Introduction to Green Walls
Technology, Benefits & Design
September 2008

Developed by:

GREEN ROOFS
FOR HEALTHY CITIES
www.greenroofs.org

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Introduction

Hanging Gardens of Babylon
Source: Hand colored engraving, Maarten van Heemskerck, Dutch

Plants have served humanity since the dawn of time, supplying food, clothing, building materials and a host of other goods. With the advent of the modern industrial city, now home to more than half of the world's population, planners, designers and urban advocates are once again turning to plants – green infrastructure - as a key strategy to provide cleaner air and water, while improving living environments, human health and mental well being. The integration of the living, organic systems characterized by green walls and green roofs, with the inorganic and lifeless structures that have come to dominate modern architecture, holds the promise of a new type of 'living' architecture. Living architecture is multi-disciplinary, blending the talents of architects, landscape architects, engineers and horticulturalists. Its practitioners are committed to the greening of cities and buildings and recognize that plants are an underutilized resource in the larger green building movement.

Green Roofs for Healthy Cities' (GRHC) mission is to increase the awareness of the economic, social, and environmental benefits of living architecture across North America and focus on advancing the development of the market for green wall products and services. GRHC has worked closely with green wall manufacturers to advance this new industry. To date, we have developed a full day training course entitled, Green Wall Design 101; established a Green Wall Award of Excellence to celebrate innovative green wall projects; and established the Green Wall Research Fund to support more scientific research on green wall performance benefits. This introductory paper provides readers with a basic understanding of the current state of green wall technology including:

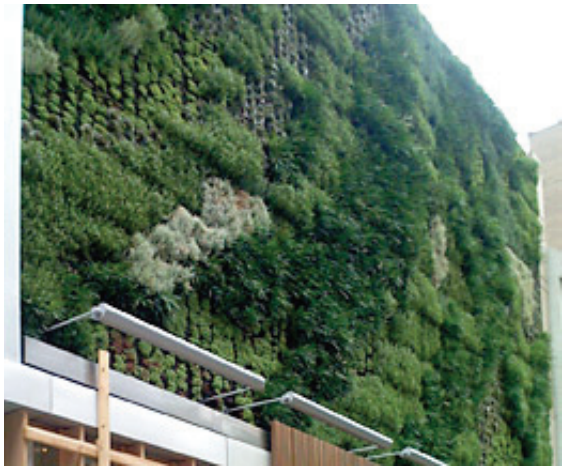
- A basic introduction to various green wall technologies
- Overview of the benefits and cost factors of green walls
- Identification of the major design considerations
- Case studies

A Brief History of Green Walls

The concept of green walls is an ancient one, with examples in architectural history reaching back to the Babylonians – with the famous Hanging Gardens of Babylon, one of the seven ancient wonders of the world. Highlights of the history of green walls are provided below:

3rd C. BCE to 17th C. AD: Throughout the Mediterranean, Romans train grape vines (Vitis species) on garden trellises and on villa walls. Manors and castles with climbing roses are symbols of secret gardens.
1920s: The British and North American garden city movement promote the integration of house and garden through features such as pergolas, trellis structures and self-clinging climbing plants.
1988: Introduction of a stainless steel cable system for green facades.

Early 1990s: Cable and wire-rope net systems and modular trellis panel systems enter the North American marketplace.
1993: First major application of a trellis panel system at Universal CityWalk in California.
1994: Indoor living wall with bio-filtration system installed in Canada Life Building in Toronto, Canada.
2002: The MFO Park, a multi-tiered 300' long and 50' high park structure opened in Zurich, Switzerland. The project featured over 1,300 climbing plants.
2005: The Japanese federal government sponsored a massive Bio Lung exhibit, the centerpiece of Expo 2005 in Aichi, Japan. The wall is comprised of 30 different modular green wall systems available in Japan.
2007: Seattle implements the Green Factor, which includes green walls.
2007: GRHC launches full day Green Wall Design 101 course; the first on the subject in North America.
2008: GRHC launches Green Wall Award of Excellence and Green Wall Research Fund.



Top left: Grape vines used to shade patio area in Spain.
Source: Randy Sharp

Top right: Cable facade at MFO Park, Switzerland
Source: Jakob

Left: Living wall installation, New York
Source: Green Living Technologies

Nomenclature

A 'Green Wall', also commonly referred to as a 'Vertical Garden', is a descriptive term that is used to refer to all forms of vegetated wall surfaces. Green wall technologies may be divided into two major categories: Green Facades and Living Walls, both of which are described below.

Green Facades

Green facades are a type of green wall system in which climbing plants or cascading groundcovers are trained to cover specially designed supporting structures. Rooted at the base of these structures, in the ground, in intermediate planters or even on rooftops, the plants typically take 3-5 years before achieving full coverage. Green facades can be anchored to existing walls or built as freestanding structures, such as fences or columns.

Self-clinging plants such as English Ivy have commonly been used to create green walls. Their sucker root structure enables them to attach directly to a wall, covering entire surfaces. These aggressive plants can damage unsuitable walls and/or pose difficulties when the time comes for building maintenance and plant removal.

Above: Ivy attaches to a building using aggressive adhesive suckers or climbing roots that can damage surfaces and enter voids and cracks. Source: greenscreen®

Technological innovations in Europe and North America have resulted in the development of new trellises, rigid panels and cable systems to support vines, while keeping them away from walls and other building surfaces. Two green facade systems that are frequently used are **Modular Trellis Panel** and **Cable and Wire-Rope Net** systems. Each of these systems is described below.

Modular Trellis Panel System

The building block of this modular system is a rigid, light weight, three-dimensional panel made from a powder coated galvanized and welded steel wire that supports plants with both a face grid and a panel depth. This system is designed to hold a green facade off the wall surface so that plant materials do not attach to the building, provides a “captive” growing environment for the plant with multiple supports for the tendrils, and helps to maintain the integrity of a building membrane. Panels can be stacked and joined to cover large areas, or formed to create shapes and curves, are made from recycled-content steel and are recyclable. Because the panels are rigid, they can span between structures and can also be used for freestanding green walls.

