VERTISCAPING

A Comprehensive Guide to Living Walls, Green Screens and Related Technologies

Presented by Hart Farrell Hedberg
University of California, Davis
College of Agriculture & Environmental Sciences
Landscape Architecture Department

June 13, 2008

VERTISCAPING

A Comprehensive Guide to Living Walls, Green Screens and Related Technologies

A senior project presented to the faculty of the program of
Landscape Architecture at the University of California, Davis
in partial fulfillment of the requirements for the degree of
Bachelors of Science of Landscape Architecture

Accepted and Approved by:

____

James Harding, Committee Member

____

Jeff Loux, Committee Member

____

Rob Thayer, Faculty Senior Project Advisor

Hart Farrell Hedberg
June 13, 2008

Abstract

Green architecture has become a popular topic in discussions concerning environmental sustainability. Minimizing our impact upon the environment and creating healthy places for people to live will be critical to the continued development of human civilization. Green walls present an interesting opportunity in that they are able to fill an underutilized portion of the urban fabric. This document aims to communicate the advantages and scientific workings of living walls and green screens. The different types of walls, how they are constructed, their biological components and effects on their environments are the major points of interest. A few case studies aim to look into some of the green wall methods that have been put to use around the world. Similar approaches of vertical planting are also looked at, including retaining wall systems and methods of adding green space to skyscrapers.

Acknowledgments

I would like to thank everyone that made this project and the completion of my degree in the Landscape Architecture program possible.

Jim Harding, Jeff Loux and Rob Thayer, for their collaboration and input on this paper, as well as all they taught me in class.

My fellow students of the LDA program, for helping me keep my nose to the grindstone and not letting me slack.

My parents, Sten and Alice, for their support through all the rough spots of my long academic career.

Table of Contents

List of Figures

"Imagine a 10-story building whose walls are green and growing – nurtured by the structure's biopermeable skin and compatible mechanical structural system. Picture mile after mile of leafy, flowering sound barriers along our highways, every square yard producing oxygen, fixing atmospheric carbon, settling particulates and even sheltering bird nests. Green walls."

-Jon Charles Coe

<u>Chapter 1: Introducing the Green Wall</u>

What are Green Walls?

This paper looks at means of masking architecture in facades of plant material. Covering them with green screens (climbing plants) and living walls (plants rooted on the wall) is the primary focus. Other means, such as the use of hedges or green roofs, should be considered outside the immediate scope of research. They may be referred to at times, but the goal is to look at the functions, advantages and disadvantages of green wall technology. The hope is that green walls and similar elements will achieve a more mainstream understanding and acceptance and be added to the toolbox of every landscape architect. Designers are often limited by more than just their

1.1. A living wall located in Paris, France designed by Patrick Blanc (estudiochicago.com, 2006) imaginations, and this paper should provide ammunition to any designer who wishes to make the case for green walls.

1.2. An example of a green screen (greenscreen.com)

Classification of Green Walls

The term ‘green walls’ is used here as sort of a catch-all term describing any form of plant barrier that clings to a near-vertical surface (a wall). Green walls can be broken up into two distinct subsets: living walls and green screens. Each has its own engineering specifications, planting restrictions, maintenance requirements and positive and negative effects on the setting.

Living walls are defined as a wall with plants rooted in some substrate attached to the wall itself. Green screens are defined by their vegetative layer being rooted on the ground and growing up the wall, using it for structural support but not actually deriving any moisture or nutrients from it. The classic green screen plant is the vine, which climbs up structures to better receive light but still pulls nutrients and water from its roots in the ground. The division between living walls and green screens may seem arbitrary, but how and where their plant layers obtain what they need to live makes a marked difference in how each is designed.

The fact that the slopes of walls can vary according to architectural style or use means that the field of study can blend a bit into something more resembling green roofs. A-frame houses, for instance, have such steeply pitched roofs that they in effect act as walls. Though green walls and green roofs should not be thought of as interchangeable terms, their implementation sometimes fits somewhere on the spectrum between roofs and walls. Ultimately, the distinction is unimportant as long as the desired goals are achieved.

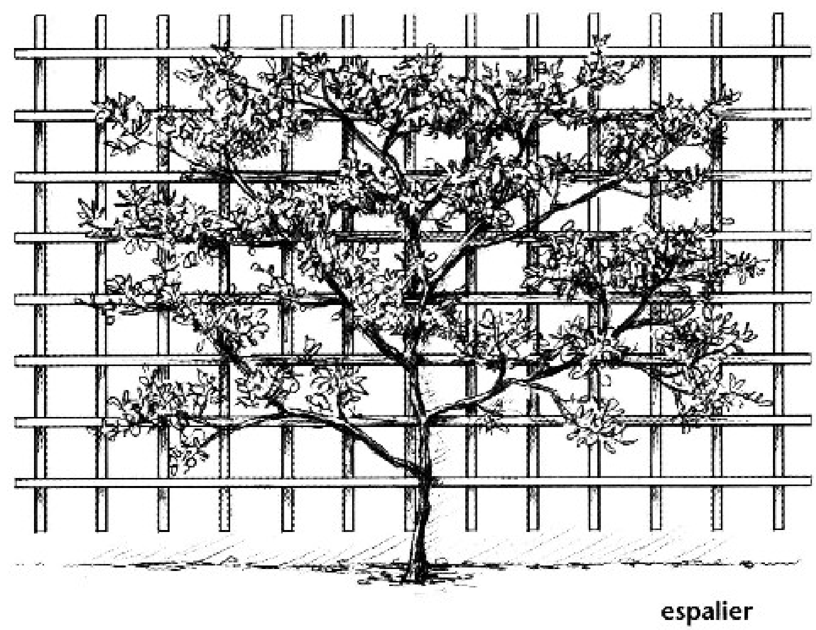
Chapter 2: Historical Significance

Historical Uses

Historically, green walls and similar methods of construction have had extensive use throughout the world. Despite the recent resurgence of the technology, the advantages associated with green walls have been known and put to use for thousands of years. Techniques similar in style and effect to green walls and screens include espalier, green roofs, turf houses and earth shelters.

Espalier

Espalier, the system of training plants to twine into a latticework, is nearly as old as human civilization. While most types of vines will climb of their own free will, other plants, such as rose bushes, need some encouragement and can be helped into forming green screens that they would not normally form in the wild. The first major plant to be espaliered was the grape vine, as it allowed for better maturation of the grapes and led to sweeter wine.



2.1. Espaliered plants covering a latticework (answers.com)

The latticework the plant is adhered to reduces the strain and encourages an upright habit that's necessary where space is limited. The cultivation of other fruits, such as kiwi, pears and peaches, followed. And though it began out of need, espalier later moved to a more aesthetic practice that simulated the look of ancient, overgrown castles, popular during the Romantic Era. Espalier has since mostly been relegated to a form of green screen, as its horticultural benefits have been mitigated by advances in farming and transportation (Fassadengruen, 2004).

