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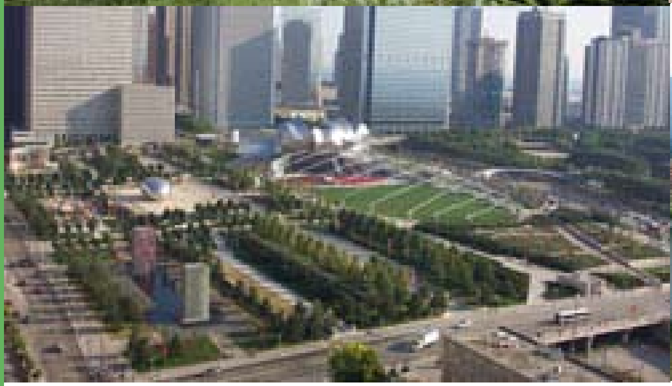
Green Roof Infrastructure

Steven Peck, Honorary ASLA



AMERICAN SOCIETY OF LANDSCAPE ARCHITECTS

ASLA FUND

Green Roof Infrastructure

Part I: The Basics of Green Roof Infrastructure

LATIS

Green Roof Infrastructure

by Steven Peck, Honorary ASLA

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About the Authors[1]

Green Roofs for Healthy Cities (GRHC) is a nonprofit industry association dedicated to bringing green roof technologies to the forefront of high-performance, restorative green building design, implementation, and maintenance in North America. Working with its members and other stakeholders, GRHC provides technical and policy resources to realize the outstanding economic, social, and environmental benefits of green roofs.

Steven Peck, Honorary ASLA, founder and president of Green Roofs for Healthy Cities, prepared this text with the support of Alex Johnston and staff at ASLA. Much of this material is drawn from the "Green Roofs Design 101: Introductory Course", a full-day course provided by GRHC.

[1] Appendix provides additional information about Green Roofs for Healthy Cities, or visit www.greenroofs.org.

Publisher's Note:

The American Society of Landscape Architects publishes the Landscape Architecture Technical Information Series (LATIS) to encourage professionals to share specialized expertise relating to landscape architecture. ASLA considers LATIS papers to be important contributions to a necessary and ongoing dialogue within a large and diverse community of landscape architecture researchers and practitioners. ASLA oversees a rigorous peer review process for all LATIS papers to ensure accuracy of content. Each author offers a unique perspective on the practice area covered, reflecting his or her portfolio of professional experiences.

Part I of this LATIS presents information on the history, benefits, design, and construction of green roofs. Part II discusses green roof design from a landscape architect's perspective, and provides profiles of award-winning green roofs across North America.

Feedback on this LATIS and on the series in general should be sent to ASLA, c/o Professional Practice Manager, 636 Eye Street NW, Washington DC 20001. ASLA welcomes suggestions for future LATIS topics that will broaden awareness of new and/or rapidly evolving practice areas within landscape architecture and enhance technical proficiency for practicing in these areas.

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Foreword

According to the Brookings Institution, "[i]n 2030, about half of the buildings in which Americans live, work, and shop will have been built after 2000."[2] The integration of plants and building technologies will be essential to maintaining the health and well-being of our cities and communities as we create the infrastructure that houses us in this century.

Landscape architects, horticulturalists, architects, engineers, and others will have important roles in ensuring that the transition to "green" buildings includes living systems. Green roofs, green walls, and living machines can all make substantial and multifaceted contributions to the design and function of our structures. Developing new economic incentives and business models that facilitate investment in these technologies will be of paramount importance to ensuring that they become central features of mainstream building practice. This paper provides a survey of the benefits, products, and design principles associated with green roof infrastructure. Use it to strengthen your ability to pursue more sustainable designs in your work.

[2] *Toward a New Metropolis: The Opportunity to Rebuild America*, by Arthur C. Nelson, Virginia Polytechnic Institute and State University; A Discussion Paper Prepared for The Brookings Institution Metropolitan Policy Program; December 2004

Introduction

A Brief History of Green Roofs

Green roofs, also known as rooftop gardens, vegetated roofs, and eco-roofs, are not a new phenomenon. They have been standard construction practice in many countries for hundreds, if not thousands, of years, mainly due to the excellent insulating qualities of the combined plant and soil layers (sod). In the cold climates of Iceland and Scandinavia, sod roofs help to retain a building's heat, while in warm countries such as Tanzania, they keep buildings cool.

Two modern advocates of green roof technology were the architects Le Corbusier and Frank Lloyd Wright. Although Le Corbusier encouraged rooftops as another location for urban green space and Wright used green roofs as a tool to integrate his buildings more closely with the landscape, neither was aware of the profound environmental and economic impact that this technology could have on the urban landscape.

More recent green roof advocates with a more complete sense of the potential for the technology include Malcolm Wells and landscape architect Theodore Osmundson. Malcolm Wells, often called the "father of modern earth-sheltered architecture," became an architect in 1953 and practiced for 11 years before deciding that contemporary architecture was destructive rather than creative—it destroyed the natural habitats that it built within. Ever since then, Mr. Wells has been an advocate of buildings that can "heal the wounds caused by their construction," allowing plants and animals to return to blankets of living land within the built environment. Theodore Osmundson, FASLA, is a well-respected landscape architect who began his practice in San Francisco in 1946. As well as being a past president of the International Federation of Landscape Architects and the American Society of Landscape Architects and a winner of the ASLA Medal (1983), he is recognized as a leading designer and advocate of green roofs. In 1999 he published a book on his life's work, titled *Roof Gardens: History, Design, and Construction*.

Until the mid-twentieth century, green roofs were viewed mainly as a vernacular building practice. However in the 1960s, amid rising concerns about the degraded quality of the urban environment and the rapid decline of green space in urban areas, a renewed interest in green roofs as a "green solution" was sparked in Northern Europe. New technical research was carried out, ranging from root-repelling agents, membranes, drainage, and lightweight growing media to plant suitability. This research facilitated the development of lightweight, "extensive" green roofs, in contrast to the heavier and more traditional rooftop deck garden, now referred to as an "intensive" system.

In Germany, the green roof market expanded quickly in the 1980s, with an annual growth rate of 15–20 percent, ballooning from one to ten million square meters. This growth was stimulated largely by state legislation, municipal grants, and incentives of 35–40 Deutsch Marks/m^2 (approximately $1.75 US/sf) of roof greened. Other European states have adopted similar types of support. Several cities now incorporate roof greening into regulations. Stuttgart, for example, requires green roofs on all new flat-roofed industrial buildings. Vienna also provides subsidies and grants for new green roofs at the stages of planning, installation and three years post-construction to ensure ongoing maintenance. More than 75 European federal, state, and local governments currently provide incentives or requirements for green roof installation. A key motivator for this support has been the public benefits of stormwater runoff reduction and air and water quality improvements. As a result, a new sector in the construction industry was created—the green roof industry—and both extensive and intensive green roofs are becoming a common feature in the urban landscape.

Canada and the United States are at least 10 years behind Europe in investing in green roof infrastructure as a viable option for solving the many quality-of-life challenges facing our cities. During the early 1990s, several large European green roof manufacturers started to venture into the North American market. However, the systems were hard to sell without public education, local research on technical performance, and accessible examples, especially in a cultural and political climate where many individuals, businesses, and governments do not readily invest in green technologies. This has started to change.

What Is a Green Roof?

"We look at architecture the wrong way: sideways, so what we see is only a thin sliver of the reality around us. To see architecture fully, you must tip it up, stand it on its edge. When you do, you always see dead land on display."

- Malcolm Wells, *Recovering America*

A green roof[3] is a green space created by adding layers of growing medium and plants, root repellent material, a drainage layer, filter cloth, and high-quality waterproofing on top of a roof that is located below, above, or at grade. This should not be confused with the traditional terrace roof gardens, where planting is often done in freestanding containers and planters, located on an accessible roof terrace or deck. The essential layers of a basic green roof system, from the top down, include:

- the plants, components specially selected for particular applications
- an engineered growing medium, which may not include soil
- a landscape or filter cloth to contain the roots and the growing medium, while allowing for water penetration
- a drainage layer, sometimes with built-in water reservoirs
- a root repellent layer/component,
- the waterproofing membrane
- the roof structure, with traditional insulation either above or below

[3] Alternative terms sometimes used include "living roof," "vegetated roof," "rooftop garden," "plaza deck," "brown roof" [when spontaneously seeded], or "eco-roof."

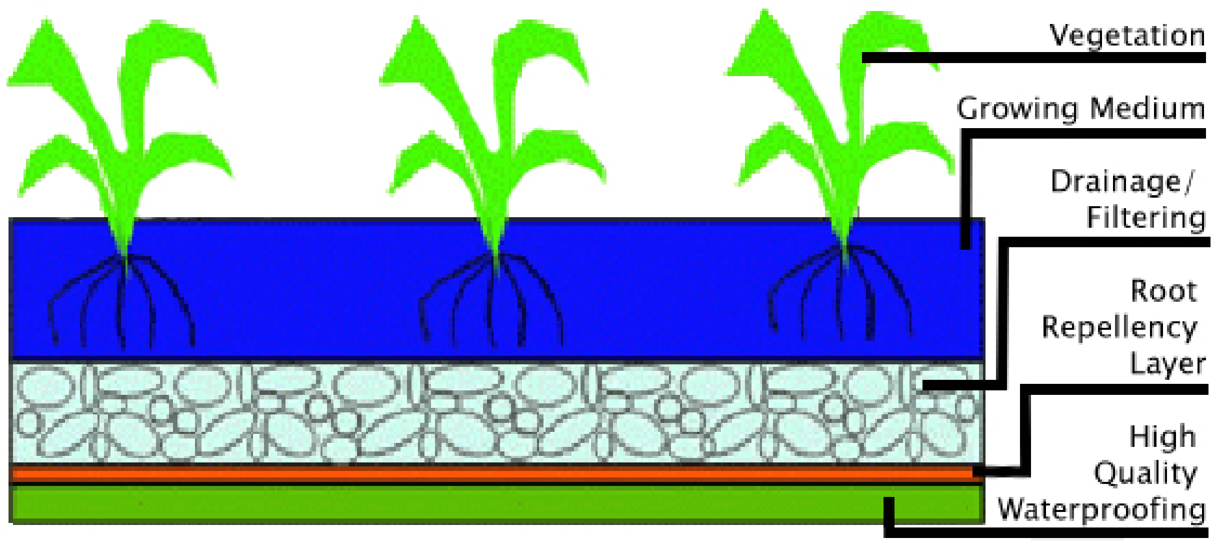

Figure 1. Generic green roof cross section showing basic components.
Source: Green Roof Design 101 Participant's Manual (Green Roofs for Healthy Cities)

Types of Green Roofs

Following the German green roof industry's nonprofit research and standard-setting body, Forschungsgesellschaft Landschaftsentwicklung Landschafts bau e.V (FLL), Green Roofs for Healthy Cities recognizes two basic types of green roof systems—extensive and intensive—differentiated mainly by the cost, depth of growing medium, required structural loading capacity, and the types of plant life they support.