Left: Close up of Modular Trellis Panel system. Source: greenscreen®

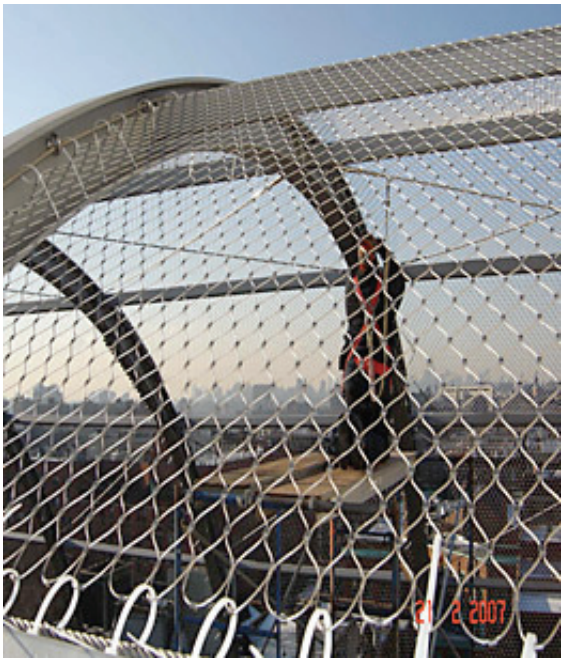
Middle left: A wall mounted Modular Trellis Panel System being fastened for support.

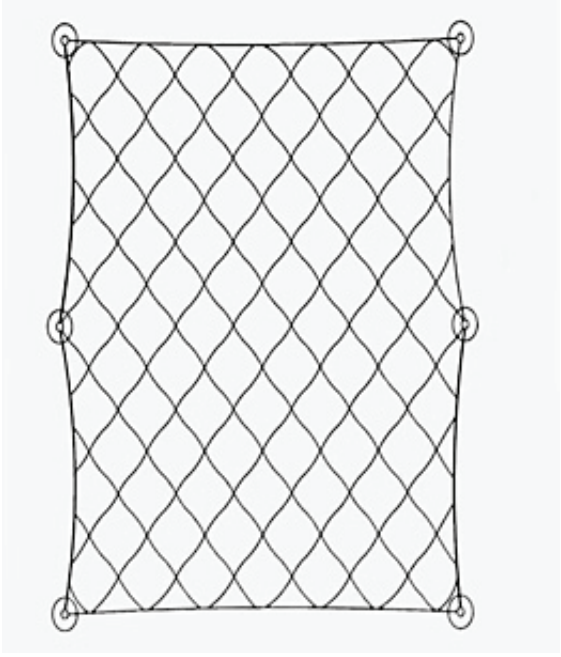
Middle right: A freestanding green wall being used for screening equipment.

Bottom: A well-trimmed and mature green wall using the modular trellis panel system. Source: greenscreen®

Cable and Wire-Rope Net Systems

The cable and wire-rope net systems use either cables and/or a wire-net. Cables are employed on green facades that are designed to support faster growing climbing plants with denser foliage. Wire-nets are often used to support slower growing plants that need the added support these systems provide at closer intervals. They are more flexible and provide a greater degree of design applications than cables. Both systems use high tensile steel cables, anchors and supplementary equipment. Various sizes and patterns can be accommodated as flexible vertical and horizontal wire-ropes are connected through cross clamps.





Top: Cable system close up showing cross clamp connector. Source: Jakob

Bottom photos: The wire-net system is more flexible than cables and is pre-fabricated to a specific design (shown during installation with temporary ties). Right is a sketch of a wire net system. Wire net systems are stretched, and may use a variety of connectors.
Source: Carl Stahl DecorCable Innovations

Above: Cable system example using vertical cables to create shapes. Note cables protruding up from plants and additional horizontal cable supports. Source: Jakob

Living Walls

Living wall systems are composed of pre-vegetated panels, vertical modules or planted blankets that are fixed vertically to a structural wall or frame. These panels can be made of plastic, expanded polystyrene, synthetic fabric, clay, metal, and concrete, and support a great diversity and density of plant species (e.g. a lush mixture of groundcovers, ferns, low shrubs, perennial flowers and edible plants).

Due to the diversity and density of plant life, living walls typically require more intensive maintenance (e.g. a supply of nutrients to fertilize the plants) than green facades. There are various forms of living walls, with the main differences occurring between interior and exterior designs.

Above: Vertical garden living wall.
Source: Queen's University, Canada

Above: A mature Modular Living Wall. Source: Elevated Landscape Technologies
Below: A diverse plant selection being pre-grown for a modular living wall installation. Source: Green Living Technologies

Modular Living Wall

A modular living wall system emerged in part from the use of modules for green roof applications, with a number of technological innovations. Modular systems consist of square or rectangular panels that hold growing media to support plant material. The composition of the growing medium may be tailored to the unique combination of plants selected, and to other design objectives. Most of the nutrient requirements for the plants can be found in the growing media within the modules. Irrigation is provided with these systems at different levels along the wall, using gravity to move water through the growing media. Modular systems are often pre-grown, providing an 'instant' green effect upon completion of the installation. Notice of between 12 –18 months may be required to secure pre-grown modular systems.

Left: A living wall constructed from modular pre-grown panels installed in an interior patio. Source: Elevated Landscape Technologies

Middle left: A standard modular unit before planting. Source: Green Living Technologies

Middle right: A pre-grown modular panel being prepared for installation. Source: Green Living Technologies

Bottom: A living wall constructed from multiple modular units. Source: Elevated Landscape Technologies

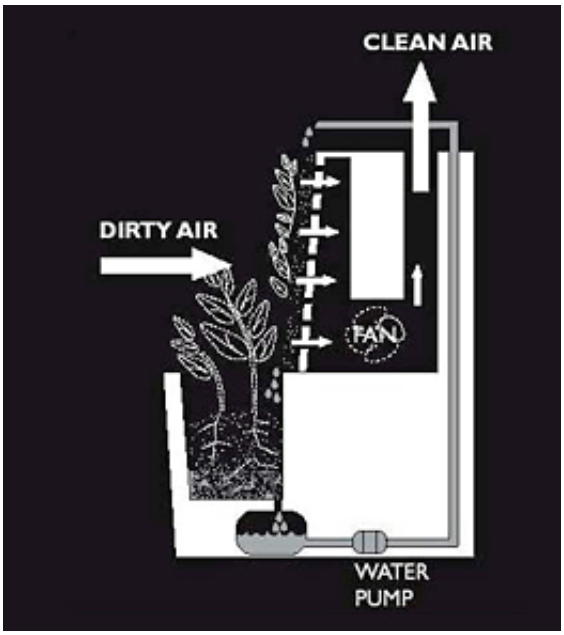
Vegetated Mat Wall

The 'Mur Vegetal' is a unique form of green wall pioneered by Patrick Blanc. It is composed of two layers of synthetic fabric with pockets that physically support plants and growing media. The fabric walls are supported by a frame and backed by a waterproof membrane against the building wall because of its high moisture content. Nutrients are primarily distributed through an irrigation system that cycles water from the top of the system down.

