminishes the amount of required nutrients. For smaller installations it is possible to have a reservoir; however, the nutrients must be mixed by hand or by some other means. These systems usually require more maintenance as the pH and conductivity must be monitored to ensure the system is kept in balance. Depending on a number of factors, the time needed for irrigation is anywhere from three to five times per day with intervals lasting for about one to three minutes (Blanc 2008). The factors dictating

how much watering is required include the exposure of the wall, what season it is, and what types of plants are chosen. Even a south facing green wall in the hot summer months would still require less water than urban parks and traditional landscaping (Green over Grey 2009). This is because the watering is targeted to the roots of the plants as opposed to watering the ground around them as well.

Companies that offer similar hydroponic systems include Green over Grey—Living Walls and Design (www.greenovergrey.com) for the North American market and Greenwall Australia (www.greenwallaustralia.com.au).

Advantages

One of the major advantages of the vertical garden system is the ability to use an extremely large diversity of plants. The system closely mimics how plants grow in nature meaning that thousands of species have been proven to thrive on this type of green wall. Having access to such a variety allows for endless possibilities in design and no limitation of artistic freedom. This system is better for people interested in more than simply covering the wall with greenery, as it has a greater aesthetical appeal.

The roots of the plants are free to grow throughout the entire green wall and are not confined to a limited space (such is the case with most modular box systems). As they grow they form a tight matrix and thus with time the strength of the system actually increases (Green over Grey 2009). This makes it possible to integrate shrubs, bushes, and even trees in addition to groundcovers and smaller vegetation. Plants are able to grow to their full potential in this system. Another advantage to using such a diversity of plants is that pests rarely become a problem. Mono-cropping is a common practice in agriculture today but a major problem with it is the fact that most pests target a single crop—potentially spelling disaster. However, when there is a diversity of plants, it is more difficult for the pest to establish and wipe out an entire crop.

Weight is a very important aspect to consider when integrating a green wall onto a building facade. Being hydroponic makes this system by far the lightest on the market. In fact it is over 10 times lighter than common modular box systems, weighing in at a mere 4 pounds per square foot (Blanc 2008).

Modular green wall companies claim that having a box makes it easy to replace if the plants die or get a disease but in hydroponic systems they tend to thrive and don't have to be replaced very often. If they do need to be changed, it is quite easy and done plant by plant instead of as a full panel.

Disadvantages

This system is more appropriate for permanent applications, as it is not modular. However, some companies offer smaller hydroponic living walls that are portable. Integrated into one convenient system is a reservoir, pump, and everything required to keep the plants thriving, all on wheels. Some companies offer

Hydroponic green walls allow for a large diversity of plant species. Image provided courtesy of greenovergrey.com.

Hydroponic green wall creation by Patrick Blanc; shopping district, Paris France. Photo: Mike Weinmaster.

these as natural, breathing dividers for offices, retail stores, hotels, tradeshows, advertising campaigns, movie sets, and others.

Patrick Blanc's Vertical Gardens are protected by copyright laws and any reproduction requires written authorization.

Modular Boxes

Background

It is unknown who was the first to invent modular green wall boxes. However, it was most likely due to the fact that the Patrick Blanc system is protected and because they are more suitable for temporary installations and DYI projects. Many of these systems have patents, making them more desirable for companies who want exclusive rights to the technology.

Certain companies such as ELT Easy Green (www.eltlivingwalls.com) offer vertical planter boxes for small projects. The empty recycled plastic trays can be purchased online. They are filled with potting soil, planted, hung on a wall, and watered by hand. Other companies such as Greenwall France (www.greenwall.fr) and VGM Green Wall (www.elmich.com) offer boxes that are pre-planted and they will do the installation.