Extensive green roofs are new to the market. These green roofs are often not accessible and are characterized by:

- low weight
- low capital cost,
- low plant diversity, and
- minimal maintenance requirements.

The growing medium is typically made up of a mineral-based mixture of sand; gravel; crushed brick; lightweight expanded slate, clay, or shale aggregate; volcanic rock; pumice stone; scoria; zeolite; diatomaceous earth; perlite; or rock wool. Organic matter may also be added, such as composted straw, sawdust, wood, grass, leaves, clippings, agricultural waste, worm castings, peat or peat moss, or manure. The growing medium on extensive green roofs varies in depth between 2–6" with a weight increase of between 12–35 lb/sf when fully saturated or at "maximum density".

Due to the shallowness of the growing medium and the extreme desert-like microclimate on many roofs, plants must be low and hardy, typically alpine, dryland, or indigenous. The plants are often watered only until they are fully established, and after the first year or two, maintenance typically consists of two visits a year for weeding of invasive species, drainage, and membrane inspections.

Intensive green roofs are roof gardens or parks on rooftops, almost always accessible to building occupants or the public, that are characterized by:

- deeper growing medium (more than 6") and therefore greater weight,
- higher capital costs,
- increased plant diversity, and
- higher maintenance requirements.

The growing medium is uniformly deeper than 6", with a saturated weight increase of between 50–300 lbs/sf and may include several blends, engineered to support different plants. Due to the increased growing medium depth, the plant selection is more diverse and can include trees and shrubs. Requirements for maintenance—especially watering—are more demanding and ongoing, and irrigation systems are usually specified. Consultation with an experienced structural engineer, horticulturist, and installer is always recommended, particularly for intensive green roofs, with their deeper growing medium, greater weight, and more diverse plant cover than extensive roofs.

It should be noted that, depending on such site-specific factors as location, structural capacity of the building, budget, client needs, and material and plant availability, each individual green roof will be different, often a combination of both intensive and extensive systems. Combinations of extensive and intensive—**"semi-intensive" green roofs**—combine growing medium depths on the same roof, with each depth range accounting for at least 25 percent of the roof's total area. Semi-intensive green roofs are almost always accessible to building occupants or the general public, and their structural loading requirements will vary.

Table 1. Green roof characteristics. Source: Green Roof Design 101 Participant's Manual (Green Roofs for Healthy Cities)

Characteristic	**Extensive**	**Semi -intensive**	**Intensive**
Depth of medium	6" or less	Combines both intensive and extensive (each category accounting for at least 25% of green roof area)	More than 6"
Accessibility to pedestrians	Often inaccessible	May be partially accessible	Usually accessible
Weight	Low (10–35 lbs/sf)	Varies (35–50 lbs/sf)	High (50–300 lbs/sf)
Plant Diversity	Low	Greater	Greatest
Cost	Low	Varies	Highest
Maintenance	Minimal	Varies	Highest

Figure 2. The Church of Jesus Christ of Latter-day Saints Convention Centre, Salt Lake City, Utah
Semi-intensive green roof combining areas with growing medium of greater and less than 6 inches
Source: Olin Partnership

Methods of Green Roof Construction

The system may be installed in a sequence of separate custom designed layers (a “loose laid” or “built-up” system). Complete turnkey systems are available for this type of green roof, with the advantages of well-established performance and warranty.

Figure 3. Drainage cloth: a component of a "loose-laid" or "built-up" system. Location: San Bruno, CA. Source: McDonough + Partners

Loose-laid systems, also referred to as "built up," tend to have the following characteristics:

- Involve use of multiple layers
- Often rolled out or positioned in sections
- Layers can incorporate different functions
- Often used for large projects

The alternative to "loose-laid" or "built-up" systems is modular systems.

Figure 4. Modular components. Source: Green Roof Blocks (left, smaller image); Greengrid (right, larger image)

Modular systems are pre-configured containers that tend to have the following characteristics:

- Typically laid above the root repellant/waterproofing layer.
- Can be moveable/pregrown
- Often combine different functions / elements such as:
  - Drainage layer
  - Borders
  - Growing medium
  - Plants
- Can be easily installed by roofing contractors

There are advantages and disadvantages of each system that will vary depending on factors such as the size of the project, the budget, and the desire of the client for immediate vegetation, which can be provided by more readily by pregrown systems.

Benefits of Green Roofs

There are few, if any, technologies that can provide as many public and private benefits as green roofs.[4] The type of benefit accrued is a function of budget, design, and the building. Green roofs provide many benefits for both the public and private sectors. Some benefits are common to almost all green roofs, but many are project- or design-specific in their nature. This section provides an overview of these benefits and examples.

The majority of green roof benefits are public in nature, but in the absence of public incentives, are often not reflected in the market. So in the case of two big-box retailers operating side-by-side, one with an extensive green roof and one without, the one with the green roof will have paid approximately twice the roofing cost of the other. While the more expensive green roof will confer a number of quantifiable benefits to the public, the building owner will face most of the same fees and taxes as the owner of the building with a traditional roof.

Nonetheless, green roofs also confer a number of private benefits, particularly if they are integrated into the building's systems and overall objectives. Green roofs improve building performance and desirability in ways that may not deliver financial returns directly but translate into higher rents or investment value. Direct financial benefits of green roofs derive principally from energy savings and increased roof membrane durability, as will be further discussed below.

Common Private Benefits

All green roofs provide certain basic private benefits.

- Energy savings (heating and cooling)
- Increased membrane durability
- Noise reduction
- Fire retardation
- Blockage of telecommunication radiation
- Aesthetics

For many building owners, the common private benefits are insufficiently quantified and not immediate enough to justify the additional upfront capital investment in the absence of policy support. The value of many of these benefits, however, accrues over time; the longer the building is held by the owner, the better the return on investment for a green roof.

Design-Specific Private Benefits

When specialized private benefits are incorporated into the green roof design, the business case to justify the higher upfront capital cost can often be made. An important role for a landscape architect or other knowledgeable green roof consultant is to provide clients with solutions to meet their design and financial objectives. For example, the value of a private roof park can be incorporated in higher rental rates or condominium values. Green roofs, if part of a holistic or integrated design process, can have a positive

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[4] Green Roofs for Healthy Cities has developed The Green Roof Tree of Knowledge, an interactive, searchable online database of research summaries addressing technical benefits, materials performance (including plant research), and policies that is free of charge at www.greenroofs.org.

impact by reducing the capital and operational costs of mechanical systems.[5] Additionally, when green roofs are integrated into other aspects of a project, it is much more difficult to eliminate them near the end of the project due to cost overruns. Forms of specialized private benefits include:

- Accessible amenity space—roofparks/golf/product showcase/four-season aesthetic/ etc.
- Solar energy efficiency improvement—synergy with photovoltaics (due to the lower ambient temperatures above the green roof)
- Contributes multiple credits to LEED™ certification
- Increased air conditioning efficiency due to lower ambient temperature of interior air
- Better community acceptance of project—reduces NIMBYism[6]
- Horticultural therapy for hospitals and recovery centers
- Integration with building systems to reduce costs—stormwater management, HVAC, drainage, etc.
- Access to government policy or program support—density bonusing, stormwater fee reduction, grants, faster processing of development applications, etc.
- Improved employee productivity
- Food production and community gardens

Membrane Durability and Energy Efficiency

Green roofs extend the life expectancy of a waterproofing membrane by protecting it from ultraviolet radiation, the stresses of freeze-thaw cycles (expansion and contraction), and operational impacts. This thermal protection is due primarily to the insulating function of the materials placed above the membrane, which is extended to the building itself. Green roofs reduce heat gain in buildings in the summer and, to a lesser extent, reduce heat loss in the winter, resulting in energy savings.

In 2003, the National Research Council of Canada published its findings on the thermal performance and energy efficiency of green roofs in Canada. The Field Roof Facility, located in Ottawa, separated its roof into two equal areas: one was greened while the other was maintained as a reference roof. The study found that the green roof "significantly moderated the heat flow through the roofing system and reduced the average daily energy demand for space conditioning due to the heat flow through the roof in the summer by more than 75%" (Liu and Baskaran, 2003). The following diagrams detail the heat flow and ambient temperature of both roof types.

Table 2. Normalized (per unit area) heat flow through the roof surfaces of test plot, Nov. 22, 2000–Sept. 30, 2002. Source: Liu and Baskaran, 2003

	Reference Roof	Green Roof	Reduction
Heat Gain	19.3 kWh/m^2 (5900 BTU/ft^2)	0.9 kWh/m^2 (270 BTU/ft^2)	95%
Heat Loss	44.1 kWh/m^2 (13500 BTU/ft^2)	32.8 kWh/m^2 (10100 BTU/ft^2)	26%
Total Heat Flow	63.4 kWh/m^2 (19400 BTU/ft^2)	33.7kWh/m^2 (271 BTU/ft^2)	47%

[5] Green Roofs for Healthy Cities has launched the GreenSave Calculator, an online life cycle cost benefit tool, through the Green Roofs for Healthy Cities website (www.greenroofs.org). The Calculator will estimate the financial benefits of a wide range of values, including stormwater, energy, and useable green space, using project-specific values supplied by the user or reference values provided. The Calculator allows for comparisons of the costs and benefits of different roofing systems over their total life cycle and can be used to determine the cost-effectiveness of a green roof project.
[6] The "(N)ot (I)n (M)y (B)ack (Y)ard" anti-development attitude.

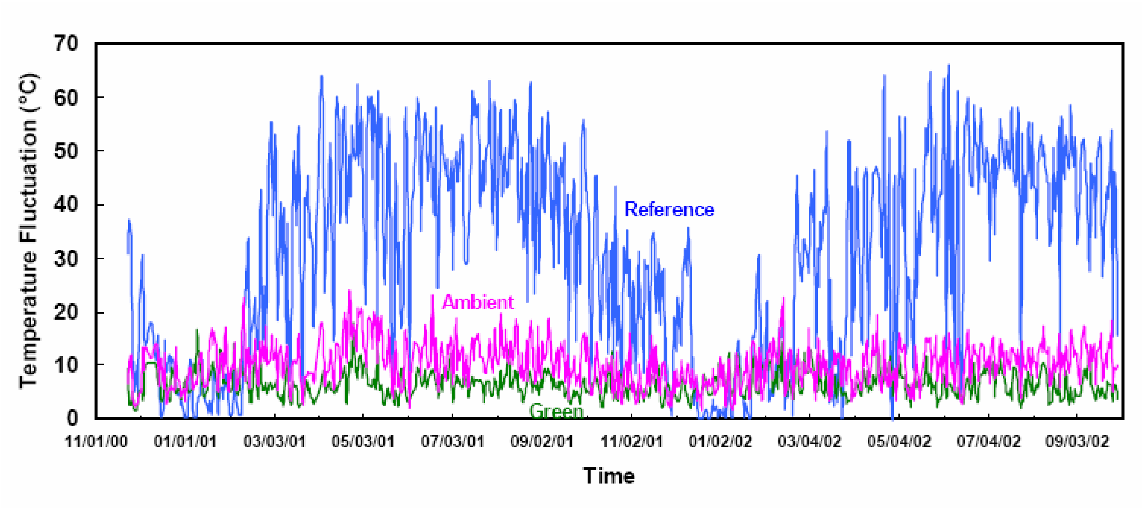

Figure 5. Daily fluctuation of membrane temperature, Nov. 22, 2000–Sept. 30, 2000. Source: Liu and Baskaran, 2003

The following images demonstrate the effect of a green roof on local heating. The conventional bitumen roof and the extensive greened roof differ in the magnitude of in energy absorbed and heat radiated. The greened roof radiates 52.3 percent less, or 1,000 watt hours per square meter (Wh/m^2 or 92.9 Wh/f^2). The greened roof increases energy dissipated via evaporation by 1,062 Wh/m^2 (98.7 Wh/f^2)—9.6 times more energy is dissipated via evaporation on the green roof. The greened roof also increases surface reflection by 321 Wh/m^2 (29.8 Wh/f^2), a 66 percent increase.