Left: Mur Vegetal
Source: Patrick Blanc

Biofiltration

An 'active' living wall is intended to be integrated into a building's infrastructure and designed to biofilter indoor air and provide thermal regulation. It is a hydroponic system fed by nutrient rich water which is re-circulated from a manifold, located at the top of the wall, and collected in a gutter at the bottom of the fabric wall system. Plant roots are sandwiched between two layers of synthetic fabric that support microbes and a dense root mass. These root microbes remove airborne volatile organic compounds (VOCs), while foliage absorbs carbon monoxide and dioxide. The plants' natural processes produce cool fresh air that is drawn through the system by a fan and then distributed throughout the building. A variation of this concept could be applied to green facade systems as well, and there is potential to apply a hybrid of systems at a large scale.



Above: The basic mechanics of a biofiltration wall. Source: GM Canada and Air Quality Solutions, Naturaire

Landscape Walls

These walls are an evolution of landscape 'berms' and a strategic tool in an approach to 'living' architecture. Landscape walls are typically sloped as opposed to vertical and have the primary function of noise reduction and slope stabilization. They usually are structured from some form of stacking material made of plastic or concrete with room for growing media and plants.

Above: Examples of landscape walls – typically used for noise reduction.
Source: TensarEarth Technologies (above left), Deltalok GTX (above right)

Benefits of Green Facades and Living Walls

There are significant benefits to both the public and private sectors resulting from the successful use of green walls. Green walls have a great potential for positive environmental change in dense urban areas, particularly given the large surface areas on buildings that are available for retrofitting to these technologies. For example, the emissions that can concentrate in multi-level parking areas in downtown cores can be reduced by the presence of large leafy areas. A green wall with a mass of plant leaf material can absorb carbon oxides and heavy metal particles while shading and screening these large structures.

Above: A large parking structure with a cable system green facade. Source: Jakob

The benefits accrued by a green wall depend on design factors that include leaf area, leaf density, site conditions and the scale of the project. Some benefits are shared by almost all green walls, herein referred to as 'common benefits'; while others are a function of the particular design/client objectives, herein referred to as 'design specific benefits'. The discussion of common green wall benefits has been divided further into two major categories: **Public** and **Private,** since some benefits are for the building occupants while others are shared by the community at large.

Public Benefits of Green Walls

Area of Impact	Description	Benefits
Reduce Urban Heat Island Effect	The temperature increase in urban areas caused by the replacement of "natural vegetation with pavements, buildings, and other structures necessary to accommodate growing populations." This results in the conversion of sunlight to heat. Vegetation cools buildings and the surrounding area through the processes of shading, reducing reflected heat, and evapotranspiration.	▪ Promotes natural cooling processes ▪ Reduces ambient temperature in urban areas ▪ Breaks vertical air flow which then cools the air as it slows down ▪ Shading surfaces/people
Improved Exterior Air Quality	Elevated temperatures in modern urban environments with increasing numbers of vehicles, air conditioners and industrial emissions have led to a rise in nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), carbon monoxide (CO) and particulate matter.	▪ Captures airborne pollutants and atmospheric deposition on leaf surfaces ▪ Filters noxious gases and particulate matter
Aesthetic Improvement	Green walls provide aesthetic variation in an environment in which people carry out their daily activities. Numerous studies have linked the presence of plants to improved human health and mental well being.	▪ Creates visual interest ▪ Hides / obscures unsightly features ▪ Increases property values ▪ Provides interesting free-standing structural elements, etc.

Above: An example of a modular living wall. Source: Green Living Technologies

Left: With consideration of basic design issues of irrigation, adequate light and nutrients, this ten foot high wall thrives in an interior installation. Source: Elevated Landscape Technologies

Above: An interior green wall using modular trellis panels. Source: greenscreen®

Private Benefits of Green Walls

Area of Impact	Description	Benefits
Improved Energy Efficiency	Improves thermal insulation capacity through external temperature regulation. The extent of the savings depends on various factors such as climate, distance from sides of buildings, building envelope type, and density of plant coverage. This can impact both the cooling and heating.	• Traps a layer of air within the plant mass • Limits movement of heat through thick vegetation mass • Reduces ambient temperature via shading and plant processes of evapotranspiration • May create a buffer against the wind during the winter months • Interior applications may reduce energy associated with heating and cooling outdoor air for indoor use.
Building Structure Protection	Buildings are exposed to the weathering elements and over time some of the organic construction materials may begin to break down, as a result of contraction and expansion shifts due to freeze-thaw cycles and UV exposure.	• Protects exterior finishes from UV radiation, the elements, and temperature fluctuations that wear down materials. • May benefit the seal or air tightness of doors, windows, and cladding by decreasing the effect of wind pressure.
Improved Indoor Air Quality	For interior projects, green walls are able to filter contaminates that are regularly flushed out of buildings through traditional ventilation systems. The filtration is performed by plants, and in the case of bio-filtration, micro-organisms.	• Captures airborne pollutants such as dust and pollen • Filters noxious gases and VOC's from carpets, furniture and other building elements
Noise Reduction	The growing media in living wall systems will contribute to a reduction of sound levels that transmit through or reflect from the living wall system. Factors that influence noise reduction include the depth of the growing media, the materials used as structural components of the living wall system, and the overall coverage.	
LEED®	Green walls contribute directly to achieving credits, or contribute to earning credits when used with other sustainable building elements. (See below)	
Marketing	Improved aesthetics may help to market a project and provide valuable amenity space.	

Design Specific Benefits

Value can be added to the installation of green walls by designing for a variety of specific benefits. Most green walls are implemented to create an element of aesthetic diversity that adds to the palette of building materials and the surfaces created. Designers of green walls can work at a great range of scales, from the creation of small private space interactions like intimate garden settings, to the monumental scale of a multistory project. Green walls can also be integrated into the entire building site design and utilize multiple systems and forms. Specific benefits can include security, privacy screening, shade, biodiversity, habitat, and even urban agriculture. These design specific benefits are not mutually exclusive.

Above: A green wall designed with aesthetics and biodiversity in mind. Source: George Irwin

Bottom left: A living wall created to provide a variation of visual textures. Source: Green Living Technologies

Bottom right: Flowering green wall elements celebrate a pedestrian entryway. Source: greenscreen®

Improved Aesthetics

Currently, aesthetic improvements are the primary design objective for most green wall projects. Large parking structures, campus buildings, urban streets with repetitive facades, public park buildings, transit shelters, retail buildings, all provide an opportunity to design with green walls to create aesthetic improvement. Implementing patterns, rhythms, and shapes and the use of plant textures and the inviting qualities of designing with nature can all contribute to aesthetic improvement.

Wall mounted and freestanding green walls can be used to screen and isolate views. They can be used to hide mechanical equipment, service areas, storage access and other aspects of a building's system requirements that detract from the aesthetic experience. These opportunities also exist for interior applications and for the integration into rooftop environments. Plant materials used for green facades and living walls can be flowering, may change color with the season's change, or may be deciduous and change their visual character significantly. Because of the vertical nature of a green "wall" they create large and efficient green areas while using a relatively small footprint.