Earth Shelters & Turf Houses

Equally as old is the use of earth shelters and turf houses. These forms of shelter meld green roofs and green walls into a seamless vegetative blanket that both insulates and beautifies. Earth shelters are defined by their use of existing or built-up masses of earth as protective insulation around a building. These houses are commonly built into existing hillsides with at least a 15-18" layer of soil and plants encasing one or more of the walls and roof. Today, their use continues as a long-lasting construction method with low visual impact and strong aesthetic and landscaping opportunities (British Earth Sheltering Association).

2.2. Icelandic turf houses (kalad-karen.blogspot.com)

Turf houses are a less extreme approach and much more similar to what today would be considered a green roof. Icelandic architecture made frequent use of turf houses. Though the thick layers of soil and sod that served as a roof for these houses were good insulators, its use was spurred on more by Iceland's lack of available lumber for construction. Even the United States saw the use of "sod houses" during the early 18th century. Again, it was a lack of building resources that drove American settlers to use prairie grasses and straw-bales in construction, leading to cheap and well-insulated (if a bit damp) dwellings (Martinez, 2007).

2.3. An example of a small earth shelter (British Earth Sheltering Association)

Chapter 3: Methods of Construction & Attachment

Engineering Living Walls

Despite living walls being such a niche element, there is still some variety in their methods of plant attachment. Whatever the method used, plants have a few common needs that cannot be compromised: sunlight, water, nutrients and something to support their weight. Light is the easiest and cheapest to provide and tends to become an issue more with indoor plants (or an indoor living wall as may be the case) or outdoor plants in urban environments where much of their light is blocked (Manhattan, for example). Further consideration will be given to light when discussing what plants are appropriate for living walls and screens as well as their influence on solar gain.

Soil Cells

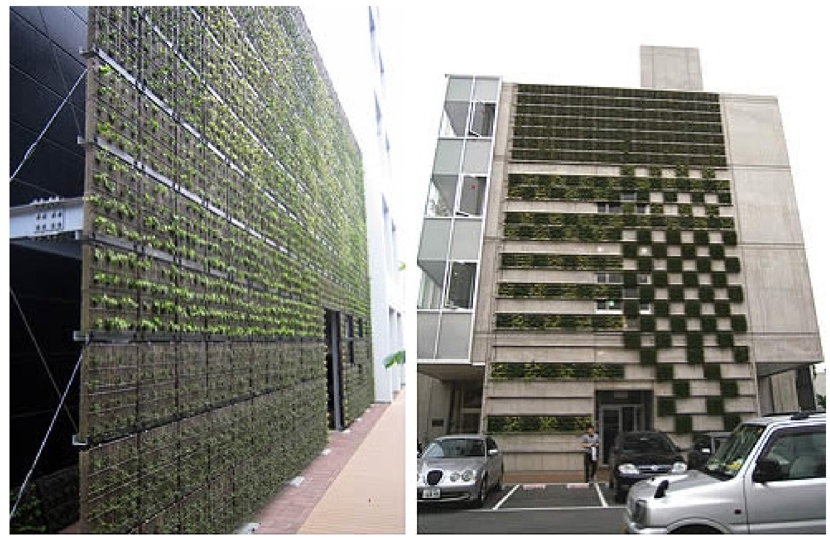
One commonly used means of attachment is any of a number of systems that fall into the soil cell category. Soil cells take the conventional method of growing plants - i.e. in soil - and simply flip it on its side. The primary problem with this is that plastering a layer of soil, no matter how thinly or thickly applied, simply will not adhere to the side of a structure for any meaningful length of time or with any amount of strength. Soil cells essentially break up the wall into dozens of 1 - 2 sq. ft. sections and reduce the problem down in scale. While a 4” deep layer of soil may not be able to cling to a wall 20’ wide by 30’ tall, it can be packed into a smaller 1’ by 1’ cell and maintain adherence when flipped vertically.

Soil cells are a modular system composed of hundreds or even thousands of cells. Each cell is filled individually with soil and whatever amendments are desired and then planted as though it were a pot. The cells are then attached to a support system which has been connected to the building or wall in question. Generally a metal frame on the exterior of the building which has been bolted into place is sufficient, but designs can vary from between manufacturers. Key considerations here are being able to hold the combined weight of the cells, keeping them locked in place to prevent injury, permeability to water and air and resistance to corrosion. (ELT Living Walls)

3.1. Soil cells, filled with amended soil and ready to be planted (ELT Living Walls)

3.2. The exposed mounting frame during construction of a living wall (The Greenroof Project Database, 2006)

Equally important is the design of the cells themselves. Most cell systems use a trickle-down watering system that irrigates the top cells only and relies on gravity to provide water to those below. The cells must be designed so that water is funneled from one cell into the next to minimize water loss. The advantages of cell systems lie in their modularity and ease of construction. A single panel can be removed for repair or replanting at any time without disturbing the other plants. The panels' rectangular shape can be somewhat limiting aesthetically, however, and living walls using soil cells tend to take on a very geometric and squad appearance.



3.3. A living wall in Japan with a strong gridded feel (The Greenroof Project Database, 2006)

Hydroponics

A radically different method of achieving a living wall is through hydroponics. The science of hydroponics involves growing plants in an inert medium, rather than soil, and providing them with all the nutrients they need through a liquid solution. The inert medium provides structural support for the roots and can also aid in holding moisture (Kentucky University, 1994). Designer Patrick Blanc has pioneered the hydroponics-style system for creating living walls. Blanc describes his technique in an interview with the Japanese magazine PingMag:

"The Vertical Garden is composed of three parts: a metal frame, a PVC layer and felt. The metal frame is hung on a wall or can be self-standing. It provides an air layer acting as a very efficient thermic and phonic isolation system. A 1 cm thick PVC sheet is then riveted on the metal frame. This layer brings rigidity to the whole structure and makes it waterproof. After that comes a felt layer made of polyamide that is stapled on the PVC. This felt is corrosion-resistant and its high capillarity allows a homogeneous water distribution."

Blanc is somewhat vague about the materials but it can be inferred that the polyamide felt material that he describes is either a type of rockwool or something very similar to it. Rockwool is a thick, felt-like material composed of coke, diabase and basalt that have been melted and extruded into small strands and woven into a mat. The product is 96% air-space and, despite its name, is surprisingly lightweight. Its high porosity makes it useful in construction as an insulator, but also an ideal hydroponics growing medium (Kentucky University, 1994). As Blanc mentions, the strong capillary action allows for even water distribution and facilitates his top-down irrigation system similar to that used in soil cells.