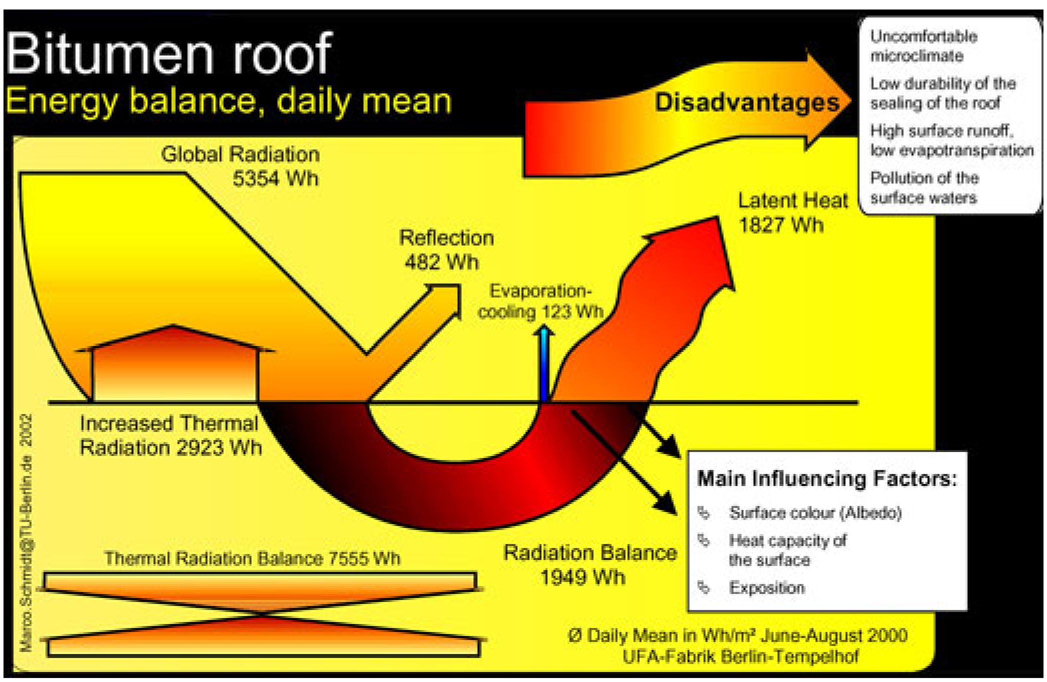

Figure 6. Effect of a bitumen roof on local heating. Image courtesy Marco Schmidt, Berlin University

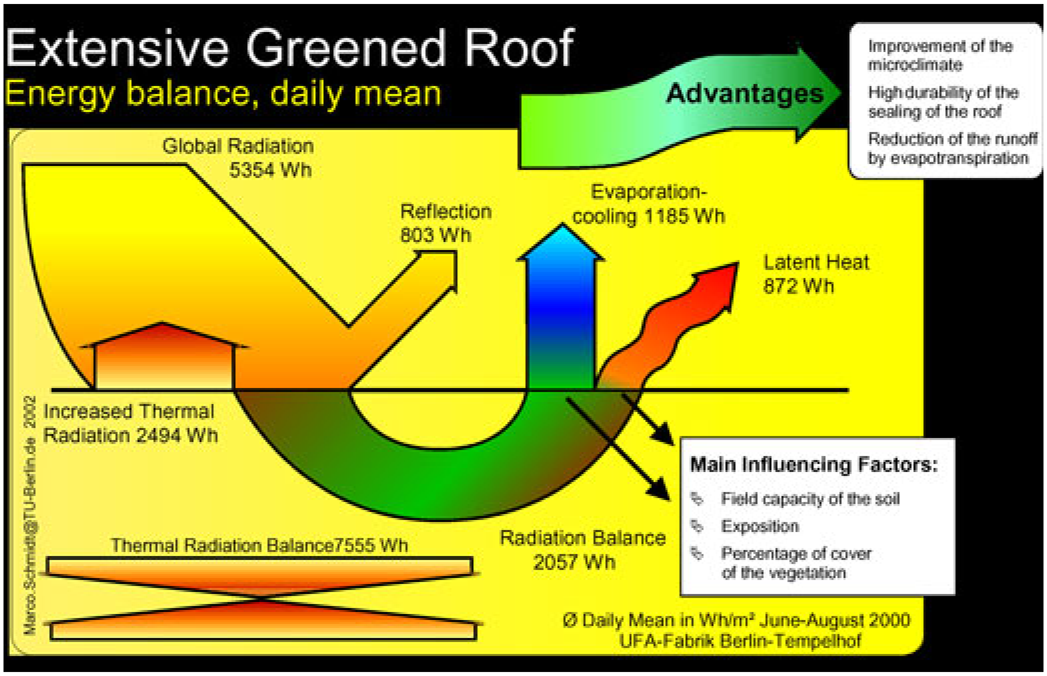

Figure 7. Effect of a green roof on local heating. Image courtesy Marco Schmidt, Berlin University

An example of the potential private benefits of a successful, integrated green roof project is the 901 Cherry Offices for GAP, Inc., designed by William McDonough + Partners in concert with green roof consultants Hargreaves and Associates, Paul Kephardt, and Ove Arup. Located in the hills above San Francisco International Airport, the building blends almost seamlessly into its steeply sloping site, and into the surrounding hills and savannah. The undulating profile of its roofline echoes and responds to the surrounding terrain. But the building's connection to place is more than skin deep: a 69,000 ft^2 green roof, covered in native grasses and wildflowers, re-establishes the indigenous coastal savannah ecosystem atop 195,000 ft^2 of office space.

Figure 8. GAP Headquarters, San Bruno, California.
Courtesy Green Roofs for Healthy Cities and McDonough + Partners

Figure 9. GAP Headquarters interior, San Bruno, California. Courtesy Green Roofs for Healthy Cities and McDonough + Partners

The building benefits from its green roof in the following ways:

- Reduces energy consumption by an estimated $25,000 per year
- With natural daylighting and other measures, 30 percent less consumption than California's strict energy code
- Reduces noise pollution (up to 50 Db) from nearby airport
- Visible green space for employees in several areas of building
- Native plants/wildflowers used on roof to replace building footprint
- Downsized mechanical systems for important savings
- Studies of the roof showed initial costs to be about 130 percent of the conventional base case, net first-costs approximately 185 percent, and the annual operational cost just 70 percent of a conventional roof

Common Public Benefits

Green roofs have much to offer urban environments needing to moderate climate, improve overall environmental quality, minimize stress on stormwater infrastructure, and stimulate the economy. Policy makers can use a variety of tools to leverage private roofing investment and roof space for public good with grants and other incentives. These common benefits will result from virtually any green roof project:

- Stormwater management—quality and quantity
- Reduction of urban heat island (unnatural overheating of cities)
- Noise reduction
- Aesthetics
- Improved air quality—trapping of particulate matter
- Local job creation
- Improved “livability”

Design-Specific Public Benefits

Public benefits can be fine-tuned by specific public policies or programs, such as a requirement for a minimum amount of stormwater retention linked to an incentive like a stormwater feebate.[7]

[7] “Feebate” refers to a rebate on stormwater fees, such as the City of Minneapolis, Minnesota’s Stormwater Utility Fee Credit Program, which reduces the standard Stormwater Utility Fee by 50 to 100 percent when a site improves the quality and/or decreases the quantity of their stormwater runoff.

Other potential design-specific public benefits can include the following:

- Additional accessible green space/community gardens
- Multiple uses of limited spaces/smart growth development
- Biodiversity/habitat creation
- Aesthetics
- Encourage use of local, reused, and recycled material (compost/aggregates/rubber)

Growth of the Green Roof Industry

Data collected in 2006 and 2007 from Green Roofs for Healthy Cities' corporate members indicated significant growth in the industry:

- 2004–2005: Over 72 percent growth in the green roof market in North America
- 2005–2006: Over 25 percent growth in the green roof market in North America

Top ten North American cities, by square footage planted in 2006:

City	State	Total square footage
1. Chicago	Illinois	358,774
2. Washington, DC	District of Columbia	301,751
3. Wildwood Crest	New Jersey	240,000
4. Dulles	Virginia	230,000
5. Kansas City	Missouri	178,008
6. Phoenix	Arizona	168,517
7. Milwaukee	Wisconsin	79,513
8. New York City	New York	67,898
9. Portland	Oregon	64,442
10. Columbus	Ohio	58,025

Improved Stormwater Management

In many communities, stormwater management is a serious problem, resulting in polluted waterways, flooding, erosion, and loss of habitat, recreational, and commercial uses. Green roofs are one way to improve both the quantity and quality of stormwater runoff. They slow the rate of water runoff, typically reducing runoff by 50 percent, thereby limiting the occurrence of floods and Combined Sewer Overflows (CSO).

Recent amendments to the Clean Water Act in the United States require some municipalities and industries to obtain permits from the Environmental Protection Agency (EPA) for stormwater discharge and to reduce discharge volumes by implementing on-site management practices. Green roofs can provide one strategy for meeting EPA's new "Phase I" and "Phase II" National Pollutant Discharge Elimination System (NPDES) Stormwater Program requirements (see also http://cfpub.epa.gov/npdes/).

Green roofs can also improve water quality. The growing medium filters and purifies rainwater to varying degrees depending on the composition of the medium. Conversely, studies have shown that in the short term, green roofs can result in nitrogen/phosphorus loading during the establishment period. The composition of the growing medium is an important determinant of the water quality benefits.