Aesthetic value relates to human interaction and not to the quantitative evaluation of materials and system performance aspects of a building. Creating green wall elements for a waiting zone, a healing garden, a building entrance, or a rooftop garden could take advantage of the measurable improvements to the human condition that plants can provide. This specific benefit is an improvement to the *quality* of the human experience in the built environment.

Top left: A flowering living wall.
Source: Elevated Landscape Technologies

Above: Cool amenity spaces.
Source: Manfred Koehler

Left: Freestanding green walls create variation in a hardscape environment.
Source: greenscreen®

When considering a green wall design, it is important to carefully select plant species that will thrive under the given site conditions. In colder climates, for example, there are species of vines that maintain their foliage even during the winter months. Green wall design for a temperate climate zone should consider the changes of the seasons and how different plants will display their adaptation to this cycle. These changes can dramatically affect the aesthetic perception of a green wall. Plants selected may have to accommodate freezing temperatures during winter, and also show full blossom in the heat of summer. Plant choices might include both fast and slow growing species and require a combination of structures like a wire-net system in combination with a cable system. The wire-net system can support the slower growing greenery while the cables provide structure for faster developing vines.

Above left: Seasonal color change on a freestanding green wall screening for privacy on a rooftop.
Source: greenscreen®

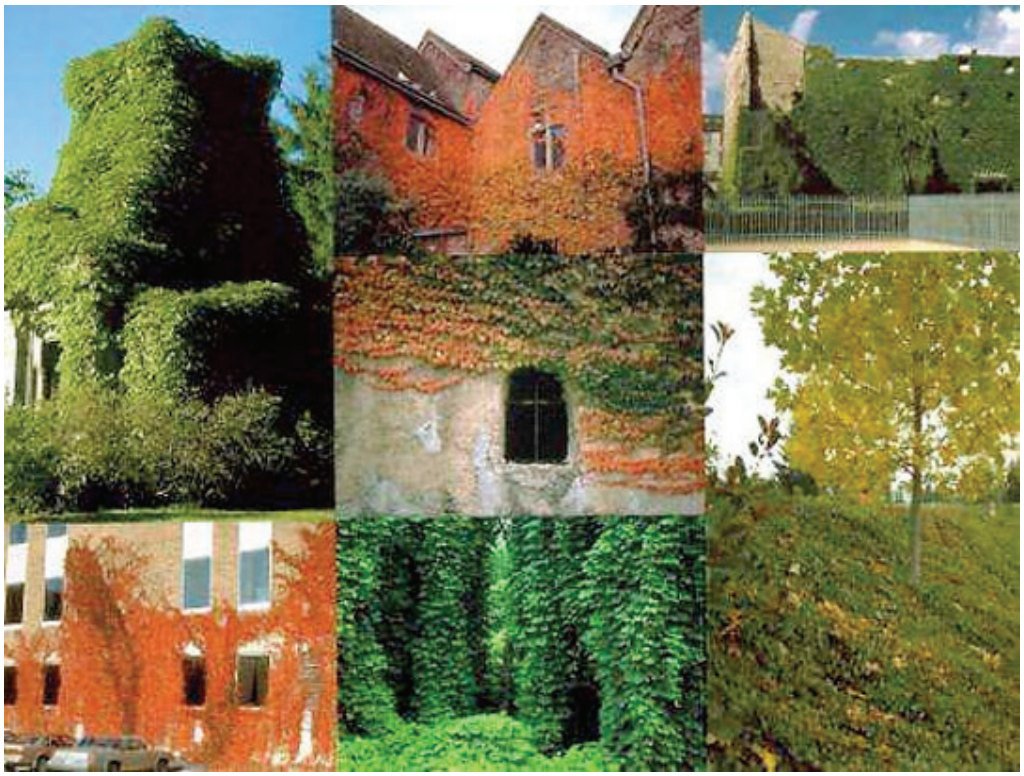
Above right: A horizontal application of modular trellis panels provides shade and a place to rest in a park setting.
Source: greenscreen®

Left: A cable system green façade screens the view and provides shade in an urban park setting.
Source: Jakob

Designing for benefits and aesthetic considerations can help determine plant selection and create a preference for an appropriate green wall technology.

Above: Winter and Spring views of a living wall installation benefiting from a careful selection of plant varieties. Source: Randy Sharp

The following montage of photos shows a variety of green walls in different seasons, illustrating a wide range of color and texture.



Increased Biodiversity

The use of green walls to support biodiversity is being explored and current research on the abilities of green wall systems to provide this benefit is scarce. Most studies have centered on green roofs in the urban environment and their ability to provide habitat for a wide range of animal and plant species. Research in England, Switzerland, Canada and the U.S. has identified plants, birds and insects that can survive successfully on rooftop environments. Green walls with the potential to link to the roof, provide a natural extension of this environment.

Large scale green wall projects have been created to use indigenous native plant species and create habitat as urban reforestation. In North America a pioneering program has been developed to create corridors of habitat for migratory species and the potential for utilizing green walls is being explored. By supporting native plant growth and creating necessary habitat, participants and site locations can become “certified” into this nurturing program. (National Wildlife Federation, www.nwf.org).

The design of green walls for biodiversity or ecological restoration requires that the designers or their consultants have an intimate knowledge of the requirements of the plants in the region where the project is being implemented, as well as the specific needs of the various fauna. Some climbing plants such as Climbing Hydrangea (*Hydrangea anonomala petiolaris)* a perennial, and Morning Glory *(Impomea tricolor)*, an annual, are known to attract butterflies and hummingbirds.

Designers are encouraged, along with willing clients, to explore these opportunities and to expand available knowledge in this specialized area.
This project photo illustrates the interconnection between the ponds, which utilize a variety of wetland plants, and the green wall. The ponds are part of the stormwater and filtration management system and native deciduous plants were selected to help recreate habitat. The green wall provides additional shading benefits.

Above: A freestanding green facade is planted with four varieties of indigenous vines to help reestablish habitat. Source: greenscreen®

Urban Agriculture

Green walls have yet to be extensively studied as a forum for urban agriculture, but this potential specific benefit is obvious. Where land is scarce, green walls of many sizes can utilize their vertical aspect to grow a variety of crops. The coordinator for the Urban Management Program for UN-Habitat has written that the research of the last two decades indicates that,”…urban agriculture has multiple roles and functions and plays an important role in: enhancing urban food security, nutrition, and health…and urban greening and maintenance of green open spaces…”
A green wall designed for urban agriculture can provide a multitude of benefits such as providing the basis for better community interaction (community gardening), improving access to fresh food (a significant problem in poorer neighborhoods); and reducing the environmental impacts associated with traditional food production and distribution.