The hydroponics method has numerous advantages over soil cells. As already stated, capillary action ensures even irrigation. Hydroponic growing mediums - in this case rockwool - allow for excellent drainage in areas where this may present an issue. While uncommon, the lack of soil eliminates the possibility of soil-borne pathogens. Still another benefit is the general inability of weeds to sprout on a hydroponics-based living wall. In the case of rockwool, plants or seeds initially need to be physically inserted into the medium for them to successfully take root. The wool acts as a largely impermeable growing surface to weeds, yet allows for pre-existing plants to spread their roots freely. Finally, and likely the biggest advantage, is the reduced weight compared to soil cells. Blanc states that his method weighs about 30 kg per square meter, which translates into roughly 6 lbs. per square foot. A major distributor of soil cell, ELT Living Walls, states that their panels weigh between 16 and 20 lbs. per square foot when planted. Whether Blanc's method is superior is debatable, but if weight is an issue then it certainly wins in that regard.

3.4. Plants embedded in a rockwool growing medium (fatalii.net)

It should be noted that one common misconception about hydroponics is that it actually leads to increased plant growth when compared to typical soil-based growing conditions. This has never been scientifically shown to be true. For all of this method's advantages, more robust plant growth is not one of them.

Engineering Green Screens

Green screens differ greatly from living walls in how their plants are supported. Whereas living walls are concerned with providing a growing medium on the wall and keeping their plants rooted in it, screens must provide support for the plants as they grow. Green screens do not create 'instant' walls of vegetation; instead, their plants slowly grow up the support structure. The main concern is creating a structure that the plants will be able to climb up and sufficiently cover to create a visual screen.

Wires and Wire Rope

Wire has been used to support climbing plants for nearly as long as it has been available. The first mass-produced wire came from the Company of Mineral and Battery Works in England in the 16th century. Wire rope came along in the 19th century when it was first developed for use in the mining industry as a replacement for chain and hemp rope (Fassadengruen, 2004). Wire rope being a stronger form of support, its use migrated to trellis creation just as wires first did. Originally constructed out of wrought iron, today galvanized and high-grade steel are used.

Cabling provides a framework for climbing plants by being held in tension between fasteners. Wires are pulled taught between eye bolts which are driven into a wall. The inherent lack of form wire rope has and flexibility in the placement of eye bolts and other fasteners gives this method of trellising a large degree of creativity in its form. Due to the thickness and heavy-duty nature of wire rope, cabling is best suited for plants that need few attachments to support themselves, such as espalier. Larger or smaller gauges can be used for either aesthetic or plant-related reasons.

3.5. Wire rope and stabilizing accessory (fassadengruen)

Wire Mesh & Chain-link

One cheap solution is the use of chain-link fencing to create climbable screens for plants. Chain-link has a wire gauge size and distance that most vines are able to grow up and is readily available due to its use as an inexpensive fencing material. One project in Seattle makes use of chain-link to spruce up an otherwise dreary sound wall that runs along a city trail. “Confronted with a limited budget, Sollod designed a series of green, vinyl-coated, chain-link panels that vary in size and dimension from east to west…. The chain-link panels serve as armatures for evergreen and deciduous vines such as honeysuckle, wisteria and various clematis species that ultimately cover them, creating a year-round green wall” (Koonts, 2003).

Similar to chain-link, custom gridded metal panels can be purchased from companies that specialize in creating screens. These modular panels are often free-standing and require little extra support. The company Greenscreen, which specializes in green wall hardware, uses “galvanized wire panels with multi-grade alkaline wash, epoxy thermal-set primer and baked on powder coat finish.” Materials can vary based on desired weight, color and durability, but all maintain functionality and aesthetics. Greenscreen can also create custom-shaped panels for clients desiring greater creative control.

Having homemade or commercially available panels installed may be more expensive than simply letting certain varieties of vines grow up the side of a building, but it is not without benefits. Panels can be set at a distance from the building to allow for added ventilation. The presence of plants in close proximity to a building wall can trap moisture and promote deterioration of the material. (Calkins, 2000). Houses with wood siding experience especially fast decay when planted with vines. Frederick Law Olmsted's home and office, Fairsted, is covered in a custom steel trellis system that separates the thick vine layer from the building. A 6" gap allows for improved air circulation while still retaining the benefits of a green wall. Olmsted took the idea one step further and created a modular trellis system, where portions of the vine mass could be unhooked and temporarily removed. Repairs can be made to the siding without the need for pruning. Olmstead's trellis system varies greatly from most you'll see today – his consists of spiraled metal strappings, resembling a piece of twisted ribbon, that create ideal vertical structures for wisteria and kiwi to grow on – but the fundamental idea is the same.

Chapter 4: The Case for Using Green Walls

Green walls have a myriad of benefits associated with their use. The most obvious is of course the aesthetic appeal the walls have, but the benefits go much deeper than that. Years of scientific research by various groups have shown that green walls can make our living environments cleaner, safer and healthier areas to live in.

Graffiti & Vandalism

One use for green walls is as a means of discouraging vandalism. Any form of plant material covering a building will act as a regenerating buffer between it and vandals. The government of Western Australia recommends hedges, green screens or living walls as a method of protecting “properties on corner-blocks or next to vacant blocks [which] are often subject to vandalism” as part of what they call CEPTED: crime prevention through environmental design. Would-be graffiti artists are unlikely to attempt to tag a mass of plant material. Whether their intention is creating art or marking gang territory, neither is going to be effective on a plant wall. 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 façade of a building.

Biofiltration

The concept of using plants as chemical filters is hardly a new one. Plants help scrub the atmosphere through the absorption of carbon dioxide and release oxygen. The importance comes from rapidly approaching changes to the climate. The Intergovernmental Panel on Climate Change states that carbon dioxide levels have increased 32% worldwide since 1750. While reducing the amount of CO_2 added to the atmosphere may be out the scope of green walls, they can be used to offset that which is being added. Adding plant material to urban settings, where it currently is sorely lacking, is an attractive method of carbon sequestration that also has wider beneficial ramifications.

More recently the idea of plants as biofilters has been applied on increasingly smaller scales. Long term data on how well plants do at capturing and storing hazardous chemicals is sketchy, but in the short term they have been shown to be effective at cleaning both air and water. Organic nitrogen compounds, such as fertilizers and soil amendments, as well as other nitrogen-carrying chemicals like car exhaust and industrial pollution can decompose into atmospheric nitrogen and gaseous ammonia. Airborne nitrogen can make its way into water bodies in “dust, rain drops or simply due to gravity” (London Ecology Unit, 1993).