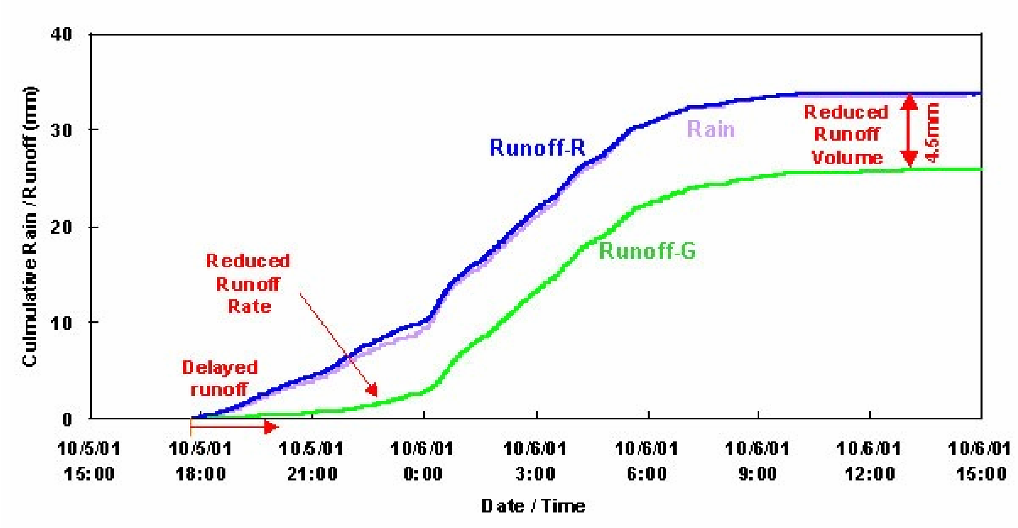

Figure 10. Seven stormwater runoff rates. Source: National Research Council, Institute for Research in Construction

Urban Heat Island Effect Mitigation

The Urban Heat Island (UHI) effect is the localized temperature increase in urban centers associated with the replacement of "natural vegetation with pavements, buildings, and other structures necessary to accommodate growing populations" (Wong 2005). Higher summer temperatures increase demand for air conditioning, thus increasing energy consumption and air pollution, which in turn creates unhealthy living environments. A recent study by Environment Canada scientists in Ontario found that a 1.8 ° F/ 1º C reduction in summer temperature correlates to a 4 percent reduction in the peak load demand for energy.

Green roofs, urban forests, and reflective roofing can all reduce the UHI effect. The Environment Canada study, "Mitigating the Urban Heat Island with Green Roof Infrastructure," found that a 5 percent green roof coverage in the City of Toronto would lower the temperature by 1.7-3.6 ° F/ 1-2 °C.

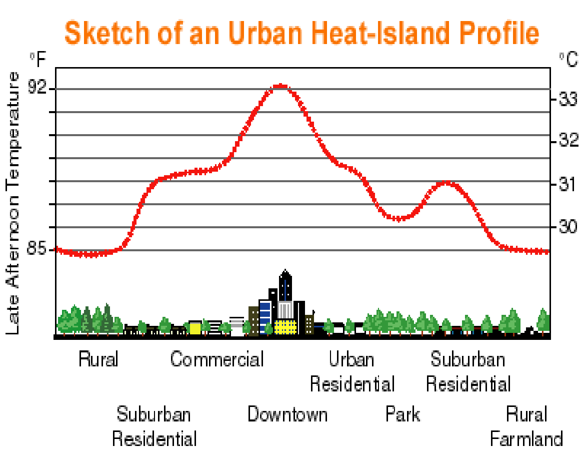

Figure 11. Sketch of an urban heat island profile.
Image courtesy Heat Island Group of Toronto

Biodiversity

Green roofs can provide habitat for a variety of plants, invertebrates, and bird species and can be designed to maximize that potential.[8] In some countries, such as Switzerland and the United Kingdom, biodiversity preservation is helping to drive green roof implementation. By contrast, green roof design and implementation in North America is driven more by concerns about stormwater management; however, stormwater management techniques are protecting local watersheds and so encouraging marine biodiversity.

Figure 12. Varying depth and composition of growing medium allows for greater biodiversity.
Image courtesy Sibylle Erni

Community Food Production

Green roofs can provide new opportunities for urban agriculture and support community gardening. For example, Earth Pledge, a non-profit organization based in New York City, uses its green roof to cultivate vegetables and herbs for its Sustainable Cuisine courses. There are many benefits to growing and distributing food locally:

- Support of the local economy in growing, processing, and distributing
- Increased access to food by everyone and increased food security
- Fresher produce
- Decreased travel time to market and related environmental costs
- Control of soil, fertilizer and pesticides

Green Roofs and Smart Growth

Green roofs are an important strategy for enhancing the livability and ecological function of densely developed environments. Development in the twentieth century has taken the form of low-density sprawl. This pattern has utilized land inefficiently, thereby increasing traffic congestion and straining infrastructure. Furthermore, it has led to the replacement of green space with hard, impermeable surfaces. City officials and urban dwellers are now demanding that cities be redeveloped following the

[8] Green Roofs for Healthy Cities has developed a half-day design workshop focused particularly on green roof design for biodiversity and habitat restoration.

tenets of the “Smart Growth” movement. Promoted by planners and visionaries to counteract urban sprawl and inner-city deterioration, Smart Growth aims to make cities more livable, healthy, and environmentally sustainable. In order to do so, policies, tools, and regulations must to be implemented to encourage denser development and efficiently utilize existing infrastructure (APA, 2002).

Smart Growth brings the following benefits to urban environments:

- Increased amenity and green space
- Conservation of biodiversity through added green space
- Reduced strain on municipal stormwater systems
- Reduction of the urban heat island effect and cooling demand load
- Reduction of community resistance to infill

In their paper *Green Roofs’ Contribution to Smart Growth Implementation*, Peck and Loder (2004) establish four categories of amenities that green roofs can provide:

- **Fully or partly accessible active recreation space:** These green roofs provide space for community gardening, horticultural therapy, children’s playgrounds, sports fields, etc. (Example: Chicago’s Schwab Rehabilitation Hospital).
- **Fully or partly accessible passive recreation space:** These areas attract visitors with gardens, water features, and shaded areas (Examples: Toronto’s Roundhouse Park and Convention Center, Chicago’s Soldier Field).
- **Fully or partly visible and inaccessible:** These areas can be designed to provide four-season aesthetic enjoyment through careful selection of plants or particular design theme (Example: Vancouver Public Library and Chicago’s City Hall).
- **Inaccessible and not visible:** These green roofs provide other “indirect” community benefits, such as habitat for birds and insects, reduction of the urban heat island, and stormwater retention. (Example: the 601 Congress Street Building in Boston).

Green roofs can multiply a city’s available green space, performance of essential ecological services, and offerings for public aesthetic and recreational enjoyment. Coordinated with other Smart Growth tools, green roofs allow urban landscape to combine the benefits of compact development with the benefits of functional green space, both indispensable to true livability.

> *“The challenge of Restorative Environmental Design must be going beyond simply avoiding harm and damage to natural systems to restoring beneficial and satisfying contact between nature and humanity as a basis for people’s physical and mental health.”*
>
> – Stephen R. Kellert, Tweedy Ordway Professor, Yale University

Green roofs are a component of restorative design. Most sustainable, green, or low-impact building design has focused on reducing harm to natural systems and human health by avoiding, minimizing, and mitigating the adverse effects of modern construction and practices. This emphasis on being “eco-efficient” is reflected in the majority of sustainable design guidelines such as the much-acclaimed U.S. Green Building Council’s Leadership in Environmental and Energy Design (LEED) rating system. “Eco-efficient” design methods thus far have reduced the impact of the building industry, but fall short of achieving long-term sustainability.

A truly “eco-effective” approach to sustainable design must accomplish more than simply minimizing man’s harmful impacts on natural systems and human physical health (McDonough and Braungart, 2002). Instead, it must positively affect its environment, drawing on and restoring natural systems. Restorative buildings allow for human interaction with natural systems, which is essential to our physical and mental well-being and health. Buildings need to become not only less damaging and more efficient, but generate a net positive impact over their life cycle, or in other words, be *restorative*. Any green roof can be designed to have limited or no negative effects on the environment. Green roofs, if designed properly, can play a huge role in meeting most of the goals of restorative environmental design, particularly in urban centers. Landscape architects have the potential to play a very broad role in incorporating restorative design features into new and existing buildings.

High performance, restorative buildings should:

- Be competitive over traditional buildings
- Generate clean/green energy
- Manage/clean water
- Conserve resources
- Provide healthy indoor/outdoor environments
- Reconnect people to nature
- Restore biodiversity

Emerging evidence, particularly in the writings of J. Heewagen and Roger S. Ulrich, has linked human functioning and positive contact with the natural environment. Research has demonstrated the following:

- There is a strong relationship between contact with nature and human health. Even passive viewing of nature in hospital rooms has been found to influence the course of recovery from surgery.
- People living in or near parks and other green spaces experience have statistically fewer health problems than people with little or no access to the natural environment.
- Outdoor urban settings with natural amenities attract neighbors and foster stronger social networks.
- The functioning of the human brain is intricately tied to the sensory features and patterns of the natural environment.
- Natural lighting and ventilation in an office can improve the quality of work and reduce stress.
- Views of nature and natural lighting are correlated to improved cognitive performance on tasks requiring concentration and memory.
- Contact with nature can promote a restful state that maintains levels of psycho-physiological activation necessary for complex work.

Table 3. Characteristics of restorative environmental design. From Green Roofs for Healthy Cities Design 101 manual, adapted from Kellert, 2005

Goal	Example(s)	Relevant Green Roof Function
Prospect (An ability to see into the distance)	• Brightness in the field of view (windows, bright walls) • Ability to get to a distant point for a better view • Horizon/Sky imagery (sun, mountains, clouds) • View corridors	Green roofs alter the nature of the urban landscape such that it does not appear to be completely man-made.
Refuge (Enclosure or shelter)	• Canopy effect (lowered ceilings, screening, branch-like forms overhead)	Trees on accessible green roofs may provide a sense of enclosure in what would otherwise be a highly exposed area.
Water	• Glimmer / reflective surface (suggests clean water) • Moving water (also suggests clean, aerated water) • Symbolic forms of water	Water features can be used to display water that would otherwise be considered waste.
Biodiversity	• Varied vegetation indoors and out (large trees, plants, flowers) • Windows designed and placed to incorporate nature views • Outdoor natural areas with rich vegetation and animals	Green roofs designed with various depths of growing medium, plant communities, and branches will foster ecological biodiversity.
Sensory Variability	• Changes and variations in environmental color, temperature, air movement, textures, and light both in different places in the environment and as time of day changes • Natural rhythms and processes (natural ventilation and lighting)	Green roofs introduce greenery and visual texture to areas that were once barren.
Biomimicry	• Designs derived from nature • Use of natural patterns, forms and textures • Fractal characteristics (self similarity at different levels of scale with random variation in key features rather than exact repetition)	Green roofs can be designed to mimic natural communities (e.g. prairies or wet meadows).
Sense of Playfulness	• Incorporation of décor, natural materials, artifacts, objects, spaces whose primary purpose is to delight, surprise and amuse	Green roofs can incorporate the same elements as at-grade landscape, including playgrounds, art, and other design elements.
Enticement	• Discovered complexity • Information richness that encourages exploration • Curvilinear surfaces that gradually open information to view	Depending on their design and function, green roofs can satisfy this characteristic.