These photos show examples of products that can be grown on green walls designed for agriculture. On the right are modular living wall panels.
Sources: www.museums.org (top left), Randy Sharp (bottom left), Green Living Technologies (right)

Factors for Successful Green Facades

Design, installation and maintenance considerations for green facades and living walls will vary by system type selected and the conditions of the built and natural environment.

Green facade projects require that the designers, installers, manufacturers and maintenance staff take the following into careful consideration:

- Attachment to building envelope – how the system will be secured to the building or freestanding structure.
- Calculation of structural loads for larger systems, resulting from loads such as snow, plants, and wind.
- Plant selection for wind and light exposure, hardiness zones, and amenity context.
- Realistic expectations related to plant aesthetics and growth – some systems require 3 to 5 years to become fully established.
- Plant maintenance and/or long term maintenance plan to secure the health of these living systems, including proper soil and irrigation considerations.
- Check with manufacturers who may have registered or specially trained installers that will be able to complete the project successfully.
- Appropriate plant selection for the geographic region, correct plant spacing for desired coverage, and release from the temporary support structure used by the nursery.

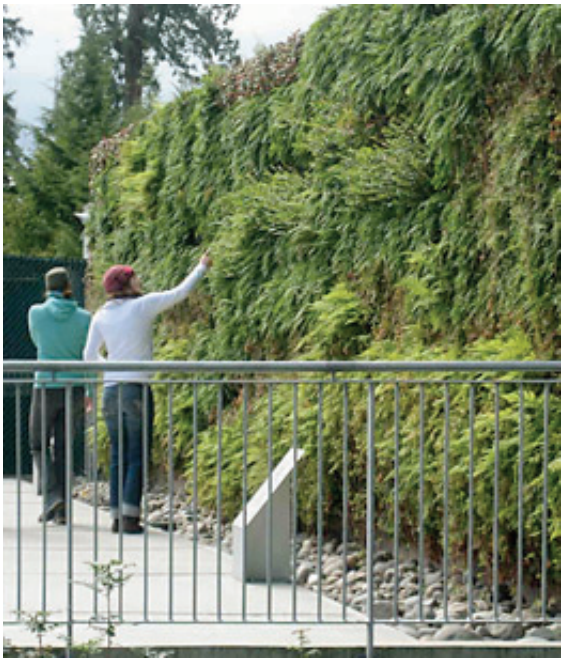
Above left: Several multi-story green walls thrive with correct plant spacing and adequate irrigation and nutrients. Source: greenscreen®

Above right: A cable system supports a section of green wall showing a riot of color. Source: Carl Stahl DecorCable Innovations

Factors for Flourishing Living Walls

Living Walls are robust when constructed in the correct manner. Success depends heavily upon the following:

- Irrigation (establishing appropriate levels of watering and appropriate levels of nutrients).
- Plants correctly specified by architects for hardiness zone and geographic location.
- Consideration of the microclimates that may have different impacts on one part of a living wall relative to another (e.g. varying light, heat, humidity conditions).
- Growing medium must be designed to sustain chosen plants and to provide the correct nutritional needs.
- Indoor applications need to determine correct light for plant survival.
- Check with manufacturers who may have registered or specially trained installers that will be able to complete the project successfully.



Above left: A thriving living wall installation. Source: Elevated Landscape Technologies

Above right: Flourishing living wall with passers by being drawn to the wall at the Vancouver Aquarium. Source: Randy Sharp

Left: A colorful palette of plantings in living wall modules ready for installation. Source: Elevated Landscape Technologies

Maintenance

All green walls require some degree of maintenance because they are living systems. The amount of maintenance a client is willing to provide is an important design factor that may impact the selection of the type of system and plants installed.

Green facades generally use vines that may grow from ground soil or from containers and each location will have different irrigation and nutrient requirements. Site location and conditions may require that a normally robust or non-dependent vine species be given additional irrigation and nutrients. Some vines will be deciduous and some provide fruits or flowers in abundance that may require additional care and maintenance. Most vines will benefit from pruning and respond to the care given to landscape elements in general. Cable and Wire-Rope Systems may require periodic checking of the cable tensions to ensure that the elements are properly in place as the plants mature.

Living walls require regular irrigation and the precise degree to which maintenance will be required will depend on the type of living wall system and the vegetation used. Vegetation with high nutrient requirements will generally require a greater degree of care than those that have evolved from nutrient poor environments. The degree of maintenance may also be influenced by client expectations of the aesthetic qualities of a living wall installation and at what level flourishing vegetation needs to be maintained.

Maintenance issues should be discussed with the client in the early stages of design to ensure that they can be properly addressed. When the opportunity is available, the creation of project specifications for soil, irrigation, nutrients, and long-term maintenance should be considered.

Above left: A cable system green wall may need adjustment as the plant material matures. Source: Jakob

Above right: In a elevated cast planter irrigation and drainage are supplied. Source: greenscreen®

Standards, Policies and Incentives

Because the implementation of new green wall technologies is still relatively new, there are currently no North American performance standards that deal specifically with the installation of green facades or living walls and few of the numerous benefits have been fully quantified.

Of the limited number of policy programs in place to encourage green wall construction, one outstanding example is a new ordinance passed by the City of Seattle (outlined below). In terms of incentives to build green walls, the US and Canadian Green Building Councils offer a variety of achievable credits through the LEED® rating system (see p.26). Several cities have now adopted LEED® rating systems as the basis for their own standards in green building.

Above: A large multi-level parking structure with a green facade. Source: greenscreen®

Currently available in draft form, the Sustainable Sites Initiative is being co-produced by the American Society of Landscape Architects, the Ladybird Johnson Wildflower Center, and the U.S. Botanical Gardens. This document will give guidelines and suggestions for evaluating site conditions and will have a goal to create a system of values that can lead to sustainable development standards. Green walls have a role in contributing to the positive values in such a system.