While living walls are certainly able to filter water and can do so with roof runoff, their effectiveness lies more in the reduction of the actual amount of roof runoff in storm events. As cities develop the amount of impermeable or semi-permeable surfaces (e.g. concrete and asphalt) increase and put increased strain on municipal stormwater drainage systems. Living walls can mitigate the total runoff by holding, even if only temporarily, stormwater in their soil cells or inorganic growing medium. Data on how much water green walls are actually able to hold is scarce, but some idea can be garnered by looking at green roof studies. The American Society of Landscape Architects (ASLA) recently installed a green roof on the top of their Washington, D.C. headquarters, partly with the intention of using it as a source of statistics. Their studies have shown that over a 10-month period, nearly 75% of the rainfall - or 27,500 gallons of water - that fell was retained within the roof. Due to gravity and the vertical nature of living walls this number would be significantly reduced, but if even a fraction of the water was retained it would still represent a considerable reduction in runoff. Also consider the ratio of roof space to wall space on a building. While green roofs may be more efficient at holding water, living walls could have considerably more square-footage on tall buildings with a small footprint.

Where green walls really shine, however, is in air filtration. Specifically, in reducing the amount of volatile organic compounds (VOCs) present in indoor airs systems. Poor indoor air quality is not a very widely publicized hazard and yet is responsible for a considerable loss of worker productivity. The United States EPA estimates that “one-third of absenteeism due to illness stems from poor air quality.” This is sometimes referred to as sick-building syndrome and can cause eye, nose and throat irritation, dizziness and headaches (Queen’s University, 2006). The VOCs are caused by man-made chemicals, such as adhesives, paints, lubricants, cleaning agents and inks and dyes, present in many work places. The emission rates vary widely but extended exposure can cause symptoms from even small daily doses. The table below shows some common sources of VOCs and the hazardous chemicals associated with them.

Commonly Encountered Indoor VOCs	
Source	Chemical
Paint, coatings, finishers, paint remover, thinner, caulking	Acetone
Paint, adhesive, gasoline, combustion sources, liquid process photocopier, carpet, linoleum, caulking compound	Aliphatic hydrocarbons (octane, decane, undecane hexane, isodecane, mixtures, etc.)
Combustion sources, paint, adhesive, gasoline, linoleum, wall coating	Aromatic hydrocarbons (toluene, xylenes, ethylbenzene, benzene)
Upholstery and carpet cleaner or protector, paint, paint remover, lacquers, solvents, correction fluid, dry-cleaned clothes	Chlorinated solvents (dichloromethane or methylene chloride, trichloroethane)
Acoustic ceiling tile, linoleum, caulking compound	n-Butyl acetate
Carpet, moth crystals, air fresheners	Dichlorobenzene
Carpet, paint	4-Phenylcyclohexene (4-PC)
Deodorizers, cleaning agents, polishes, fabrics, fabric softener, cigarettes	Terpenes (limonene, a-pinene)

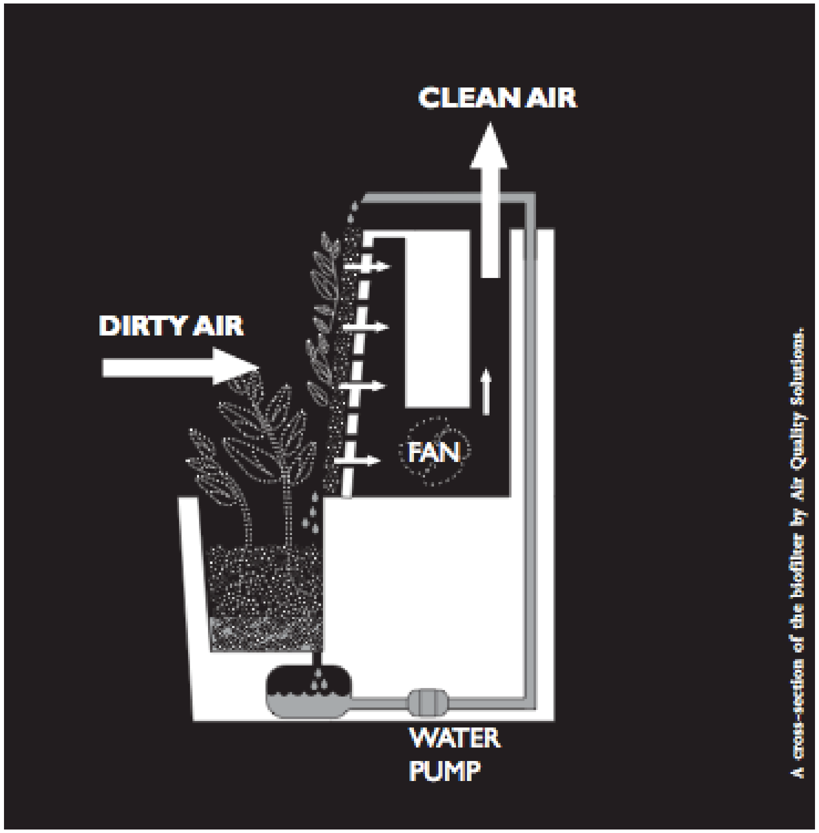
4.1. A table of volatic organic compounds commonly found indoors (Health Canada, 2007)

The combination of plants and microbes found in the growing medium - called the rhizosphere near the roots, where microbe populations are much higher - are what actively break down these chemicals (Natureaire, 2004). Plants act as a naturally regenerating air filter that doesn't need to be periodically replaced, unlike mechanical air filters. Naturaire, the company that designed the University of Guelph's living wall, has been receiving data on its operation for over 8 years and suggests that a ratio of 1:100 be used for effective air filtration. This means that the living wall should have one square foot of plant material for every hundred of indoor floor space.

Queen's University has had success with indoor livings walls being used to reduce VOCs in the same way that a conventional air filter would. The University describes their setup:

"The plants are all chosen to spread no pollen, and the constantly running water and fresh air stop mould from getting a foothold. A vapor barrier has been installed in front of the concrete wall and behind the drywall to stop water vapor from permeating the building. On each of the three floors, fans pull air through the wall into the building."

By setting up a circulation system behind their living wall, air is pulled through the plant layer which aids in delivering the normally harmful chemicals to the plants. Their three-story wall services the entire building and requires "no more maintenance than any other indoor landscaping feature" and has been in operation for over a year.