Table 3 describes many of the characteristics of restorative environmental design and provides examples of their implementation. These positive effects can result in economic benefits. Research has revealed that improved lighting, heating, and cooling can enhance worker comfort and enhance productivity gains between 6 and 16 percent. Studies have also found that efficient lighting and use of natural daylight can increase work quality, reducing errors and manufacturing defects. Direct and indirect contact with nature has also been found to result in significant stress reduction, leading to substantial cost savings.[9]

These goals need to be established during the pre-design period when the designer assists "the owner in establishing the program, financial and time requirements, and limitations for the project" (AIA, 2001). Restorative design cannot be an afterthought. It requires extensive cooperation across disciplines and a careful integration of building systems.

[9] This research has broad significance for the built environment. More information on designing restorative outdoor environments can be found in the *LATIS Forum on Therapeutic Garden Design* (November 2005) – see especially "Therapeutic Landscapes in the Public Realm: Foundations for Vancouver's Wellness Walkways" (Patrick Mooney and Don Luymes) in that publication.

The Role of the Landscape Architect in a Green Roof Design Team

Green roof technology enhances synergy between landscape and buildings, expanding the very definition of “landscape.” The use of green roofs and green walls offers new opportunities for landscape architects to provide value-added design, implementation, and maintenance solutions as part of a larger team in building design and construction. The landscape architect’s contribution would begin in the early stages of project analysis and building design.

The professions of consultants needed on a green roof team depend on the function of the green roof, the size of the project, the location of the project, and the green roof experience of the primary consultant and/or project instigator.[10] A landscape architect would be involved in a multi-disciplinary team including some or all of the following professionals: a building architect, a structural engineer, a civil engineer, an environmental engineer, a mechanical engineer, a roofing consultant, a growing medium consultant, a horticulturalist/agronomist, a cost estimator, the owner’s testing agent, a general contractor, landscaping contractors, roofing contractors, a leak detection specialist, an irrigation specialist, landscaping maintenance specialists, and representatives of green roof manufacturers and local regulatory bodies.

The landscape architect will be integral to the green roof design and construction, essentially taking responsibility for the components of the green roof above the roofing membrane in the same way the architect takes responsibility for the building components up to the roofing membrane. Landscape architects’ work on the green roof project will begin in the design stages, as they:

- Analyze the site and work on cost estimates
- Design the actual green roof (though large projects will also potentially incorporate a growing medium consultant, a horticulturalist, and various other specialists)
- Choose the appropriate planting method for the project
- Write specifications for the materials and components
- Work on some of the paper work associated with the project (grants, shop drawings, permits, etc.)

As construction approaches, landscape architects may:

- Assume liability for project components designed under contract to the landscape architect
- Be responsible for coordination of the landscape design team
- Review contractor proposals
- Participate in leak detection and waterproofing quality assurance before and after the installation of plants
- Choose, source, and inspect vegetation for the roof and observe that it is (if possible) grown in conditions that approximate those of the roof
- See that the vegetation is cared for if there is a time gap between delivery and installation

Finally, as the project is nearing completion, the landscape architect may be involved in creating the maintenance plan. Maintenance is especially important during the first 2-3 years of the life of the project, as plants become established. After the first 2-3 years, maintenance requirements for extensive green roofs drop off considerably, although intensive and semi-intensive green roofs will continue to require a higher level of care. Initial maintenance is often carried out by the installing contractor, and if continual maintenance is to be contracted out, the landscape architect may be involved in that process as well.

[10] Green Roofs for Healthy Cities worked with a multidisciplinary committee led by Jeffrey L. Bruce, FASLA, president of Jeffrey L. Bruce & Company, to develop a new training course called “Design and Installation 201.” The course covers in detail the roles and responsibilities required in a green roof project.

A specialized practice area, green roof design and construction requires unique knowledge and interdisciplinary understanding.[11] As green roofs become more prevalent, demand will grow for professionals with specialized and sophisticated understanding of green roof design and construction. Accreditation may be one strategy for professionals to distinguish themselves in the marketplace.[12]

[11] Green Roofs for Healthy Cities offers training courses covering essential Green Roof topics: “Design 101 Introductory Course,” “Design and Installation – 201,” “Waterproofing and Drainage – 301.” “Design for Plants and Growing Medium – 401” will be launched in the spring of 2008.

[12] Green Roofs for Healthy Cities will launch an accreditation program for green roof professionals in the spring of 2009. Professionals eligible for accreditation will have the knowledge and skills training to fully understand the complete range of options and best practices associated with each stage of a green roof project.

Green Roof Construction, Components, and Functions

Each green roof is unique and is designed to achieve specific functions and performance results. Still, all green roof systems contain some basic components and require similar steps in the construction process.

These essential steps and features must be included in all green roof projects:

- Determination of structural capacity
- High-quality waterproofing
- Leak detection
- Root repellency
- Drainage system
- Filter cloth
- Growing medium (substrate)
- Vegetation

Other elements, like railings, are optional in that they are not an integral part of every green roof, although they may still be required by code in certain cases. Some common optional elements include the following:

- Insulation
- Membrane protection layer
- Leak detection system
- Erosion protection system
- Pools and ponds
- Irrigation system
- Walkways
- Curbs and borders
- Railings
- Lighting

This section will expand on previous discussions of these components and their functions.

Determination of Structural Capacity

Structural loading capacity is a fundamental design constraint in green roof design. All roofs that are going to be covered with vegetation must have their structural loading capacity calculated by a structural engineer. Structural loading capacity limits a green roof's function and form, from the extent of access to placement of design elements; plant selection; growing medium composition and depth; and strategies for material transportation, installation, replacement, and repair.

There are two kinds of loads that affect green roof design: dead loads and live loads. Dead loads include all permanently placed materials, including those that are a part of, or below, the green roof (e.g., growing medium, plants, gravel, drainage layer, waterproofing, ceiling fans, hardscape, and benches). Live loads are not constant and are affected by things like wind, rain, snow, temporary equipment, and people.

Different areas of any given roof can carry different loads, allowing for variation in design. For example, trees can be point-loaded over structural columns and/or around the perimeter of the roof if the structure permits, while the rest of the roof is covered by sedum plants.

On retrofit projects, where the loading capacity is already determined, creative solutions may be necessary to overcome potential weight restrictions. For example, lightweight forms can be used to create contours. In new construction, however, the structure can be designed to support the weight of the green roof at the outset of the project.

Structural calculations should take into account:

- Plant weight at maturity
- Fully saturated growing medium
- Fully saturated drainage layers
- Weight of all system components
- The need for staging and material loading

High-Quality Waterproofing

Figure 13. Hot-applied rubberized asphalt. Courtesy Jeffrey Bruce, FASLA

Absolutely essential to any green roof assembly is a high-quality waterproofing layer to prevent water from penetrating into the building as well as to facilitate runoff during storms.[13] Although there is considerable debate about the merits of different waterproofing systems, it is best to go with a product that has a proven track record under a green roof assembly. It is also critically important that the integrity of the waterproofing be protected at all times and that it be tested prior to installing green roof components. Installing a green roof over a leaking membrane will result in costly repairs and possible legal action.

[13] Green Roofs for Healthy Cities has developed a course called "Waterproofing and Drainage 301" which focuses on these subjects from the perspective of green roof design and installation.

An Essential Process in Green Roofing: Leak Detection

The waterproofing membrane **must** be tested to ensure that it does not have any leaks. The testing should be carried out under the following circumstances:

- After membrane installation, as close to installation of green roof elements as possible
- After repairs to the membrane and prior to installation of green roof landscaping
- When the membrane is subject to construction stress
- To ensure that an existing waterproofing membrane has no leaks prior to a retrofit project
- After installation of green roof elements, if necessary

There are seven different methods for testing the integrity of the waterproofing membrane: Electric Field Vector Mapping (EFVM), infrared thermal imaging, flood testing, capacitance testing, nuclear testing, low voltage testing, and high voltage testing. Non-destructive testing can be used to locate roof leaks and design errors, thereby reducing the cost of repairs by pinpointing the problem areas before they create further damage—it is cheaper and easier to take up a small part of a green roof for repairs than the entire system. Furthermore, in some situations, an EFVM-type leak detection system may be placed onto the waterproofing layer.

Root Repellency

In the roof assembly, it is important to prevent plant roots from compromising the waterproofing over the long term, particularly when selected species have aggressive root systems. Many waterproofing membranes are made of a carbon-based material, which plants will decompose, while others are naturally root repellent. Root repellent elements can take several forms:

- Impervious concrete, rubber, metal (such as copper), or other material
- Modular
- Waterproofing membranes that have inherent root repellent abilities (example: EPDM rubber).

The German green roof industry's non-profit research and standard-setting body, Forschungsgesellschaft Landschaftsentwicklung Landschafts bau e.V (FLL), has established tests for root repellency (testing the membranes against the most aggressive plants) that may also be cited by manufacturers. No such standards exist in North America at present.

Drainage System

Figure 14. Drainage pipe on membrane.
Courtesy Jeffrey Bruce, FASLA

A drainage system is necessary to facilitate runoff during major storms, prevent the drowning of vegetation, and provide venting for excess water vapor. The drainage system provides the principal mechanism for discharging stormwater when the growing medium is fully saturated. A drainage system may also provide root repellency, insulation, and water storage benefits.

Possible elements for the drainage system include the following:

- Porous mats (example: coconut fiber)
- Granular media (example: polystyrene)
- Rigid drainage (example: specially designed systems made from various plastics)

A wide variety of drains allow water to be transported to pipes and downspouts. Some types of drainage systems allow a certain amount of water to remain on the roof for irrigation purposes. Modular systems may have built-in drainage, while others are designed to retain water for the plants.

Local building codes will specify the amount of drainage required, and calculations should be made by an engineer.

Filter Cloth

The filter cloth prevents fine sediments from the growing medium from accumulating on the layer below, potentially clogging drains. This function may sometimes be performed by the drainage layer. The filter cloth can also enhance the function of other root repellent elements, helping to prevent roots from working their way toward the waterproofing membrane.

The proper functioning of the filter cloth requires care in medium selection. The organic components in the growing medium will naturally break down over time, settling out 2–5% of the entire material by weight. When the growing medium contains too much organic matter, settling in excess of this amount can clog the filter cloth and hamper drainage, thereby jeopardizing plants. What constitutes “too much” organic material is a matter of debate among growing medium experts, but the current “rule of thumb” is: up to 40 percent in arid climates and 10-20 percent in humid climates (Friedrich, 2005). Typical materials for a filter cloth are lightweight, water-resistant, polyester fiber mats or polypropylene-polyethylene mats. They are relatively inexpensive, typically non-woven, non-biodegradable landscape fabric.