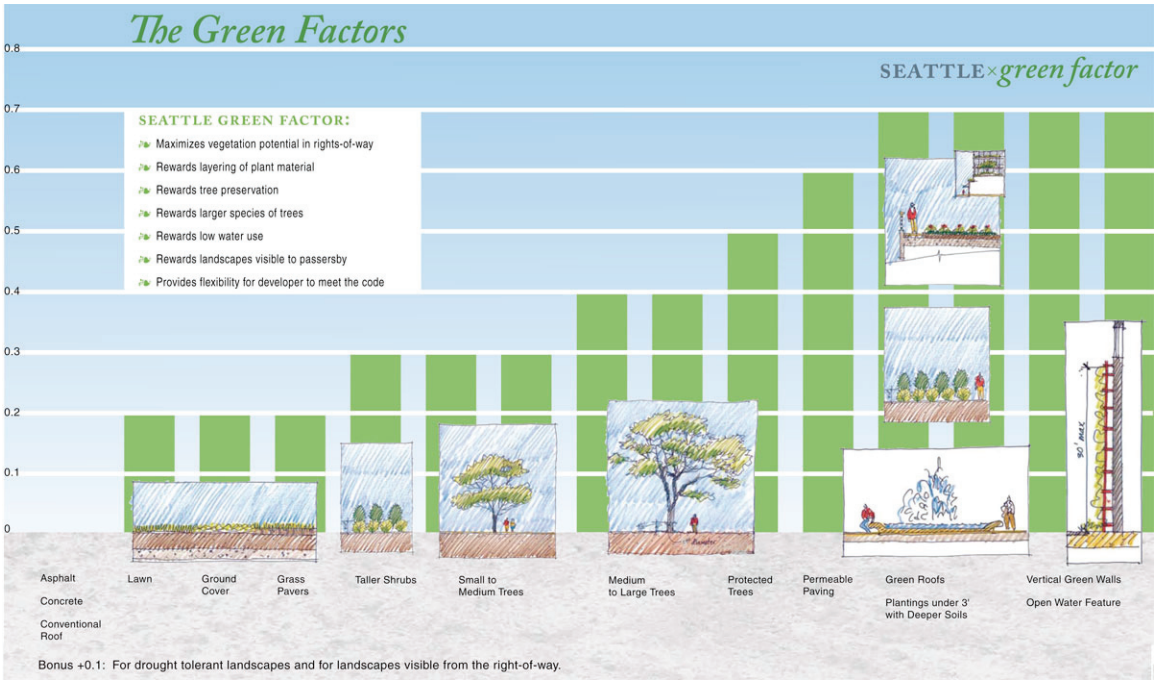
City of Seattle

In 2007, the City of Seattle passed an ordinance in the Neighborhood Commercial (NC) zone, requiring that all developments have 30 percent vegetation coverage, or its functional equivalent (e.g. permeable surfaces in commercially zoned areas). A building applicant, architect or landscape architect chooses from a menu of landscape strategies including large trees, permeable paving, rain gardens, green roofs and green walls. The main drivers of the program are:

- Improving microclimates and reducing the urban heat island effect.
- Maintaining and improving soil function and water quality.
- Enhancing the quality and quantity of plant and animal habitats.

A design's ability to meet this requirement is determined using the Seattle Green Factor, a weighted system that has been designed to support green infrastructure implementation by planners, building owners and designers. Additional weight is given to features using rainwater harvesting and/or low-water use planting techniques (e.g. larger trees, tree preservation, green roofs and green walls).

The figure below graphically represents the weighting of the different greening methods. A worksheet has been developed that will assist applicants in calculating their "score," allowing them to try different feature combinations to reach the 30 percent regulatory requirement for greening. It is possible for freestanding green walls with two exposures to earn twice as many points as one affixed to a wall. Program details are available online at: http://www.seattle.gov/dclu/news/20060623a.asp



The green factor of Seattle shows that green walls will become a significant factor for greening the city in the next few years. Source: City of Seattle

LEED® Certification

The US Green Building Council and Canadian Green Building Council's Leadership in Energy and Environmental Design (LEED®) rating systems have become the touchstone for green buildings and are now being used by a wide number of jurisdictions as the basis for green building procurement, and in some cases regulatory requirements for the private sector. In LEED, higher ratings are synonymous with greater environmental benefits.

The following is a summary of how green walls can contribute to securing up to 18 credits under the LEED® for new buildings. There is a need to have more green walls implemented as part of registered LEED buildings.

SUSTAINABLE SITES CREDITS

Sustainable site development reduces the impact of the building and its site on the larger urban and global environment. Opportunities for a building that incorporates a green wall to reduce its impact on the surrounding environment include:

Above: The Aquarium Learning Center at the Vancouver Aquarium registered for LEED® Gold. Source: Randy Sharp

SS Credit 7.1 Landscape Design That Reduces Urban Heat Islands, Non-Roof (1 Point)

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

Exterior green walls reduce the solar reflectance of a structure and thereby impact the urban heat island effect, helping to moderate the city's temperature. The LEED® rating system recommends "considering replacing constructed surfaces (i.e. roofs, walls, sidewalks, etc.) with vegetated surfaces such as green walls and open grid paving or specify high-albedo (light reflective) materials to reduce the heat absorption."

WATER EFFICIENCY (WE) CREDITS

Storm water management and water conservation measures have the potential to save an enormous amount of water while reducing the demands on the urban infrastructure to supply and treat waste water generated from a building and reduce the impact of large areas of hard surfaces on local water bodies.

WE Credit 1.1: Water Efficient Landscaping: Reduce by 50% (1 point)

Limit or eliminate the use of potable water, or other natural surface or subsurface water resources available on or near the project site, for landscape irrigation.

A building can incorporate a collection system to store storm water from the buildings site and roof surfaces to be used for irrigation of the green walls and other landscape features.

WE Credit 1.2: Water Efficient Landscaping: No Potable Water Use or No Irrigation (1 Point in addition to WE Credit 1.1)

Eliminate the use of potable water, or other natural surface or subsurface water resources available on or near the project site, for landscape irrigation.
Using only captured, recycled water or non-potable water for irrigation will allow projects to achieve this additional credit. One could also design a green wall that does not require irrigation.

WE Credit 2: Innovative Wastewater Technologies (1 Point)

Reduce generation of wastewater and potable water demand, while increasing the local aquifer recharge.
Green walls can be utilized as wastewater treatment media through a number of innovative techniques. The incorporation of compost tea from a composting toilet is another innovative use of a green wall to aid in reducing wastewater generation. This is not recommended for indoor air quality living walls.

Above: Conceptual image of the EDITT Tower in Singapore, designed with a grey water filtration system that includes water-purification, water and sewage recycling. Only 45% of building water usage draws from the main water supply. Source:TR Hamzah & Yeang Sdn Bhd

ENERGY AND ATMOSPHERE CREDITS

The intent of this initiative is to realize opportunities to improve the performance of the building's envelope and increase the efficiency of the building systems. Should the commissioning authority deem a green wall to be a contributing factor to a building's reduced energy consumption it can contribute the following points.

EA Credit 1: Optimize Energy Performance (1-10 points)

Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Green walls provide additional insulation and natural cooling mechanisms to a building, thereby reducing its reliance on mechanical systems in both the summer and winter months. A green wall can be an integral part of a building's cooling strategy.

Above: Large green walls shade a south and west exposure. Source: greenscreen®

Above: A flowering 4-storey green wall is used in a mixed urban environment, University of Guelph-Humber College, Toronto, ON. Source: Randy Sharp

INNOVATION IN DESIGN CREDITS

Since they are not explicitly acknowledged throughout the documents the most likely way that a green wall can contribute to LEED® Certification is through innovation in design.