4.2. A schematic for an indoor air filter system incorporating a living wall. Note the fans behind the living wall, which aid in pulling contaminated air towards the plants

Social Benefits & Biophilics

The environments people live in have an impact on their attitudes and behavior. Few would doubt this to be true and yet the approaches that have been taken vary widely. The City Beautiful movement of the early 20th century attempted to create “moral and civic virtue among urban populations” through monumental architecture (Bluestone, 1988). The 1960’s in the United States saw the widespread emergence of socialized project housing in an attempt to revitalize depressed areas. The present day consensus is that both movements did little good, and in the case of housing projects actually created blighted areas. More recent studies show that greenery and vegetation play a large role in determining contentment among residents:

“A study conducted at six low-rise apartment communities, using a survey with both verbal and visual material, provides considerable support for the premise that having natural elements or settings in the view from the window contributes substantially to residents' satisfaction with their neighborhood and with diverse aspects of their sense of well-being… The potential of nature content in the view from the home to contribute so significantly to satisfaction and well-being suggests clear action mandates" (Kaplan, 2001).

Green walls have the opportunity to green up urban spaces in ways that other methods do not, most notably dense city environments. Cities are infamous for their concrete jungle appearance, with towers of brick and concrete lining the horizon and presenting a rather bleak living environment. Imagine instead looking out a window and seeing plants cascade down 30 stories of a building face. Not even counting the environmental benefits, adding green walls to urban settings could do wonders for overall satisfaction and well being, as Kaplan's study suggests.

This concept of happiness coming from living amongst areas with sufficient natural elements to them is sometimes called biophilics. The terms come from Harvard biologist Edward O. Wilson and "what he considered the innate human attraction to nature." A colleague of Wilson, Stephen R. Kellert, states "we lived in natural habitats for most of our evolutionary period, so knowing how to respond to light, weather, terrain, plants and animals was absolutely critical to our survival as a species." Dr. Kellert believes that our positive reactions to natural elements have been encoded into our genetics (Sole-smith, 2006). Green walls present an interesting spin on turning our environment into something that more closely resembles an untouched, natural one. Improving workplaces where people spend large portions of their time has the potential to lead to physical and mental well-being.

Indoor Climate Moderation

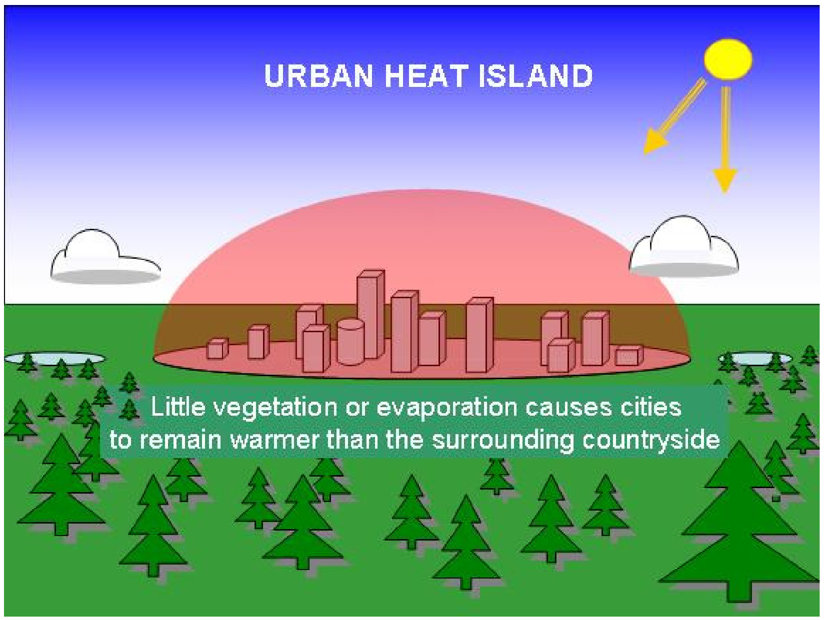
Successful use of passive solar principals in indoor climate moderation has been around for thousands of years. Passive solar is the idea of designing buildings around a combination of the movements of the sun and utilizing naturally occurring heat sinks. Constructing a building underground, for example, uses the earth as a means of moderating the interior temperature from hot or cold extremes. Green walls have an application in controlling indoor temperature by absorbing solar radiation and acting as heat sinks.

In the same way that a building covered in an earthen barrier is buffered from the swings in temperature that occur between night and day, one covered in plants can experience a similar benefit. Constructing a green wall on a south-facing wall will maximize exposure to light throughout the year and provide the greatest impact in screening radiation. The shading effect walls have can significantly reduce the ambient air temperature inside and cut back on cooling costs during the summer. "A prototype hydroponic vertical garden was constructed for research and demonstration purposes at the University of Toronto… In the simulation model, using vertical gardens as shades reduced the energy consumption by 23% for cooling" (Brad and Baskaran, 2001). Given the trend towards more of the planet's populations living in large cities, the potential energy savings here are considerable.

Combating the Urban Heat Island Effect

Another drawback to the continued removal of green space from cities is the increase of the urban heat island effect.

This describes the effect of cities - with their many square miles of concrete and asphalt - acting as huge heat sinks and raising the overall temperature of the area. Plants can cool air temperatures through evapotranspiration as "heat energy is drawn from the surrounding air to convert water to water vapor" (Martinez, 2007).



4.3. A depiction of the urban heat island effect

The result is increased heat storage and production on such a scale that it even alters weather and rainfall patterns. The temperature variance between urban cores and rural areas can be as much as 7° Fahrenheit (Martinez, 2007). Adding plants back into the urban mix can begin to return temperatures back to those which would be considered normal (i.e. unaltered by human civilization). The reduction in solar gain would mean less reliance on artificial indoor climate control (air conditioning) and thus less waste heat. If significant steps were taken to vegetate the walls of urban areas, part of this heat island effect could be mitigated and perhaps someday eliminated altogether.

Chapter 5: Plant Selection

Plant selection is a critical aspect of designing green walls. The plants used differ tremendously between living walls and green screens, and each requires carefully chosen species that can tolerate the specialized environments.

Plants for Green Screens, Vines & Vine Morphology

Facades require any of a variety of climbing plants (vines) that are able to graft themselves onto structures, which they use for support. Methods of attachment vary greatly among vines and determine which variety of plant can be used on a given structure. Climbing plants can be divided up into five distinct groups based on their method of growth and attachment. (Western Garden Book) These groups are:

1.) plants with tendrils

2.) plants with twining stems or leaves

3.) plants with suction disks or pads

4.) holdfasts, plants with aerial roots or stem roots

5.) scramblers, which have no direct means of attachment

Vines with tendrils grow skinny, wiry growths from their stems or leaves. The tendrils reach out in all directions until they make contact with an appropriate structure, at which point they curl and wrap around the object. The combined tension on these coiled tendrils supports the weight of the plant. Peas (Pisum sativum), grapes (Vitis) and passion flower (Passiflora) are all examples of tendril plants. Because of their morphology these types of vines require a fine structure to attach to. Anything thicker than roughly 1/4” is too large for the tendrils to wrap around. Thin wires or string work best, so a trellis system using chain-link would be best suited for these plants (Western Garden Book).