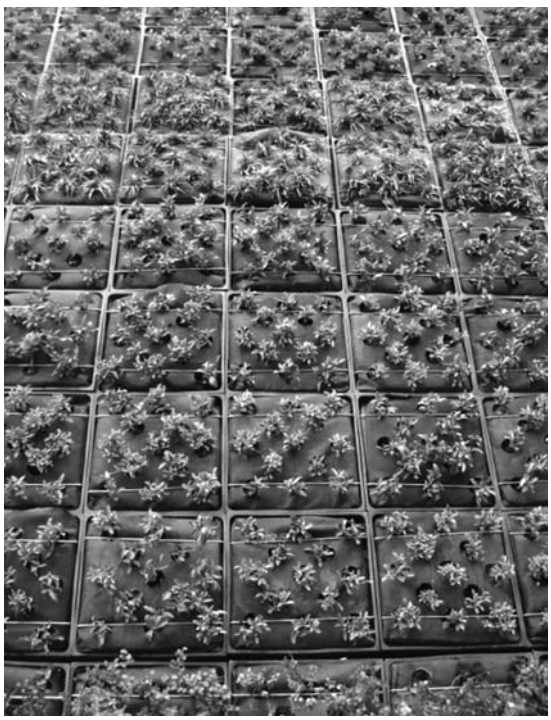
Technical Details

There are two main variations of the modular box technology, outlined below.

The first is the true box system, utilizing an empty square container made of plastic, metal, or some other material. This is filled with coco-coir, rock/mineral wool, peat, or some similar substrate. The number of plants used in a single box can range from six to fifteen, depending on the size of the species and type of box used. Most plants are added as plugs. Layers of plastic, fabric, mesh, and/or metal bars cover the boxes to hold everything in place. The sizes of the boxes vary widely depending on the manufacturer but generally are about one square foot and a few inches thick.

The second variation uses plastic or metal trays containing multiple slanted cells. These are filled, usually with soil, and then planted. The slanted cells help to keep the plants in place and facilitate irrigation. The water drips through the back of the panels. This technique is slightly more complex than hanging potted plants on a wall as each cell can be thought of as a small pot. These systems usually can be placed side by side and stacked to add height.

Modular green wall; true box system. Photo: Mike Weinmaster.



Substrates

The type of substrate used in a modular green wall box system gives a good idea of how "green" the product is. The following list details which substrates are commonly used and how sustainable each one is:

Rock Wool. Rock wool (also known as mineral or stone wool) requires a great deal of energy to produce. It is manufactured in a furnace, at temperatures approaching 1600°C. At this temperature the rock becomes molten and can either be spun or have air blown through it to produce a mass of fine intertwined fibres (Grove-Rasmussen and Elmekilde 1999). Because of the high energy requirements, rock wool is not the best substrate choice for modular green walls.

Coco-Coir. The outer husk of coconuts provides a valuable fibre called coir. Coco-coir peat is produced as a by-product when the long fibres of the coconut husks are extracted for manufacturing ropes and matting (Younus and Mirza 2000). The fact that it is a waste product makes it appropriate and most likely the best choice.

Peat. Peat, which is the decomposed organic matter of mosses, sedges, and other semi-aquatic plants, only accumulates at an average rate of 5 cm per century (BOTT 2009). Peat that has taken thousands of years to develop is usually removed within a single harvest. This can be thought of as an unsustainable resource as currently we are extracting it from fens, swamps, marshes, and bogs (collectively known as peatlands) faster than it is being created. Peatlands are important ecosystems as they raise groundwater levels with naturally filtered water and provide essential habitats for plants and animals that thrive under harsh conditions (BOTT 2009).

Peat filled metal mesh boxes, planted and ready to be hung. Photo: Mike Weinmaster.

Potting soil. Ironically potting soil usually contains little to no actual soil and is instead made up primarily of peat and sand. Sometimes bark, perlite, vermiculite, or vermicompost is also added (Hessayon 2004). With peat usually being the main component of potting soil, it goes back to the aforementioned negative aspects of peat as a substrate. Potting soil can attract insects such as fungus gnats and can harbour pathogens, which can be detrimental to plants.

Advantages

Modular box systems are the most appropriate for temporary installations. The individual boxes are easy to install, replace, and remove. Kits are available for purchase online making them great for do-it-yourself projects. Another advantage, especially with the tray system, is that they are the best for growing short seasoned food crops such as lettuce. This is because they are not as permanent as the hydroponic systems and can be easily replanted panel by panel.