ID Credit 1-14: Innovation in Design (1-4 Points)

To provide design teams and projects the opportunity to be awarded points for exceptional performance above the requirements set by the LEED-NC Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED-NC Green Building Rating System.

Innovation in Design credits allow a green wall designer to think beyond the scope of the LEED® rating system and create sustainable solutions to building challenges and earn additional credits under the system.

Budget

No two green walls are the same, so that each needs to have the associated costs and benefits calculated individually. Some of the most important variables that influence the capital and maintenance costs of green walls include the following:

Project size.
Design team costs.
System type.
Support structure requirements.
Building location.
Complexity of design, use of standard or custom components.
Site conditions and access.
Cost of installation labor.
Local availability of materials.
Project timeline.
Type of plants used.
Short and long term maintenance.

Conclusion

Green walls are a key component of living architecture and they will become increasingly important fixtures in our cities in the years to come. Green wall technologies provide a wide range of options for designers who are interested in using the building envelope to accomplish multiple objectives and to provide new free standing design features on the interior and exterior of buildings.

Those seeking more detailed technical information on green walls are invited to attend a full day course, Green Walls 101 (see website for dates and locations, www.greenroofs.com). It is always advisable to work closely with system providers and manufacturers when designing and planning a green wall, for they have the knowledge, experience and local installation support that can help your project succeed.

The design, installation, and maintenance of green buildings are vital to the long-term health and sustainability of our communities. We welcome the opportunity to work with you to bring green walls into your suite of design options.

Above left: Cable system green facade. Source: Jakob
Above right: Modular living wall. Source: Elevated Landscape Technologies

Case Studies

The following case studies give some indication of the range of costs you are likely to find for different types of applications; descriptions of the design goals; and an overview of the project solutions.

Pritzker Family Children's Zoo at Lincoln Park Zoo (Cable System)
Location: Chicago, IL
New construction or retrofit: New
Date of implementation: 2004
Size: 4,000 sq.ft
Cost: $7800

Source: Carl Stahl DecorCable Innovations

Green Wall System:
Plants used:
Vitis Riparia; Riverbank Grape (Special Hybrid)
Structural support information:
4mm stainless steel vertical wire ropes and 4mmø horizontal wire rods connected in a rectangular grid using UV-Resistant cross clamps. Hand-installed terminal end fittings allowed field trimming of ropes and rods for simplified installation. System attachment and tensioning allows easy dismount/remount for plant control and building maintenance.

Project Overview:
Design objectives / criteria:
Create a natural, imaginative, multi-sensory experience of the North American woods and the creatures that call it home
Provide a variety of opportunities to experience and learn for children of different age levels
Filter out urban distractions by managing the placement of topographic elements, buildings, and animal exhibits.
Design solutions/decisions:
The vine support system that fronts the west side of the zoo building accomplishes several goals: it helps control late afternoon summer heat gain in the building by acting as a natural sunshade; allows winter heat gain for natural heating when the deciduous vine leaves drop in the fall; and looking outward, it resembles the view through a tree canopy. For those looking down on the Pritzker Family Children’s Zoo from the surrounding high-rises, it helps the building blend into the woods that have been created around it. In addition, the structure is quite safe as the cross clamps allow the horizontal rods to slip as force is applied, eliminating any horizontal climbing elements.

MFO Park (Cable and Wire-Rope Net System)

Location: Zurich, Switzerland
New construction or retrofit: Retrofit
Date of implementation: May 2002
Size: 37 500 sq.ft. (328ft x 114ft)
Cost: $180,000 (materials)

Green wall system:
Plants used:
Fallopia aubertii
Vitis coignetiae
Campsis radicans
Celastrus orbiculatus
Ampelopisis brevipedunculata
Structural support system information:
Steel Structure with tensioned stainless steel cables.

Source: All photos Jakob

Project overview:
Design objectives/criteria:
To create a green environment within an industrial zone where people come to relax and have lunch without truly leaving the city.
It is also used for events such as open-air cinemas in the summer and various festivals.
Design solutions/decisions:
The structure needed to be as tall as 56ft as the other factories surrounding it.
Finding plants to grow this tall was particularly difficult. As a result the wall was designed with different levels of planter boxes with various plant types.
The base level used Ampelopisis brevipedunculata to grow to a maximum of 20ft.
The second level used Campsis radicans and Celastrus orbiculatus to grow a medium height of 43ft.
The third level used Fallopia aubertii and Vitis coignetiae to grow up to 56ft.

The Marketplace at Oviedo Crossing (Modular Trellis System)

Location: Oviedo, FL., (East of Orlando)
New Construction or Retrofit: New
Date of Opening: March 5th, 1998
Size: 100,175 sq. ft.
Cost of underlying system: $426,000

Green Wall System:
Plants Used:
Confederate Jasmine, trachelospermum jasminoides
Structural support system:
Wall-mounted greenscreen® panels
#5132 clips and #5105 steel edge trim

Source: All photos greenscreen®

Project Overview:
After creating high-profile 'Festival' marketplaces in Boston (Faneuil Hall) and Miami (Bayside Marketplace), the developers stated that they wished to differentiate the Oviedo project from the others. They were challenged to create a sense of place without being able to depend on the historic setting of central Boston or the elegant architectural texture of Miami Beach.
Design schemes involving elaborate surface treatments of exterior blockwork were proposed and put aside in favor of a strategy incorporating "a wall of green" that acknowledged the lush rural environment of the Orlando area. A green wall, thick with flowering vines, that ranges from 16-90 feet in height, created the desired effect.
A second objective was to integrate the outside of the building with the interior. The central food court and play area resemble a huge greenhouse with a sweeping view of two forested wetlands, one on each side, and a brook that meanders from the patio outside through the food court.
Vegetated trellises comprised of over 2000 greenscreen® panels flank all sides of the building and entranceways to the 830,000 sq. ft. mall. Vines were contract grown to have tendrils at least 7 feet long before being woven into the greenscreen® panels and were planted one month to one week before the opening. The ambitious greening project was a new venture for the developer, who chose to reject more expensive decorative exterior architectural proposals in favor of an integrated green wall and landscape design approach.

171 Broadway Restaurant (Modular Living Wall)

Location: NYC
New construction or retrofit: Retro
Date of implementation: Oct 2007
Size: 300 sq.ft.
Cost: $110 per sq.ft.