Growing Medium (Substrate)

Figure 15. Expanded shale. Courtesy Chuck Friedrich

Growing medium is critical to long-term plant survival, stormwater retention, and thermal mass transfer. It also may provide habitats for birds, mammals, and invertebrates. A number of companies have developed specialized growing media for green roof applications. Growing medium products typically utilize a mixture of organic and inorganic matter, with significantly more inorganic matter in extensive systems. Inorganic matter used includes vermiculite, expanded slate, shale, clay, volcanic rock, coarse sands, pumice stone, zeolite, diatomaceous earth, perlite, and rock wool.

Decisions about growing medium will obviously have a significant impact on factors such as the system's saturated weight, evaporation, drainage capacity, action-exchange, nutrients, wind resistance, and compactability, to name a few. Depending on its composition, growing medium can also provide fire resistance, insulation, and protection of waterproofing. Transportation costs should be considered when selecting a medium.

Vegetation

Figure 17. Vegetation on an intensive roof. Courtesy Green Roofs for Healthy Cities and Walker Macy Landscape Architects

Figure 16. Vegetation on an extensive roof. Courtesy Green Roofs for Healthy Cities and Sanitation District No. 1, Wright, Kentucky

Figure 18. Pre-grown sedums on an extensive roof. Courtesy Green Roofs for Healthy Cities and Intrinsic Landscaping, Inc.

The vegetation is the most visible component of a green roof, and the health of the vegetation will be a client's key indicator of a project's success. As well as the obvious aesthetic benefits, the vegetation layer will largely or exclusively determine how effective the system is for:

- Insulation
- Stormwater management
- Biodiversity protection
- Fire retardation
- Filtering air pollution
- Shading
- Transpiration
- Sequestering CO_2
- Producing oxygen

Ensuring the long term health and growth of the vegetation is a fundamental design, installation, and maintenance objective. After ensuring the soundness of the waterproofing and structure, this task is essential.

Green roof vegetation must be chosen carefully and with special consideration of the rooftop climate. A rooftop environment, particularly one that is above grade, is very different from at-grade environments where plants are placed into the earth. Rooftop environments typically face more solar radiation, more wind, and more heat than traditional landscaping. The often shallow growing medium and dry conditions mean that many plants will simply not survive in a rooftop environment, particularly if the green roof is extensive, significantly above-grade, and there are no plans for ongoing irrigation.

Green roof vegetation can be perennial, biennial, or annual. The plant selection on an intensive system can make use of the whole plant palette within the framework of the particular design and climatic conditions. Plant selection on an extensive system requires careful thought because there is less room for design error. Extensive systems will primarily use perennials that are specially adapted to the conditions of the green roof.

Plant Type	Medium Depth	Green Roof Type
Sedums	1" to 3" +	Extensive
Groundcovers and Grasses	6" to 10"+	Extensive/Intensive
Shrubs	18" to 24"+	Intensive
Large Shrubs and Small Trees	24" to 3' +	Intensive
Trees	3' +	Intensive

Table 4. Depths of growing medium needed to support specific plant types.
Source: Design and Installation – 201 Participant's Manual (Green Roofs for Healthy Cities)

Optional Functions and Components

PLEASE NOTE:

The following features are optional in that they are not an integral part of every green roof. Depending on the design objectives of the project, however, many of these components in fact will not be optional; for example, railings on accessible green roofs may be mandated by safety concerns and building codes.

Insulation

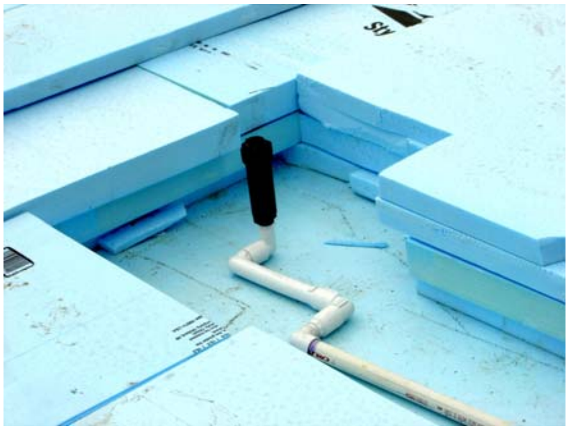

Figure 19. Irrigation inside the insulation layer.
Courtesy Jeffrey Bruce, FASLA

Insulation reduces the transfer of heat to and from the building. It may be placed above or below the waterproofing. It is definitely recommended for green roof assemblies in cold climates, to prevent waste heat from the building below interfering with the plants' ability to adapt to winter conditions.

Membrane Protection Layer

The membrane protection layer is installed to protect the waterproofing membrane from construction stress and from the installation of the drainage layer (if necessary). Typical materials for a membrane protection layer include protective non-woven fabrics, boards, and sheeting that are lightweight and water-resistant.

Leak Detection System (see also text box, pg. 24)

An Electronic Field Vector Mapping (EFVM) system uses electrical flow to pinpoint the location of leaks as small as a pinhole and is used in a 48-hour or longer flood test prior to landscaping installation to ensure quality of waterproofing, particularly on sloped roofs where water tests are impractical. One option, for some types of waterproofing, is to build such a system into the roof so it can be used to locate leaks after vegetation and growing medium have been installed.

Erosion Protection System

An erosion protection system is intended to protect the growing medium from wind erosion while plants become established and is likely to be required on sloped roofs and when wind is a factor. Typical materials for such a system include protective non-woven fabrics, aggregates, photo-degradable protective sheeting, and mulch.

Ponds and Pools

Figure 20. Ponds and pools. Courtesy Green Roofs for Healthy Cities and Conservation Design Forum

Water features such as waterfalls, fountains, and ponds can be incorporated into green roof design. These features will have aesthetic and psychological benefits for the users of the roof. They may also have a stormwater management function.

When constructing these features, separate waterproofing membranes may be used, with the existing drainage system as a backup. Precast fiberglass shells may be used for ponds and as artificial lightweight rocks.

Irrigation System

Irrigation will be required to help plants establish through initial dry periods. Building a more permanent irrigation system into the green roof system will help ensure initial plant survival, as well as the ongoing health of the plants.

Factors such as climate and type of plants selected determine the need for permanent irrigation. Most extensive green roofs are designed to function without an irrigation system after an initial start-up period of one to two years; in these cases, the initial irrigation system may be designed to be temporary. Built-in irrigation systems are more common on intensive green systems; intensive green roofs are often planted with vegetation that requires ongoing irrigation.

There are a wide variety of irrigation systems: overhead or spray, surface or near-surface drip irrigation, capillary irrigation, and base drip or trickle irrigation. In addition to those techniques, water retention mats may also be used to provide additional water for plants, as can drainage systems designed to hold water.

Walkways

Figure 21. Walkways, borders, and railings. Courtesy Green Roofs for Healthy Cities and American Hydrotech

Walkways on green roofs will have many of the same functions as they would in a more traditional landscape design, offering aesthetic benefits, controlling traffic, and preventing people from walking on the plants. They also may function as firebreaks, needed especially in cases where grasses are used in the planting and may be subject to periodic low-temperature burning. In addition to these functions, walkways on a green roof will sometimes be necessary to allow access to various mechanical equipment and other roof-specific features.

Walkways can be constructed using a variety of products such as precast concrete pavers, natural stone, gravel, wood, fiberglass rocks, and recycled plastic decking. Walkways may also be set on pedestals to allow unimpeded drainage beneath them.

Curbs and Borders

Like walkways, curbs and borders will have the same aesthetic function as they would in a traditional landscape design. They may be used to separate vegetation components and to provide a potential fire-break. However, in the context of a green roof, they may also be used to provide protection from wind uplift (particularly in corners) and to separate vegetation areas from structural roof components such as parapet walls, drains, and skylights.

Curbs and borders will use a wide range of options similar to those for walkways, including precast concrete curbs, aluminum edging, timber borders, planter boxes, recycled curb products, and modular systems. Also, like walkways, they may be set on pedestals to allow unimpeded drainage.

Railings

In some green roof contexts, railings are a requirement. They have the obvious function of protecting people on accessible green roofs from falling off the roof, as well as limiting access to parts of the roof, especially to areas which may not, for example, support an intensive green roof system or live loads. Of course, as in any other landscape design, they may also perform an aesthetic function. Fall protection measures must be included in green roof design and implementation in order to protect worker health and safety.

There are a wide range of railing technologies available, the performance of which should be specified in the local building code. In addition to railings that are integrated into the finished design, worker safety anchor systems should also be considered during green roof implementation.

Lighting

Lighting will perform the same functions as in traditional landscape design—providing aesthetic benefits as well as facilitating night time use of a space and enhancing security.

The American Society for Testing and Materials (ASTM) has recently developed a number of standards for green roof performance. These include the following:

- Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems (E2397-05)
- Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems (E2396-05)
- Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems (E2398-05)
- Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems (E2399-05)
- Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems (E2400-06)

In addition, two further standards are under development:

- Standard Guide for Use of Expanded Shale, Clay or Slate (ESCS) as a Mineral Component in Growing Media for Green Roof Systems (WK7319)
- Practice for Assessment of Green Roofs (WK575)

Please check www.astm.org for more information on any of the items listed here or to purchase downloads of the active standards (these standards are listed under Technical Committees/Committee E06/Committee E06.71 on Sustainability).

Conclusion

Inclusion of green roofs in built environments should soon be standard operating procedure. The past three decades in North America have seen a rising interest in mitigating the impact of buildings on their surroundings. Green roof infrastructure has unique potential not only to mitigate that impact, but to bring buildings more into harmony with their surrounding environment. Landscape architects, as planners, designers, managers, and stewards of natural and built environments, are in a unique position to appreciate this opportunity.

Knowledge of green roof technology and benefits is growing, and continued education of both designers and clients will accelerate expanded use of green use technology. The benefits of green roofs are many and varied, with this paper providing only an introduction. Research underway at facilities all over North America will better quantify these benefits. Design professionals interested in green roofs will need to work to keep current on the most up-to-date and accurate information about this remarkable technology and its applications. It is also vital for interested design professionals to educate clients—owners, developers, and planners—about the potential returns on an investment in green roof infrastructure.

Ultimately, it may be possible for green roofs, living walls, and living machines to create a culture of building that not only minimizes impacts on the surrounding environment, but actually enhances and improves that environment—resulting in buildings that “heal the wounds caused by their construction,” as Malcolm Wells once said. Landscape architects, with their unique skills and perspective on the interface between the built and natural environments, have a key role to play in shifting building culture toward a more sustainable future.

Image courtesy www.chicagogreenroofs.org

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Online Resources

www.greenroofs.org Official website of Green Roofs for Healthy Cities, which is developing a professional accreditation program for green roof designers and installers. This website contains intensive information about green roofs, their installation, benefits, and demonstration projects. The resources available include all the issues of the semiannual newsletter *Green Roofs Infrastructure Monitor*, other Green Roofs for Healthy Cities publications, useful websites, and other publications.

www.greenroofs.com Has the directory of Green Resources News, upcoming events, recommended readings, and latest news about green roofs, including projects and research links

www.usgbc.org Official website of United States Green Building Council. This website contains detailed information about LEED™, latest news and events, all the USGBC chapters' websites, industry publications, and links

www.cagbc.ca Official website of Canadian Green Building Council. The website features the most recent green building projects, news, and upcoming events. All information about the building rating system and other resources is included in the website.

www.asla.org Official website of the American Society of Landscape Architects. ASLA provides information about the green roof at the ASLA headquarters building in Washington, D.C., and performance measurements collected through an ongoing monitoring program.