Disadvantages

Modular boxes tend to be the green wall technology most widely used in North America. With these systems there are usually more disadvantages than advantages. This may be part of the reason why green walls have not caught on in North America as they have in other parts of the world; people associate them with problems.

The main problem is that the space available for root development is limited to a few cubic inches. Therefore, only groundcovers and small plants can be used. This severely reduces diversity, which in effect limits the freedom of design and the potential to recreate natural ecosystems. The overall effect tends to be boxy, squat, and geometrical—not something nature would create.

With the true box systems, the panels must be pre-planted and slowly tilted to a vertical position in order for the plants to properly adjust to the new

Plants in tray systems can be washed away during heavy rain. Photo: Mike Weinmaster.

angle. The process can take anywhere from one to six months. This potentially can increase the price as more of an infrastructure is required to prepare the panels prior to being hung.

A drawback to the tray system is that, because the plants cannot firmly take root in the plastic/metal cells, they can easily be washed out or removed when there are heavy rains or strong winds. If soil is the chosen substrate, the dirt can fall out; this being problematic, especially for interior installations.

Modular boxes can weigh up to 30 pounds per square foot (G-Sky 2007). This is a substantial difference when compared to 4 pounds per square foot for hydroponic systems.

Green Facades

Background

Green facades differ from green walls in that their vegetative layer is rooted in the ground and grows up. The plants use a vertical surface, such as a wall, fence, or wires, for structural support but do not receive any moisture or nutrients from it. Common examples include buildings covered in ivy or trellises with vines.

Another type of green facade occurs when cascading groundcovers are used to cover a wall. These are different than the traditional green facades in that they are planted in soil or pots above a wall, instead of below. Terraces can also be integrated in order to cover a larger vertical space.

The last type of green facade is created when bushes or trees are encouraged to grow right up against a building. This method is known as espaliering and is commonly used with fruit trees in cooler climes. The extra warmth from the solar radiation hitting the building helps to extend the growing period. The buildings also act as protection from cold winds. The effect can be quite amazing but requires regular pruning and manipulating.

Green facade plants

Ivies (*Helix hedera*) are commonly chosen to cover buildings. They are supported by aerial roots, and where these are allowed to penetrate cracks or joints they can jeopardize the structural integrity of a building (Royal Horticultural Society 2009). Old plants can have very well developed root systems and can compromise the foundation of adjacent buildings.

Some types of creeping plants, especially ones in the genus Parthenocissus, such as Boston Ivy (*Parthenocissus tricuspidata*) or Virginia Creeper (*Parthenocissus quinquefolia*) do not have aerial roots that penetrate building materials. They instead adhere to smooth surfaces by means of five- to eight-branched tendrils ending in cup-like, adhesive tips (Francis 2004). They pose little threat to the building masonry, other than small marks, and are therefore a better choice than ivies for green facades.

Climbers in the genera *Jasminum*, *Clematis*, *Lonicera*, plus many others, are also good choices for green facades. They do, however, require some form of support to grow vertical. This can be in the form of trellises, wires, or a metal framework placed next to a building's exterior. These provide support for the plants to climb up without having them touch the building exterior. An American company called greenscreen® (www.greenscreen.com) provides wire mesh and trellis systems.

Example of a typical green facade (i.e., ivy wall).

Green facade using a wire mesh system. © greenscreen®.

Suitable cascading groundcovers for a terrace system include Snow-in-Summer (*Cerastium* sp.), Creeping Rosemary (*Rosmarinus officinalis* "Prostratus"), Evergreen Candytuft (*Iberis sempervirens*), Creeping Jenny (*Lysimachia nummularia*), Stonecrop (*Sedum rupestre*), and numerous others.

Advantages

The main advantage of green facades is the cost. They are, for the most part, the cheapest "wall greening" system available.

Disadvantages

The biggest disadvantage is the fact that the plants take a long time to cover the wall completely, often more than a decade. If a plant dies, it will take many years to fill the gap left behind.

As outlined above, ivies can do permanent structural damage to a building if allowed to grow freely. They require regular maintenance to ensure the plants do not grow in front of windows.

There is a limitation in what can be done with green facades with regard to artistic freedom and the use of different plants to create patterns and designs. Basically, only vines, cascading plants, or meticulously manicured trees can be used.