Source: Green Living Technologies

Green wall system:
Plants used:
Pothos
Climbing jade
Philodendren
Aglonema
Green Living™ Wall system, Standard 2'x 2'x 3" depth
Structural support system:
Custom GLT mounting Brackets

Project overview:
Design objectives/criteria:
This high end restaurant wanted to create an ambience of relaxed fine dining, and decided on a green wall with a purely cosmetic intent. The green wall enhanced the ambience, sound attenuation, and intimacy.
Provides increased air quality within the restaurant, and was found to have increased humidity within the restaurant.
Design solutions/decisions:
This wall was originally old brick with uneven spacing. The GLT mounting brackets were custom designed to fit the wall and its uneven surface.
The base of the wall was at the same level as the top of the staircase, which spirals down to the bar. Scaffolding had to be built and modified to the stairs in order to lift panels into place, which was physically labor intensive.
An irrigation system was built in with a catch basin custom manufactured for below the wall. The catch basin can retain 240 gallons of water.

Living Wall at the Aquaquest Learning Centre, Vancouver Aquarium

Location: Vancouver, BC, Canada
New construction
Date of implementation: September 2006
Size: 500 ft^2
Cost: ($100 per ft^2)
LEED status: GOLD
Client/Developer: Vancouver Aquarium
Design, Implementation, and Maintenance Team:

- Landscape Architect / Green Wall Designer: Randy Sharp, Sharp & Diamond Landscape Architecture Inc.
- Architect: Clive Grout, Doug Hamming, Stantec Architecture
- Mechanical Engineer / Energy Modeling: Jason Manikel, Cobalt Engineering
- Green Wall Supplier and Plant Maintenance : Chad Sichello, G-Sky Inc.

Source: Randy Sharp

Green wall system:
Plant List:

Dryopteris expansa	Spiny Wood Fern
Fragaria vesca	Woodland Strawberry
Gaultheria procumbens	Wintergreen (native eastern Canada)
Polypodium glycyrrhiza	Licorice Fern
Tellima grandiflora	Fringecup
Tiarella trifoliata	Foamflower
Vaccinium ovatum	Evergreen Huckleberry (blueberry)
Dicentra formosa	Pacific Bleeding Heart (removed)

Structural Support and Modular System
A galvanized steel frame consists of vertical support rails spaced 12” (300mm), and horizontal rails to hold and support the wall panels. The frame is secured to the high-density concrete wall allowing a 1” (25mm) air space behind the panels. Each panel is 12” x 12: x 3.5” (302 x 302 x 85mm), and comprises a dark green polypropylene module complete with an integral non-woven fabric and metal straps (all components non-flammable) to secure the growing medium and plant roots. The modular system allows for the replacement of individual plant panels. Water and nutrients are supplied through an automatic drip irrigation system with two emitters per panel.

Project overview:
The education program and interpretive displays at the Vancouver Aquarium teach the one million visitors each year about aquatic life, the temperate rainforest and green building design. From a habitat perspective, the new building addition replicates a cliff face or escarpment. Therefore, an ecosystem of plants representing a canyon wall was selected to withstand the vertical exterior wall conditions and to attract insects, birds and butterflies for viewing. The integrated design team wanted to ensure that the green building features and the sustainable methods are visible to visitors.

Design objectives/criteria: The team took a daring approach with a new vegetated building envelope system; the first modular living wall installation in North America. A range of custom designs was explored before final selection of a well-proven modular living wall system. G-Sky provided all components required for the green wall – panels with frame, irrigation, native plants, growing medium – plus the installation and maintenance of the complete system.
Sharp & Diamond's original plant 'wish list' of 15 possible species included ferns, grasses, sedums, perennial wildflowers and evergreen groundcovers. G-Sky participated in the success of the project by testing these plant species to identify suitable candidates. Sword ferns and fescue grasses propagated very quickly, but their fast growth and clumping root systems applied excessive pressure inside the containers. The rubbery branches of the native BC Sedums were tender and susceptible to breakage from wind and daily handling by hundreds of school children. In the final analysis, tough hardy native groundcovers, ferns and wildflowers were selected. The Green Wall Panels were pre-grown in a greenhouse, delivered to the site and installed in one day to create an instant green wall.

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This paper was co-authored by:
Randy Sharp, Sharp & Diamond Landscape Architecture Inc.,
James Sable, greenscreen®,
Flavia Bertram and Eva Mohan, Green Roofs for Healthy Cities.
Steven Peck, Green Roofs for Healthy Cities

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Green Walls 101 is the first green walls course presented by Green Roofs for Healthy Cities Inc. (North America) which introduces system and design issues in greater detail. This introductory training course on green wall infrastructure design presents an overview of the many tools and techniques needed to satisfy your green wall project objectives. The course will focus on:

- Identifying the costs and benefits of green walls to reach your green wall performance goals;
- Identifying a variety of green wall products and understanding the performance criteria of different green wall elements, and their relevance to your design intent;
- Introducing the major design principles of a successful green wall project and discusses causes for error, which might lead to an unsuccessful project.

For more information about this course, where it is being held in a location near you, and other training programs offered by Green Roofs for Healthy Cities, please visit our website at www.greenroofs.org.

Test Questions (DRAFT)

1. Which of the following is a type of Living Wall system?
    A. Green Façade
    B. Modular Trellis Panel System
    C. Cable and Wire-Rope Net System
    D. Mur Vegetal

2. Which of the following is a type of Green Façade system?
    A. Mur Vegetal
    B. Biofiltration wall
    C. Cable and Wire-Rope Net System
    D. Landscape wall

3. A Modular Trellis Panel System is:
    A. Sometimes self-supporting
    B. Requires custom fabrication of materials
    C. Supports horizontal and vertical plant growth
    D. All of the above

4. Which of the following benefits is not 'common' to all green walls located on the sides of a building?
    A. Noise reduction
    B. Aesthetic improvement
    C. Indoor air quality improvement
    D. Energy efficiency

5. Project costs do not depend on which of the following:
    A. The mood of the architect and contractor
    B. Design team costs
    C. Availability of materials
    D. Location of project

6. Green walls provide visual stimulation in an environment in which people carry out their daily activities defines which public benefit?
    A. Urban Island Heat Effect
    B. Improved Air Quality
    C. Psychological Enhancement
    D. Aesthetic Improvement

7. The cooling energy given off green walls which alters the ambient air temperature addresses which issue?
    A. Urban Island Heat Effect
    B. Improved Air Quality
    C. Psychological Enhancement
    D. Aesthetic Improvement

8. Green walls assist in private energy efficiency by:
    A. Reducing ambient temperature via evapotranspiration and photosynthesis
    B. Protecting buildings from the elements and temperature differentials
    C. Capturing airborne pollutants and atmospheric depositions
    D. None of the above

9. Green walls improve air quality by:
    A. Providing thermal insulation
    B. Protecting buildings from the elements
    C. Capturing airborne pollutants and atmospheric depositions
    D. None of the above

10. Correct plant selection depends on which of the following factors?
    A. Aesthetic goals of the client
    B. Maintenance budget available
    C. Climate (e.g., temperature, wind and light)
    D. All of the above