5.1. Examples of vine attachments (Fassadengruen)

Twiners fall into two categories: twining stem and twining leaf vines. Twining stem plants have a stem them coils either clockwise or counter-clockwise - depending on species - around the support structure. Twining leaf plants use their leaves in a fashion similar to tendrils, which wrap around nearby objects. Whatever the plant comes in contact with it tends to coil around. Species of Clematis have twining leaves, while Honeysuckle (Lonicera), Wistera and Jasmine (Jasminum) all have twining stems. Twiners are less picky about what structure they attach to and will do well even on thick arbor beams (Western Garden Book).

Vines with suckers attach themselves through sticky pads or disks. These pads are less suited to attaching to a trellis system and do well on flatter surfaces, such as the side of a building or trunk of a tree. In this way they are a less demanding plant for creating green screens, though are not without their disadvantages. Their growth right up against buildings, rather than on a trellis system, means that they trap more moisture than other types of vines and can cause degradation in this way. Boston Ivy and Virginia Creeper (Parthenocissus tricuspidata and P. quinquefolia) are commonly used species that do well in most climates. Another disadvantage is the lack of control the owner has over where they grow. While twiners, scramblers and vines with tendrils require some artificial latticework for them to grow on, vines with suckers will grow to cover nearly any surface they come in contact with. Constant pruning and management is required to keep them from totally engulfing a building.

Holdfasts are a group of vines which make attachments with small roots that grow out of their stems and cling to surfaces. Similar to suckering vines, holdfasts benefit little from trellis systems and prefer fairly flat surfaces with some degree of unevenness to them, such as brick or stonework. Their stem roots grow into cracks and crevices and expand until they can provide enough tension to help support the vine. English ivy, Irish Ivy (Hedera helix and H. hibernica) and Hydrangea are examples of holdfasts. This group of vines is notorious for finding its way into weak points in building exteriors and exacerbating structural problems. Over time their stem roots can expand cracks and split already weakened hardscape materials. Like vines with suckers, holdfasts will also grow wherever they please and must be periodically pruned.

The final group of vines is sometimes referred to as scramblers, or those vines with have no means of attaching to the structures they climb. Bougainvillea and roses (Rosa sp.) are commonly seen examples. These plants have long, flexible stems that can be loosely woven through a supporting structure such as a trellis or arbor. Scramblers are often woody and possess thorns which can help grip and entangle nearby structures. While they may be showy, these plants are not low maintenance due to their relative inability to climb without assistance. Their shrubby form also limits their height to significantly less than what other climbers can attain, even with their limbs tied or tacked in place. On the other hand their woody and thorn-covered stems can form a painful deterrent to would-be trespassers (Western Garden Book).

Plants for Living Walls

As with many other aspects of living walls, a good place to begin when looking at their biological components is to start with Patrick Blanc. Blanc is adamant that he owes much of his success as a wall designer to his choice of plants. His background is that of a botanist turned landscape architect/interior designer (Hohenadal, 2007). His fascination with cliff-dwelling plants led him to experiment with bringing these plants back into urban settings where they otherwise have been relegated to horizontal surfaces. In a 2006 interview with Japanese magazine PingMag, he describes the occurrence of these plants and its influence on his work:

"For instance in Malaysia, 2,500 out of the 8,000 known species are growing without any soil. Even in temperate climate zones many plants grow on cliffs, cave entrances or cracked up rocks. On these rather steep places many Berberis, Spiraea, and Cotoneaster species are able to grow. Their naturally curved branches indicate that they originated from natural steep biotopes and not from flat areas like the gardens where they are usually planted. So - it is possible for plants to grow on virtually any vertical surface nearly free-of-ground, as long as there is no permanent shortage of water."

Of course Blanc's opinions are not the final word on plant selection. If taking matters into one's own hands, a number of characteristics become important when selecting appropriate plants. One of the key concerns is the amount of light these plants receive. Indoor living walls suffer from one of the same problems indoor potted plants do: they receive very minimal light. The problem can be addressed partly through smart placement of light fixtures and skylights, but the biggest gains can be seen by using shade-tolerant plants. Plant genuses adapted to low light tend to have large, thin leaves year-round and are often seen living under thick tree canopies. The University of Guelph in Wisconsin manages an indoor living wall and has planted it in part according to the amount of shade it receives. The lower portion of the 60 foot installation contains croton, spider and umbrella plant, ferns and philodendrons (Vowles, 2007). Towards the top of the wall, closer to the skylight, are geraniums, hibiscus and fuchsia. Queen's University in Canada has an indoor living wall used for studying biofiltration that uses much same plants. Some notable additions are rubber plant, snake plant and ficus, all of which are reported to thrive (Queen's University, 2006).

5.2. Tropical indoor plants used by ELT Living Wall Systems

Cremnophytes

Another important consideration for living walls is the physical plant structure, including height and root structure. These tend to be closely related but are worth mentioning individually. Whether using soil cells or hydroponics, the growing medium available for plants is going to be at most a few inches deep. Plants with deep growing roots, such as those with tap roots, will not do well and should not be considered. It almost goes without saying that taller, heavy plants such as large shrubs and trees simply won't have the depth necessary for them to take root and hold themselves onto a vertical surface. Ground covers and very low growing shrubs are better suited to this environment. Plants which have naturally adapted to growing on cliffs are sometimes referred to as cremnophytes. This term applies to any plant which is most often found on cliff surfaces. Plants which are able to grow on cliffs but are found mainly on flat surfaces are called opportunistic cremnophytes. Species vary widely but share a tolerance for harsh conditions, including species of Aloe in southern Africa and columbine (Aquilegia sp.), nodding wild rye (Elymus canadensis) and species of lichen to name a few in Minnesota (Department of Natural Resources of Minnesota).

Epiphytes

Another group of plants important to living walls are epiphytes. These are plants which have evolved to grow without soil. Epiphytes are commonly found in tropical areas where competition for sunlight is such that evolution has dramatically altered what would usually be considered a growing requirement for a plant. The result is tropical plants that sprout and take root on tree branches rather than the jungle basin (Texas A&M, 1996). Notable epiphytes include orchids, mosses, bromeliads and some tree-dwelling cacti, such as crab cactus (Schlumbegera truncata). These plants are well suited for use on living walls with hydroponics systems. Because of their tropical nature, however, they are best suited for use indoors where they will receive minimal direct sunlight and will be buffered from extreme cold or hot temperatures.

5.3. Epiphytes growing in a natural habitat (Wikimedia Commons)

Chapter 6: Analysis of Applications Throughout the World

Now that the workings of green walls have been thoroughly covered, let's look in depth at some applications from around the world.