Appendix: About Green Roofs for Healthy Cities

In 1999, Green Roofs for Healthy Cities began as a small network of public and private organizations working to increase the availability of technical information on green roof performance and to raise public awareness of their outstanding economic, social, and environmental benefits. Today, Green Roofs for Healthy Cities North America Inc. (GRHC), is a rapidly growing non-profit industry association, with over 4,000 individual and organizational members who share the dream of a more sustainable future and healthier communities through green roof implementation. GRHC is striving to bring green roof technologies to the forefront of high-performance, restorative green building design, implementation, and maintenance by:

- Researching the private “building focused” and public “community scale” benefits of widespread green roof infrastructure implementation in various cities and climate zones across North America;
- Engaging a wide variety of stakeholders and educating the general public on the many benefits of green roof infrastructure;
- Establishing cost-effective public policies to recognize the public benefits and fund the widespread implementation of public and private green roofs, thereby helping to reduce the higher upfront capital costs;
- Developing professional training courses to facilitate excellence in green roof design, implementation, and maintenance, which will contribute to the *Accredited Green Roof Professional* designation program;
- Facilitating the international exchange of information on policies, products, science, and research.

To achieve these goals, Green Roofs for Healthy Cities:

- Is developing the *Accredited Green Roof Professional Designation Program*, to be launched in 2009;
- Develops Best Management Practices through the Training Committee;
- Delivers cutting-edge courses and workshops across North America;
- Provides information on green roofs to the public through the media and at trade shows;
- Hosts the *Green Roofs Tree of Knowledge*, an online searchable database on research and policy related to green roof infrastructure;
- Hosts the *GreenSave Calculator,* an online *Life-Cycle Benefit Tool*, which enables comparison of up to three roofing alternatives over a specific time period to determine which has the lowest life-cycle cost;
- Hosts an online searchable membership database;
- Publishes the semi-annual *Green Roof Infrastructure Monitor*™*;*
- Profiles its Corporate and Individual Members and works to raise the profile of its non-profit and government members;
- Publishes an annual *Membership Directory;*
- Organizes the *Annual International Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show*;
- Publishes CD-ROMs of conference proceedings;
- Runs the *Green Roof Awards of Excellence* to celebrate the most integrative green roof projects in North America and to recognize excellence in research and leadership in policy development;

- Promotes the development of supportive green roof public policies through our Local Market Development Program in partnership with local governments and other local stakeholders;
- Advocates for green roof policy program support with state, provincial, and federal governments;
- Coordinates and promotes comprehensive approaches to green roof research and cost-benefit analysis at the local government level;
- Provides assistance to policy makers in the development of programs and policies that support green roof investment;
- Facilitates the development of green roof demonstration and research projects to support the introduction of incentives;
- Establishes positive working relationships with related professional associations in North America and internationally;
- Facilitates business-to-business networking and joint ventures.

Additional information and event announcements are continually added to the website www.greenroofs.org.

Green Roof Infrastructure

Part II: The Practice of Green Roof Design

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Designing Green Roofs: A Landscape Architect's Perspective[1]

The Rise of Green Roof Design

Landscape architects exploring green roof design are finding a wide field of opportunity. Green roofs are a world apart from traditional rooftop gardens, which consist of planters perched on a complete conventional roofing system. In contrast, green roofs are an integrated roofing/waterproofing system offering enhanced environmental, aesthetic, and even economic benefits over traditional roofing alternatives. Green roof systems, originally a German technology, have evolved over the past 40 years and are now widely used in many locations in the United States.

In the past decade, green roofs have become an important new frontier in North American landscape architecture practice. Several factors have led to this phenomenon:

- **Role in Green Building Movement.** The green building and ecological design movement in general has promoted green roofs as one of the most effective multiple-benefit building practices available. This is recognized in the most widely applied green building benchmark, the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) rating system. Several points in the system can be addressed with integrated green roof design, including stormwater management, urban heat island effect, and ecosystem restoration.

- **Financial Incentives.** There are a variety of public and private grants available to help defray some of the initial extra costs associated with green roofs over conventional roofing. Watershed organizations, the EPA, and local and regional municipal governments have all supported green roofs with funding.

- **Stormwater Regulations.** Requirements for sustainable stormwater management have led to regulations and policies that encourage or even require green roofs under certain conditions.

- **Growing Familiarity.** As green roof applications have become more widespread and familiar to more people, they generally have more acceptance and appeal.

A "Green Technology"

Green roofs are increasingly used to integrate a building into its natural surroundings visually as well as ecologically. All green roofs provide ecological benefits that their conventional counterparts do not, including reduced energy use for building heating and cooling, improved air quality, reduction of urban heat island effect, and stormwater management. Because of a growing reputation as a "green technology," green roofs are often designed to maximize ecological benefits, primarily habitat creation and resource conservation. Green roofs may be designed with some or all of the following goals in mind:

- Use plants that are native or adapted to the local climate.
- Maximize diversity of plant species and structure.
- Optimize the use of rainwater for plant life.
- Retain rainwater on the roof to the extent possible; surplus rainwater can be stored and reused for irrigation and other purposes.
- Coordinate the green roof's stormwater function with elements elsewhere on the site like porous pavement, bioswales, and rain gardens.

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[1] David Yocca, ASLA, of the Illinois firm Conservation Design Forum, contributed significantly to this section.

- Create habitat for desired wildlife (primarily birds and insects).
- Select materials and design elements to evoke the character of local ecosystems.
- Establish a program for monitoring the roof's performance to contribute to the growing body of green roof research.

Often, however, a green roof design program is centered on creating a specific aesthetic or programmatic experience for the user/visitor. Such designs may feature exotic plants and materials, supplemental water use, and other departures from a strictly ecological program, while still providing many core environmental benefits.

Cost Considerations

When marketing green roofs to potential clients, cost is always an issue. It is important to distinguish between up-front costs and life cycle costs.[2] Typical costs for green roofs range from approximately $12 to $25 or more per square foot (as compared to $2 to $10 per square foot for conventional roofs), depending on the type of green roof system, building design, size, and accessibility. As explained in Part I of this report, installation and maintenance costs can be offset by reduced roof replacement expenditures, reduced stormwater detention needs, and building energy cost savings. Greater potential economic benefits can result from the integration of green roofs in a way that increases the livability of the space. For example, new residential buildings in Portland, Oregon; Chicago, Ilinois; Grand Rapids, Michigan; New York, New York; and many other cities offer access to a green rooftop terrace as an amenity to fuel sales and unit price premiums.

Maintenance Considerations

It is essential to budget and design for ongoing maintenance for a green roof. The water-impermeable roof membrane requires regular inspection, as do drainage flow paths. Green roof plants also require regular maintenance, as do all living systems. The client's budget for maintenance and concern about the possible need for repairs will influence a green roof's design.

The growing medium and plant cover of a green roof will provide a degree of protection from environmental stresses to the waterproofing membrane. A correctly installed waterproofing membrane will therefore very rarely develop a leak within the time span covered by the product warranty, with the exception of areas around flashings and penetrations. It is therefore good practice to leave a vegetation-free zone around flashings and penetrations, making access and cost of repairs comparable with conventional roofing systems. Modular green roof systems ensure access to the membrane with minimal disruption to the plantings, and are a good choice if ensuring this access is a primary concern. Leak detection systems can also expedite and simplify response to problems should they develop.

For green roof plants, proper root establishment in the first few years following installation requires regular attention, including weeding and some level of watering, depending upon time of installation. Once established, a basic drought-tolerant sedum roof requires minimal maintenance, primarily occasional weeding, and no supplemental irrigation. Maintenance requirements increase with the complexity and programs for the roof garden design.

Versatility of Green Roof Design

As green roofs gain increasing presence in the landscape, their forms illustrate the flexibility and potential complexity of green roof design. Green roofs are appropriate for new and retrofit buildings at many scales, from small sheds, garages, and homes to large warehouses and

[2] A new web-enabled tool, the GreenSave Calculator, allows designers to compare the economics of up to three roofing systems (see www.greenroofs.org).

residential complexes. Green roofs can function simply as an alternative roofing material or can be fully integrated into the building design to maximize ecological and aesthetic benefits.

Green roofs that are designed as an integral building element can more fully articulate a design program, further boosting a building's environmental performance or creating accessible garden space to benefit building tenants. Among the most significant variables driving green roof design is the load-bearing capacity of the roof and the spatial distribution of that load-bearing capacity. In new construction, the roof's structural support may be engineered to enable a specific green roof design program. In a retrofit, the roof's load-bearing capacity is a fundamental design constraint. Still, for each weight category, alternative green roof systems and designs support multiple alternative design goals and infinite design visions.

The project profiles to follow feature a broad scope of recent ASLA and Green Roofs for Healthy Cities (GRHC) award-winning North American green roof designs. Each roof is a design team's unique response to a project's parameters and design program. Together, these projects demonstrate how green roofs improve the built environment for human habitation in abundant and critical ways, improving environmental quality, expanding available open space and access to the outdoors, creating new vantage points, integrating built and natural landscape features, and multiplying the range of human experiences that can be provided by place.

Project Profiles

The following project descriptions are adapted from the Green Roofs for Healthy Cities green roof award galleries from the years 2003–2007,[3] with the exception of the description of the Chicago City Hall, a 2002 winner of an ASLA Award of Merit, Design Category. ASLA Award-winning projects are works of landscape architecture distinguished by groundbreaking vision and exceptional execution. GRHC award winning projects recognize outstanding projects that integrate green roof design with a building, its occupants, and the surrounding community.

Project: Chicago City Hall
Chicago, Illinois

Primary Project Goals: Research and demonstrate performance of green roof technology; create visual amenity

ASLA Award Winner, 2002
Award Category: Award of Merit – Design
Landscape Architect and Ecological Consultant:
Conservation Design Forum
Green Roof Consultant: Atelier Dreiseitl
Architect: William McDonough + Partners
Owner: City of Chicago
Size: 30,000 s.f. (approx.)
Estimated cost: $13.30/sq. ft. (not including structural work)

Figure 1. Chicago City Hall. Image courtesy ASLA

Centrally located in downtown Chicago, City Hall is one of the most visible and recognized structures in the city. The primary purpose of the City Hall Green Roof Pilot Project is to provide a green roof demonstration that serves to facilitate research and educational outreach within the context of a midwestern climate. Under Mayor Richard M. Daley's direction, the City of Chicago's Department of Environment initiated this project as a pilot for an aggressive city-wide initiative to promote green roof construction.