Ecological benefits such as energy savings, thermal insulation, building protection, and storm water management are not as pronounced with green facades as they are with the other green wall technologies.

ENVIRONMENTAL BENEFITS OF GREEN WALLS

Urban Heat Island Mitigation and Energy Savings

When urban centres are constructed it is inevitable that much of the existing vegetation is removed and

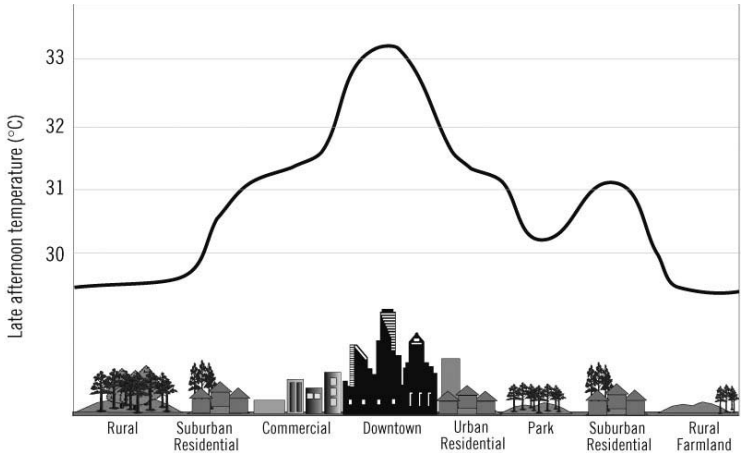


FIGURE 2. Urban heat island profile (Natural Resources Canada 2007).

replaced with typical urban surfaces such as buildings, rooftops, and concrete. In doing so this creates a phenomenon known as the urban heat island effect (UHIE); an elevation of temperature relative to the surrounding rural or natural areas (see Figure 2).

The UHIE occurs because more of the incoming solar radiation is absorbed by the many dark surfaces in the city and reradiated as long-wave radiation or heat. Below a certain temperature, the demand for electricity is inelastic. Above this threshold, every degree centigrade increase can raise electrical consumption by 5%, increasing emissions of the fossil fuels required for its generation (Bass and Baskaran 2001). Studies have found urban air temperature of up to 12°C higher than surrounding areas (Luvall, et al. 1997). This generates an additional demand on air conditioning, refrigeration systems, and the energy they require. The higher temperatures also augment the aforesaid problems associated with heat stress and the rate of ozone formation (Bass and Baskaran 2001).

The good news is that vegetation and the integration of green walls and roofs in urban areas can reduce the negative impacts of the UHIE and can save energy. Covering a building with foliage naturally shades it and depending on the type of green wall used can give additional insulating properties. This will result in a considerably less amount of heat being radiated inward. Some studies have shown that green walls can cut electricity bills by up to 30% (Conseil national de recherché du Canada 2002).

The systems and vegetation within them do this by a two-part process known as evapotranspiration. The materials that make up green walls retain water and slowly release it to the atmosphere via evaporation. Transpiration occurs when water is pulled from the roots and vapour flows from the leaves into the air (Floyd 2007). Together this reduces the UHIE because the incoming solar energy that is used for evapotranspiration cannot be absorbed and reradiated as heat. The energy used for evapotranspiration is embodied in the water vapour, which prevents it from being converted into heat at the surface (Bass and Baskaran 2001). Studies in Oregon demonstrated that non-vegetated areas could exceed temperatures of 50°C in July while vegetated areas remained at 25°C (Luvall and Holbo 1989).

Storm Water Management

During precipitation events impervious urban surfaces such as roads, sidewalks, parking lots, buildings, and compacted soil do not provide drainage. As the water flows over these surfaces it picks up pollutants that have been accumulating. When it reaches a drain the excess can overwhelm waste water treatment plants.

Parks, green roofs, and other vegetated areas absorb surplus water, filter, and slowly release it back into the environment. This alleviates peak discharge and aids in flood control.