Case Study 1: Aquaquest - Vancouver, BC, Canada

The Aquaquest Aquarium in Vancouver, Canada is home to a small outdoor living wall. Completed in late 2006, the 75 square foot wall was part of an effort by the center to gain LEED Gold certification. In addition to the wall, the center has implemented low-flush toilets, a rainwater harvesting system and a system of pipes to moderate the temperature inside the building. Aquaquest recruited Sharpe & Diamond Landscape Architecture Inc. to design and install the wall, using G-SKY's soil cell system. A stainless steel frame anchored to a concrete wall holds the 1' x 1' x 3.5" soil cells in place, which have been planted with native plants. The wall is fed by a drip irrigation system, as well as recycled rainwater which is collected and stored in underground cisterns. Canada's cool, wet climate makes possible the near year-round use of this water a reliable way of irrigating the wall. In this way the living wall becomes more than just an aesthetic piece that requires water beyond what the site would normally require; it becomes something that is both beneficial to the surroundings and has little if any negative impact (The Greenroof Project Databse, 2006).

6.1. Aquaquest's living wall (The Greenroof Project Database, 2006)

Case Study 2: Anthropologies - Huntsville, AL, USA

6.2. Anthropologies' living wall amidst a shopping center (The Greenroof Project Database, 2006)

Another implementation of living walls is on the Anthropologies building in Huntsville, AL. This 2-story commercial building previously had white, featureless walls that reflected light onto the sidewalk during the summer and did little to help bring in business from the street. The company opted to install a soil cell-based system designed and built by Green Living Technologies, completed in 2007. The cells are 2' x 2' x 3" and as is typical, slotted to allow drainage to percolate down the wall. A 3/4" space was left between the building and the living wall to allow for the movement of air. The wall is planted with a mixture of primarily sedums (listed below) and irrigated from the top down with a gravity-fed drip system. A moisture sensor placed in the wall prevents the irrigation system from activating when sufficient moisture is already present and any excess water is collected below for landscaping use elsewhere. The 2000 square foot wall is believed to be able to hold about 540 gallons, using existing data of walls being able to hold around 0.3 gallons of water per square foot. Anthropologies has reported increased foot traffic into and around their business since the installation of the living wall. With the addition of benches beneath the wall, shoppers from nearby stores gravitate to the seating “seeking refuge to rest leading us to believe that the vegetation of the green wall was a relief to the common site of concrete and stucco buildings” (The Greenroof Project Database, 2006).

List below is a summary of the plants chosen for Anthropologies' living wall:

Delosperma congestum
Sedum acre 'Aureum'
Sedum hispanica 'Blue Carpet'
Sedum album
Sedum ellecombianum
Sedum kamschaticum
Sedum sexangulare
Sedum spurium 'Dragon's Blood'
Sedum spurium 'Fuldaglut'
Sedum stefco

6.3. A different view of the Anthropologies building

Case Study 3: Equinox Fitness Center - NYC, NY, USA

6.4. Equinox's indoor living wall (The Greenroof Project Database, 2006)

A good example of an indoor living wall is the one installed at the Equinox Fitness Center in New York City. The wall is 650 square feet comprised of 2' x 2' x 3" cells, mounted onto a custom made mounting device designed to fit the wall. The reduced lighting associated with being indoors dictated the choice of plant palette, and Green Living Technologies went with a selection of tropical plants capable of growing in low light conditions. This situation was further aggravated by part of the center being underground. The 3,800 plants in addition to the water features above and below the wall give a more relaxed atmosphere to the center. The wall being in an enclosed, indoor area also goes some way towards filtering the air and improving its quality. A low-volume drip system irrigates the wall to minimize water consumption. Given New York's high variance in outdoor temperatures, an outdoor wall that also could deal with diminished light conditions amidst the city's skyscrapers would be tough to keep alive.

Chapter 7: Other Methods of Greening

Retaining Walls, Slope Stabilization & Bioengineering

In the case of extremely steep slopes, the line separating roof (or ground) from wall becomes blurred. At what point does a surface truly become a wall? The question is academic, really, because at times green wall technology is required whether the planting surface is truly a wall or not. Retaining walls and methods of slope stabilization fall into this category.

Engineers have developed efficient systems for holding back soil on steeply sloped surfaces. Netting, wire meshes, concrete masonry units and stacked plastic or geosynthetic sheets are all effective methods of holding back masses of soil. Green wall technology comes in when attempts are made at adding vegetation to their surfaces. The problem here is two-fold: a system must be developed that works as a retaining wall as well as be able to combat gravity and allow plants to grow out of a near-horizontal surface. The practice of combining these two engineering problems is sometimes referred to as bioengineering.

Many bioengineering methods have been devised, each with their other advantages and disadvantages. One such method is permeable, biodegradable netting. Rana Creek, the company that designed the green roof installed on the California Academy of Sciences building, had to devise a way to keep the vegetation attached to the roof in places where the slope reached upwards of a 60% grade. After three months of testing Rana Creek decided to go with what they call a coconut fiber bio-tray. Much like a soil cell, the bio-tray resembles a shallow box that is planted after being packed with soil. Unlike a more conventional living wall, however, the trays are only temporary. Once the plants have established their roots and provided the soil with added stability, the coconut fibers will have begun to decompose and eventually vanish altogether into the soil.

7.1. The California Academy of Sciences green roof under construction

Floating Planters

Italian architect and designer Gaetano Pesce has his own take on vertiscaping. His self-devised "vertical gardens" are created by attaching a series of planter boxes to the sides of a building. While the concept isn't terribly novel, its implementation in 1993 on perfectly vertical walls was one of the first modern attempts of its kind. His plans for an office building in Osaka, Japan have pots adhered to the sides of the walls, planted with 125 different plant species selected for their ability to survive amidst the pollution of a crowded city. The appearance has a very formal and restrained look, though there is no reason why a more organic feel couldn't be attained with larger or more closely spaced planters. Since then, Pesce has come up with an all-purpose metal frame, similar to that used in living walls soil cell systems, which can be attached to a building and fitted with fiberglass planters. His visionary designs seem have been overtaken by true living walls, as many companies now sell mass produced frames that can achieve a far more vegetated result - and all the benefits that go with it - using a near identical method.

7.2. Gaetano Pesce's planter box system in Osaka, Japan

Chapter 8: Looking to the Future

Bioclimatic Skyscrapers

Green walls can be considered the technology of today that simply has yet to be adopted. The factor that limits its more widespread use is a lack of acceptance rather than a lack of maturity of in the field. The future holds in store new and exciting uses of greened surfaces that current materials and construction methods make difficult. One such idea is that of bioclimatic skyscrapers, pioneered by Malaysian architect Ken Yeang. This idea attempts to incorporate green space into the living areas of towers, rather than simply lining the walls with plant material. Imagine a building with usable green spaces - such as gardens or small parks - on every other floor of a building. It is green walls and roofing taken to the extreme.

