ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A REVIEW ON GREEN WALLS TECHNOLOGY, BENEFITS & DESIGN

A. F. Shaikh*, P. K. Gunjal, N. V. Chaple

* Assistant Professor, at KJEI's Trinity College of Engineering, Pune 411048
Assistant Professor, at KJEI's Trinity College of Engineering, Pune 411048
Assistant Professor, at KJEI's Trinity College of Engineering, Pune 411048

ABSTRACT

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. There are significant benefits to both the public and private sectors resulting from the successful use of green walls.

This is a review paper on green walls technology. 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.

KEYWORDS: Green Facades, Modular Trellis Panel System, Vegetated Mat Wall.

INTRODUCTION

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.

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.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

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.

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.

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.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

Fig.1 Boundary Ivy attaches to a building using aggressive adhesive suckers or climbing roots that can damage surfaces and enter voids and cracks

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.

Fig.2 modular trellis panel system

- 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.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

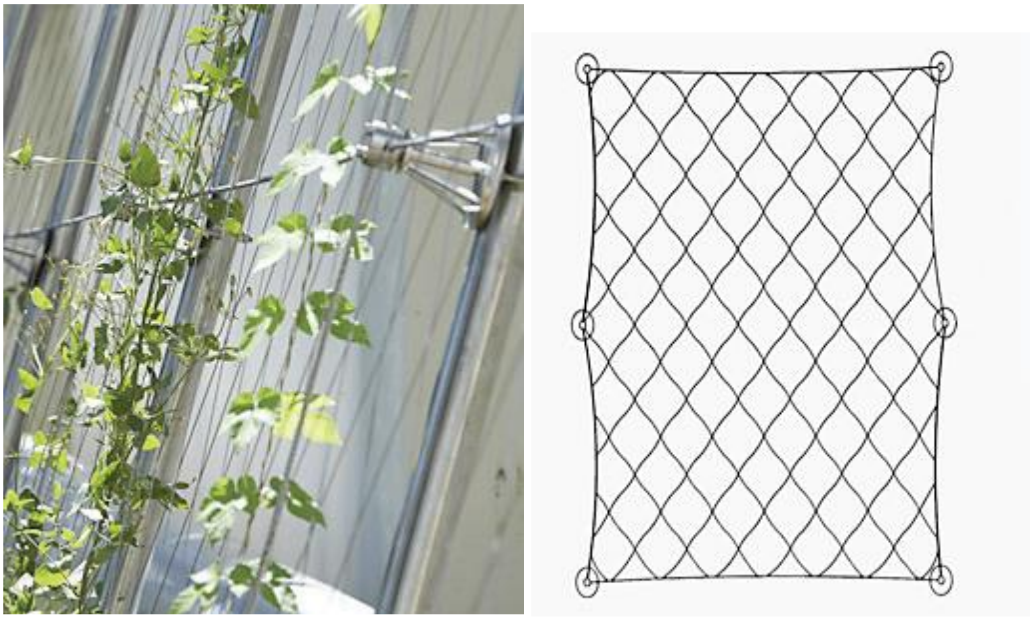

Fig.3 Cable system

LIVING WALLS

Living wall systems are composed of prevegetated 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.

Fig.4 Vertical garden living wall.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

- 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.

Fig.5 A living wall constructed from modular

- 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.

- 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.

Fig.6 Vegetated Mat Wall

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

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 façade systems as well, and there is potential to apply a hybrid of systems at a large scale.

Fig.7 The basic mechanics of a biofiltration wall.

- 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.


Fig.8 landscape walls – typically used for noise reduction

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.

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'.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

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	Benefits
Reduce Urban Heat Island Effect	• 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	• Captures airborne pollutants and atmospheric deposition on leaf surfaces • Filters noxious gases and particulate matter
Aesthetic Improvement	Creates visual interest • Hides / obscures unsightly features • Increases property values • Provides interesting freestanding structural elements, etc.
Improved Energy Efficiency	• 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	• 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	• 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.

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.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

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.

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.

Fig.9 Some Improved Aesthetics

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.

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

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

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 storm water and filtration management system and native deciduous plants were selected to help recreate habitat. The green wall provides additional shading benefits.

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.

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.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

Fig.10 green walls designed for agriculture

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.

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.

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.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

- 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.

REFERENCES

[1] Auld, H 2003, 'Modeling the Urban Heat Island Benefits of Green Roofs ion Toronto', in Proc. of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Chicago. 29-30 May, The Cardinal Group, Toronto.
[2] Brenneisen, Dr S 2004, 'The Benefits of Biodiversity from Green Roofs – Key Design Consequences', in Proc. of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Chicago. 29-30 May, The Cardinal Group, Toronto.
[3] Brenneisen, Dr S 2004, 'From Biodiversity Strategies to Agricultural Productivity', in Proc. of 2nd North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, Ore. 2-4 June 2004, The Cardinal Group, Toronto.
[4] Brenneisen, Dr S 2005, 'Green Roofs: Recapturing Urban Space for Wildlife', in 4th Annual Greening Rooftops for Sustainable Communities Conference, May 2005, Boston, MA
[5] Coffman, R & Martin, J 2004, 'The Sustainability of an Agricultural Roof Garden', in Proc. of 2nd North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, Ore. 2-4 June 2004, The Cardinal Group, Toronto.
[6] Deutsch, B & Whitlow, H 2005, 'Re-Greening Washington, DC: A Green-roof Vision based on Environmental Benefits for Air Quality and Storm Water Management', in 4th Annual Greening Rooftops for Sustainable Communities Conference, May 2005, Boston, MA.
[7] Dunnett, Dr N 2006, 'Green Roofs for Biodiversity: Reconciling Aesthetics with Ecology', in 4th Annual Greening Rooftops for Sustainable Communities Conference, May 2005, Boston, MA.
[8] Dunnett, N & Kingsbury, c. 2008, Planting Green Roofs and Living Walls, Revised and Updated Edition, Timber Press, Portland, Oregon.
[9] Gedge, D & Kadas, G 2004, 'Bugs, Bees and Spiders: Green Roof Design for Rare Invertebrates', in Proc. of 2nd North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, Ore. 2-4 June 2004, The Cardinal Group, Toronto.
[10] Lee, H 2006, 'Research on the Scenic Meaning of Rooftop Greening with Semantic Differential Measure and Joint-count Statistics', in 4th Annual Greening Rooftops for Sustainable Communities Conference, May 2005, Boston, MA