Green walls can also be used as a tool for storm water management. It is possible and highly recommended to irrigate green walls with rainwater

whenever possible. The naturally dissolved minerals found in rain provide plant nutrients, thus reducing the amount of fertilizer required. Integrating reservoirs, retention ponds, or rainwater harvesting techniques into a green wall system will increase onsite infiltration and evapotranspiration (Green over Grey 2009).

Having stormwater percolate through a green wall system can lead to a near total elimination of pollution before being released back into the surrounding environment. This process is carried out by the roots (and microorganisms living around them), which break down and utilize the dissolved contaminants.

Greywater is another possible source for irrigation. A green wall also filters the water before releasing or recycling it.

Biodiversity and Conservation

If you were to go back in time, before any city or agricultural land was developed, what you would find is an ecosystem that is very diverse, containing many different plants and animal species. Modern cities and croplands have severely reduced this biological variety.

Green walls can be viewed as mini ecosystems; the incorporation of such a variety of plant species supports many beneficial organisms such as butterflies, bees, ladybugs, and humming birds (Green over Grey 2009). In effect, they bring nature back to the city.

Although a subject of debate, supporters of zoos claim that having wildlife in captivity, where people can visit, appreciate, and learn about the animals, teaches them to conserve the ones threatened in the wild. One could then argue that the same principle can be applied to a green wall. If people are up close and personal with a multitude of plant species, perhaps they will have a greater appreciation for the natural world and try harder to halt habitat destruction.

Noise Pollution and Acoustics

Plants and trees have been used for years as barriers against traffic and other urban noise pollution (Kotzen and English 2009). Green walls installed on the exteriors of buildings will do the same. They insulate against noise, vibrations, and reduce sound penetration. In addition they help to absorb the echo bouncing off buildings, dampening the loud sounds found in modern cities.

Studies have shown that the leaves of plants attenuate sound by reflecting, refracting, and absorbing acoustic energy in small amounts (Martens and Michelsen 1981). The amount of noise reduction is proportional to the number of plants present. Green walls contain such a large number of plants that the acoustics of a room can be substantially improved.

Indoor Air Quality

We currently live in a world where little is untouched by man. Pollution is reaching the farthest corners of the planet. It is almost enough to make you want to run inside and hide! However, this may not be the best idea because according to modern scientific research, indoor environments may be as much as ten times more polluted than the outdoor environment (B. Wolverton 1996). This is known as "Sick Building Syndrome."

According to the Environmental Protection Agency, "people living and working in buildings of manmade materials inhale over 300 contaminants every day" (EPA 2009). Concerns about these contaminants arise from the hypothesis that, when combined, the toxicity of hundreds of different chemicals can "add up" to create major health hazards. The average person spends over 90 percent of his or her time indoors (American Physical Society 2008). We are constantly being bombarded with indoor air pollution. This includes toxic fumes such as formaldehyde, VOCs, trichloroethylene, carbon monoxide, benzene, toluene, xylene, and countless others (B. Wolverton 1996).

Research undertaken by the National Aeronautics and Space Administration (NASA) proves that plants are capable of cleaning indoor air of the toxic chemical soup that is common in modern buildings (Wolverton, Douglas, and Bounds 1989). Certain green wall plant species are very efficient at absorbing and removing pollutants from indoor air (see Table 1). A single plant removes a portion of these airborne toxins and with each additional plant this increases. Even a small green wall can contain over a thousand plants.

Studies have found that chemicals such as formaldehyde and carbon monoxide can be removed by the plant leaves alone. VOCs, TCE, benzene, toluene,

TABLE 1. Common indoor pollutants and the tropical (green wall) plant species that are best at removing them.