This is a field that much more strongly incorporates the talents of engineers and architects, as the spaces are integral to the structural soundness of the building in a way that green walls are not.

8.1. An example of a bioclimatic skyscraper

Bioclimatic skyscrapers attempt to find room to incorporate natural vegetative systems within their tight building envelope. The rationale for doing this is as varied as with green roofs and walls: reduction of energy expenditures, reduction in the heat island effect and increased perceived happiness to name a few. Another reason mentioned by Yeang is the concept of regionalism. Yeang argues that given that the climate of a region is essentially unchangeable and can vary greatly from place to place, designing with a greater emphasis on local natural systems leads to a better understanding of them and designs which are more tailored to their environment. “The ancients recognized regional climatic adaptation as an essential principle of architecture. In this regard, the climatically responsive building can be seen as having a closer fit with its geographical context” (Yeang, 1995).

How and where these green spaces are integrated into buildings varies based on their use, the local climate and the resources available. One of the first such towers built was the IBM Building in Kuala Lumpur. Designed by Ken Yeang, the building features “a spiraling atrium that accomodates 'vertical landscaping, improving indoor air quality and aiding natural ventilation, and external louvres that reduce solar heat gain” (Blum, 2006). In Mumbai, the Antilla, a private 27-story residence, is set to become the world's “greenest” building. Though criticized for its lack of sustainable materials or building practices, it will literally be covered in more vegetation than any other building in the world. Some floors of the building are devoted entirely to green space; in essence elevated gardens that float above the crowded streets of the densest city in the world (Ramesh, 2007). Another concept for a bioclimatic skyscraper already put into practice is the Tokyo-Nara Tower. Designed by Ken Yeang, this proof-of-concept tower created for the World Architecture Exposition in Nara, Japan demonstrated his ideas of incorporating vegetation into the interior as well as facade of the building while preserving functionality. Particularly interesting is the way in which these facilities are maintained. “The maintenance of the vertical landscaping, as well as the upkeep of external fixtures, glazing and cladding panels is ensured by specialised mechanical devices. These devices, constructed in the form of multi-purpose 'robot-arms' as 'cherry-pickers' on moveable trellises that travel along an external track that spiral and circulates [sic] the tower” (Europaconcorsi, 2008).

8.2. The Antilla in Mumbai, India (Ramesh, 2007)

"Nature Abhors a Vacant Niche"

The logical next step in the evolution of our cities is a trend towards re-greening them. Humanity is paying the price for converting thousands of square miles from untamed wilderness into asphalt and concrete. Green walls represent a compromise of sorts that will allow people the lifestyle they want in a more sustainable manner. The alternative is a society that is condemned by its reliance on limited resources and unsustainable living practices. Nature will find its way back into our cities, one way or another.

Bibliography

1. Queen's University. 2006. http://livebuilding.queensu.ca

2. Vowles, Andrew. "Guelph-Humber plant wall a breath of fresh air." University of Guelph. 2007. http://www.uoguelph.ca/atguelph/04-11-10/featuresair.shtml

3. ELT Living Walls. http://www.eltlivingwalls.com/

4. "Graffiti Prevention." Government of Western Australia. October 30, 2006. http://www.goodbyegraffiti.wa.gov.au/Information/Prevention/tabid/665/Default.aspx

5. Naturaire. 2004. http://www.naturaire.com/index.html

6. Kaplan, Rachel. "Environment and Behavior." University of Michigan. SAGE Publications. 2001. http://eab.sagepub.com/cgi/content/abstract/33/4/507

7. Bluestone, Daniel M. "Detroit's City Beautiful and the Problem of Commerce." *Journal of the Society of Architectural Historians*. Columbia University. September, 1988.

8. Yeang, Ken. "Biolcimatic Skyscrapers." Ellipsis London Limited. 1995. http://www.ellipsis.com/yeang/text.html#top

9. The Greenroof Project Database. Greenroofs.com. 2006. http://www.greenroofs.com/projects/pview.php?id=703

10. British Earth Sheltering Association. http://www.besa-uk.org

11. Health Canada. 2007. http://www.hc-sc.gc.ca/ewh-semt/pubs/air/office_building-immeubles_bureaux/organic-organiques_e.html#1

12. Koonts, Dean W. "Vine Panels." *Landscape Architecture*. 2003.

13. Calkins, Meg. "A New Twist on Trellis Design." *Landscape Architecture*. 2000.

14. Sole-smith, Virginia. “Nature on the Threshold.” The New York Times. September 7, 2006. http://www.nytimes.com/2006/09/07/garden/07bio.html?_r=2&scp=1&sq=biophilic&st=nyt&oref=slogin&oref=slogin

15. Intergovernmental Panel on Climate Change. http://www.ipcc.ch/

16. London Ecology Unit. 1993. http://www.lid-stormwater.net/greenroofs_benefits.htm

17. Martinez, Yanet. “Teaching Green.” University of California Davis. 2007.

18. Bass, Brad and Baskaran, Bas. “Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas.” March 31, 2001. National Research Council of Canada.

19. Hohenadel, Kristin. “All His Rooms are Living Rooms.” *The New York Times*. May 3, 2007. http://www.nytimes.com/2007/05/03/garden/03blanc.html?_r=2&pagewanted=all&oref=slogin&oref=slogin

20. Verena. “Vertical Garden: The Art of Organic Architecture.” *pingmag*. December 8, 2006. http://www.pingmag.jp/2006/12/08/vertical-garden-the-art-of-organic-architecture/

21. Department of Natural Resources of Minnesota. http://files.dnr.state.mn.us/natural_resources/npc/cliff_talus/cts12.pdf

22. “Plants That Grow on Other Plants.” Texas A&M University. November, 1996. http://plantpathology.tamu.edu/Texlab/Multicrop/parasites.html

23. The Greenroof Project Database. Greenroofs.com. 2006. http://www.greenroofs.com/projects/

24. Yeang, Ken. “Bioclimatic Skyscrapers.” Ellipsis London Limited. 1995. http://www.ellipsis.com/yeang/text.html#top

25. Blum, Andrew. “Green Wonders of the World.” *Business Week*. July 21, 2006. http://www.businessweek.com/innovate/content/jul2006/id20060721_195445.htm

26. Ramesh, Randeep. “Indian tycoon builds tower block home.” *The Guardian*. June 1, 2007. http://www.guardian.co.uk/business/2007/jun/01/india.internationalnews

27. Europaconcorsi. 2008. http://www.europaconcorsi.com/