Indoor pollutant(s)	Green wall plants
Formaldehyde (CH_2O)	Peace lily (*Spathiphyllum* sp.) Boston fern (*Nephrolepis exaltata* "Bostoniensis") English ivy (*Hedera helix*)
Carbon Monoxide (CO)	Spider plant (*Chlorophytum comosum*) Janet Craig Dracaena (*Dracaena deremensis* "Janet Craig") Ficus *sp.*
Volatile Organic Compounds (VOCs)	Golden Pothos (*Scindapsus aures*) Devil's ivy (*Epipremnum aureum*) Philodendron *sp.*
Trichloroethylene (TCE)	Mother-in-law's tongue (*Sansevieria trifasciata* "Laurentii") Chrysanthemum (*Chrysantheium morifolium*) Dracaena *sp.*
Benzene (C_6H_6) / Toluene (C_7H_8) / Xylene (C_8H_{10})	Kimberly Queen Fern (*Nephrolepis obliterata*) Orchid sp. (*Phalenopsis sp.*) Dieffenbachia *sp.*

Adapted from Dr. B.C. Wolverton's book *How to Grow Fresh Air,* 1996.

xylene, and numerous other toxic chemicals can be removed by the roots of plants (or by the microorganisms living around the roots which degrade and assimilate these chemicals) (Wolverton, Douglas, and Bounds 1989).

An active green wall takes the air filtering capacity of plants to the next level. It is where a green wall is actually integrated into the HVAC system of a building. This is done by the use of fans located behind the wall. They actively draw the air through the plant layer that aids in delivering the normally harmful chemicals to the plants and their roots (Hedberg 2008). The clean air is then circulated back into the building.

Indoor air quality is substantially improved by having a green wall, and this is done using little to no valuable floor space. In addition, plants do not break or have to be replaced, unlike mechanical air filters. In addition to air filtration, plants release energy-rich oxygen, which helps to keep people awake and alert.

Health and Wellness

Life in urban environments surrounds us with concrete, traffic, noise, and pollution. This is not healthy. It has a profound impact on our physical and mental wellness. Greenery softens this hard environment, acting as a tonic to ease stress and fatigue. Green walls provide a substantial and spiritual connection to nature that is missing in the modern concrete jungle (Green over Grey 2009).

Why is it that people feel more relaxed and less stressed around greenery? It is most likely due to man's evolutionary bond with plants. According to some optometrists the human eye can distinguish between 2,000 shades of green, but only 100 shades of red (Eidson 2007). Through human evolution, recognizing a plant's shade of green was really important when you were about to eat it or use it for shelter or medicine. This could be one of the reasons why we feel so comfortable around plants.

According to scientific reports carried out at American and European Universities, simply having a view of plants in a working environment gives positive physiological responses. This translates into greater employee efficiency thus resulting in increased earnings.

A study carried out at Washington State University had participants' blood pressure and emotions monitored while completing a simple, timed computer task in the presence or absence of plants. It concluded that when plants were added to the interior space, the participants were more productive (12% quicker reaction time) and less stressed (lower blood pressure). In addition, immediately after

The humble peace lily (*Spathiphyllum sp.*) is one of the best green wall plants for removing indoor air pollutants.

completing the task, participants in the room with plants present reported feeling more attentive than people in the room with no plants (Lohr, Pearson-Mims, and Goodwin 1996). Plants help people to feel more relaxed and focused, which leads to an increase in productivity, creativity, idea generation, and problem-solving capabilities.

Another study was carried out at the Norwegian Agricultural University with the goal of assessing the effect of plants in an office on the health and symptoms of discomfort among office personnel. During randomized periods the subjects were exposed to bare office environments and to ones where plants were within view. It was found that during the periods that plants were present, symptoms such as cough, fatigue, and dry/itchy skin decrease at 37, 30, and 23% respectively (Fjeld, et al. 1998). If people have a view of foliage and feel healthier at work because of plants being present, then the number of days off due to "sickness" decreases (Bringslimark, Patil, and Hartig 2006).

Gardens incorporated into hospitals have been shown to calm patients, improve their well-being, and foster improvement in clinical outcomes such as reducing pain medication intake and shortening stays (Ulrich 2002).

These studies confirm that having a green wall close to our working and living spaces will improve our overall health and well-being.

Building Protection

One of the major advantages to green walls is the fact that they protect buildings. The most important way they do this is by reducing temperature fluctuations of the envelope. A constant flux in temperature leads to the expansion and contraction of the building materials. This results in cracks, fractures, and general deterioration (Green over Grey 2009).

Covering an exposed vertical surface with a green wall shields it from precipitation and wind as well as from harmful UV radiation and corrosive acid rain. This in turn increases the integrity and longevity of a building's exterior.

Another way in which green walls help with building protection is they deter vandals from tagging. Would-be graffiti artists are unlikely to attempt to tag a mass of plant material. In the event that plants are in fact vandalized, either with graffiti or physically destroyed, the regenerative nature of plants means that repairs are likely to be cheaper than repairing the true facade of a building (Hedberg 2008).

Marketable Green Feature

Green walls are at the cutting edge of design trends. They are also great marketing tools that can be used to promote a company's green image. For example, car dealerships have installed them right before the release of new hybrid or electric vehicles. They speak directly to the green consumer.

A green wall increases property values of homes and businesses. Studies have shown that by simply having plants in and around a building or home can increase real estate values by up to 15% (Beaulieu 2009).

Furthermore, it has been proven that by having greenery in retail shops, malls, restaurants, cafés, bars, and other businesses the number of patrons frequenting the establishment actually increases. Studies have also attributed unusually high occupancy rates at hotels that incorporate gardens and plants compared to those without (Tree Canada 2008). A green wall is a great way to provide the greenery that people crave and in an innovative way.

LEED® Credits

Most people's reaction when seeing a green wall is "wow this is a green building!", but other than simply looking green they can be used to gain additional LEED® credits. LEED®, which stands for the

FIGURE 3. Key areas of human and environmental health.

Leadership in Energy and Environmental Design, is an internationally recognized green building certification system. It is broken down into categories that outline key areas of human and environmental health (see Figure 3).

Depending on the system used, a green wall can qualify directly for two LEED credits and an additional thirty points are positively affected. Table 2 lists potential credits that can be earned with the installation of a green wall either on the interior or exterior of a building.

CONCLUSION

As we battle with issues of urbanization; climate change; diminishing biodiversity; energy use; health problems; air, water, and noise pollution; plus countless others, we need to take a step back and learn from nature. She has provided us with many of the answers required to deal with these predicaments.

TABLE 2. LEED® categories with credit (and associated points) that a green wall can help earn.

Sustainable Sites	Credit 3: Integrated Pest Management, Erosion Control and Landscape Management Plan (1 point)	~
	Credit 5: Site Development: Protect or Restore Open Habitat (1 point)	+
	Credit 6: Stormwater Quantity Control (1 point)	•
	Credit 7.1: Heat Island Reduction: Non-Roof (1 point)	•
	Credit 8: Light Pollution Reduction (1 point)	~
Water Efficiency	Credit 3: Water Efficient Landscaping (1–5 points)	+
Energy & Atmosphere	Credit 1: Optimize Energy Efficiency Performance (1–18 points)	+
Materials & Resources	Credit 3: Sustainable Purchasing: Facility Alterations and Additions (1 point)	~
Indoor Environmental Quality	Credit 1.4: IAQ Best Management Practices: Reduce Particulates in Air Distribution (1 point)	+
	Credit 2.1: Occupant Comfort: Occupant Survey (1 point)	+
	Credit 3.6: Green Cleaning: Indoor Integrated Pest Management (1 point)	~
Innovation in Operations	Credit 1: Innovation in Operations (1–4 points)	+

• Qualifies for LEED® credit
+ Positively effects LEED® qualification
~ No negative effect on LEED® credit
Used courtesy of greenovergrey.com.

Green walls are not only a beautiful way to cover over unexciting vertical surfaces; they have a plethora of environmental, social, and economical benefits. They are an innovative way to bring the diversity that nature provides into everyday urban living. They help to make our cities more sustainable and our buildings greener. Green walls are, in fact, as "green" as they look.

RESOURCES

Books

- *Planting Green Roofs and Living Walls* by Nigel Dunnett and Noel Kingsbury. Publisher: Timber Press, 2004.
- *Vertical Gardens* by Anna Lambertini, Mario Ciampi, and Jacques Leenhardt. Publisher: Verba Volant, 2007.

Companies

- Green over Grey—Living Walls and Design Inc. www.greenovergrey.com
- Greenwall Australia www.greenwallaustralia.com.au
- greenscreen® www.greenscreen.com
- Greenwall France www.greenwall.fr
- VGM Green Wall www.elmich.com

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