Completed in 2001, the rooftop garden was designed to test different types of green roof systems, heating and cooling benefits, success rates of native and non-native vegetation, and reductions in rainwater runoff. The three systems integrated into the design include lightweight soils at 4, 6, and 18" in depth. These varying green roof systems are recognized respectively as extensive, semi-intensive, and intensive green roofs. Soils were fabricated using lightweight soil mixture guidelines developed in Germany over the previous 20 years.

Although the rooftop is not normally accessible to the public, it is visually accessible from 33 taller buildings in the area. The design form is intended to be read from these various vantage points. The plantings are organized in a sunburst pattern, which respects the symmetry of the historic City Hall and provides a format for arranging groups of plants over the three different roof systems. Though green roofs are typically planted with only sedums and low grasses, the

[3] Expanded descriptions of these and other award-winning green roof projects can be found on the Green Roofs for Healthy Cities website, www.greenroofs.org.

planting palette has been expanded significantly to accommodate research related to the viability of more than 100 species of plants.

The variety of plants includes native prairie and woodland grasses and forbs, hardy ornamental perennials and grasses, several species of native and ornamental shrubs, and two varieties of trees. Plants are organized by bloom color. As the season progresses from spring through fall, plants bloom across the sunburst pattern. The radiating bands of floral color are segregated by similar bands of grasses. The long bands provide opportunities for the same plant material to be applied over various depths of soil, ranges of slope, and drainage patterns.

Since City Hall's flat roof is over 100 years old, previous layers of waterproofing were left in place and a new liner water proofing system was installed. The relatively flat roof surface had gently sloping drainage lines that were left in place. Rectangular skylights (that are no longer used) had been covered and reinforced to increase weight support up to 60 pounds per square foot. The unified undulating ground surface was achieved by installing layers of lightweight insulation boards to elevate the soil layer 12"–24" above the waterproofing layer. Monitoring begun in 2002 has continued, as the rooftop serves as a living laboratory.

Project: Mashantucket Pequot Museum and Research Center
Mashantucket, Connecticut

Primary Project Goals: Visually integrate the building with its surroundings; minimize ecological impact; create attractive and usable roof space; express and interpret cultural values

GRHC Award Winner, 2006: Mashantucket Pequot Museum and Research Center
Award Category: Intensive Institutional
Landscape Architect: Office of Dan Kiley
Architect: Polshek and Partners
Owner: Mashantucket Pequot Tribal Nation
Size: 65,000 sq. ft.
Estimated cost: $25/sq. ft.

Figure 2. Mashantucket Pequot Museum and Research Center. Courtesy Green Roofs for Healthy Cities and Mashantucket Pequot Museum and Research Center.

The Mashantucket Pequot Tribal Nation’s Museum and Research Center was built on the edge of the Great Cedar Swamp, a 500–acre wetland of cultural significance to the tribe. The facility was designed to express and celebrate the tribe’s culture and connection to place. One of the functions of the green roof was to soften the interface of the building and the wooded edge of the surrounding natural terrain.

The 65,000-square-foot intensive green roof is accessible to the public and is used as a gathering place for museum events. The green roof terrace is also used for educational and cultural purposes. Many of the plants incorporated into the terrace gardens are culturally important. Several ethnobotany gardens have been developed to educate students about traditional uses of indigenous plants for food, medicine, and fiber. A root, herb, and berry garden is planned to supply the museum kitchen with local, seasonal foods that will reflect a traditional Native American harvest.

Approximately 12" of growing medium cover the museum’s green roof. Stratified layers of substrate were used to facilitate appropriate/suitable drainage and planting objectives for the green roof. A base of gravel was overlaid with coarse/medium sands. Local topsoil saved from the construction site was redeposited to serve as the principal growing medium.

Because the green roof covers all of the museum's permanent exhibits, waterproofing was very important. The green roof membrane is reinforced hot rubberized asphalt. All of the green roof areas have a double layer of insulation with an underlying water retention mat. Excess water/stormwater is channeled through ducts into a series of retention basins at the edge of the cedar swamp and allowed to rapidly filter back into the wetland.

Maintenance for the museum's green roof is minimal. Terrace maintenance staff recycle and compost grass clippings and use environmentally appropriate fertilizers. The museum terrace has drip irrigation on bushes and timed irrigation on each layer based on growing conditions. Drought-resistant sod is used, and water resistance in the growing media is measured with a potentiometer to determine irrigation cycles.

Project: 10th @ Hoyt Apartments
Portland, Oregon

Primary Project Goals: Manage stormwater; create attractive and usable roof space

GRHC Award Winner, 2006: Koch Landscape Architecture
Award Category: Special Recognition
Landscape Architect: Koch Landscape Architecture
Architect: Ankrom Moisan Associated Architects
Owner: Trammell Crow Residential
Size: 8,500 sq. ft.
Estimated cost: $30/sq. ft.

The courtyard roof design at the 10^{th} @ Hoyt Apartments near downtown Portland demonstrates innovative detention and display of stormwater. Driving the program were city requirements for onsite stormwater mitigation and the desire to provide attractive and engaging outdoor space to residents. The roof's design integrated water features with plant material in raised and at-grade planters. Sand-set paving captures and filters additional rainwater. Seat walls and partially covered formal seating allow for rest and enjoyment of the courtyard.

Figure 3. 10th @ Hoyt Apartments. Courtesy Green Roofs for Healthy Cities and Koch Landscape Architecture

Roofscape rainwater is channeled through three downspouts into pre-cast concrete runnel systems, two of which lead water into shallow detention basins filled with decorative stones. The third runnel fills a concrete cistern, which retains the water and then circulates it through a system of Cor-ten weir boxes penetrated by glass buttons that are lit from within. After several hours, water is slowly released into the city's system, thereby reducing the size of the stormwater interceptor from conventional sizing requirements.

The system has the capacity to hold all the roof rainwater for a 1/8" storm event and detain rainwater for approximately 30 hours, relieving the first storm flow burden into the urban stormwater interceptor system. Koch Landscape Architecture conducted extensive flow studies and calculations to determine flow volume and characteristics. As a result, the courtyard has assumed, and exceeded, the required 20 percent stormwater mitigation function for the project.

The courtyard roof design is enhanced by numerous trees, shrubs, potted plants, and ground covers rooted in 10 to 30" of growing medium. The plant life is supported by a drain mat with 6" of drain rock, a conventional irrigation system, and complemented by borders of clean ¾" black river rock. A W.R. Grace & Company "Procor 75" fluid applied waterproofing membrane covers a post-tension slab. Only simple landscape maintenance and an annual cistern cleaning are required to maintain the system.

Project: Seapointe Village Deck Restoration

Wildwood Crest, New Jersey

Primary Project Goals: Create attractive and usable roof space, retain historic design while improving technical performance

GRHC Award Winner, 2006: Jeffrey L. Bruce & Company, North Kansas City, Missouri
Award Category: Intensive Residential
Structural Engineer: Feld, Kaminetzky, & Cohen, P.C.
Associate Landscape Architect: Edgewater Design LL
Construction Manager: Gilbane Building Company
General Contractor: Merrell & Garaguso, Inc.
Owner: Seapointe Village Master Association
Size: 5.5 acres
Estimated Cost: $8.50–14.50/ sq. ft.

Figure 4. Seapointe Village Deck Restoration. Courtesy Green Roofs for Healthy Cities and Jeffrey L. Bruce & Co.

Seapointe Village is an oceanfront resort community in Wildwood Crest, New Jersey, constructed between 1986 and 1992. In addition to its three condominium towers, 5.5 acres of recreational amenities cover a parking structure. As the parking structure is located below sea level in a runoff- restricted water-quality district, its green roof helps mitigate stormwater impacts, allowing the stormwater management plans to meet local code requirements. However, leaks from this original 70,000-square-foot green roof began to damage the structure and vehicles below, even following 10 years of repair efforts. Studies revealed an accelerating rate of deterioration and potential for collapse well before the normal end of its useful life.

The primary design objective was the installation of a new waterproofing membrane for the plaza deck and parking structure, requiring the removal and reconstruction of all rooftop amenities. The reconstruction plan was to retain the original 1986 Peridian landscape design while complying with new building codes and accessibility requirements of the Americans with Disabilities Act. Designing the new green roof elevations to meet the existing thresholds of the three adjacent condominium structures was exceedingly complex.

The design greatly minimized the opportunities for construction defects by reducing slab penetrations and incorporating redundancy in most system functions, even installing a second membrane under water features and landscaped areas. This involved installing a multi-part hot-applied system ¼ to ½ inch over the concrete applied to both vertical and horizontal surfaces to prevent moisture seepage. A drainage mat and root barrier was installed over the membrane to prevent damage from decorative walkways and from plant material in planters. Irrigation lines do not penetrate the roofing membrane as they, control wires, and electrical service were installed above the topping slab in the decorative concrete pavement. The irrigation system incorporates advanced water management features, such as volumetric water sensors, to control irrigation operations.

The drainage system design used a variety of unique solutions. The growing media systems accept and store surface water for use by the landscape. The growing media on the roof deck are internally drained with percolation rates of between 6" and 15" per hour, resulting in little to no surface runoff. When the growing media reach material field capacity, the system releases excess water into the thin composite drainage boards, and using the slope of the deck, water finds its way into the roof drains. This maximizes water management by storing up to 4" of volumetric water in the growing media profile.

Local native plants were chosen for their summer color, and their ability to minimize maintenance, conserve water, and enhance biodiversity while also adapting in a harsh environment. Three growing media profiles were designed to meet the needs of this site. Being located adjacent to the New Jersey shore required considerable agronomic innovation to ensure sustainability of the landscape under airborne salt and hurricane-strength winds. Innovative application of emerging technologies included lightweight growing media, contoured structural foam, and sand-based sod technology. New soil laboratory testing protocols were designed to evaluate and understand specific agronomic performance of lightweight materials, which cannot be tested by traditional methods. Weight restrictions meant that traditional construction equipment could not be supported, so conveyers, along with motorized concrete buggies, were used to place media on the roof.

The design team has installed a variety of sensors and methods to observe the performance and functionality of the green roof. The data collected will be used to inform future projects.

Project: Millennium Park

Chicago, Illinois

Primary Project Goals: Create new, attractive, and usable open space at street level; expand cultural amenities; improve urban environmental quality

GRHC Award Winner, 2005: Terry Guen Design Associates, Inc., Chicago, Illinois
(Project Landscape Architect)
Award Category: Intensive Industrial/Commercial
Co-Submitted By: Jeffrey L. Bruce & Company
(Irrigation, Great Lawn and Turf Consultant)
Award Category: Intensive Industrial/Commercial
Owner: City of Chicago, Chicago Department of Transportation, Public Building Commission of Chicago
Operator: The City of Chicago, Richard M. Daley, Mayor; The Chicago Park District; Millennium Park Inc., John Bryan, Chair (park donors)
Project Director: Edward K. Uhlir, FAIA
Size: 24.5 acres
Estimated Cost: $480 million

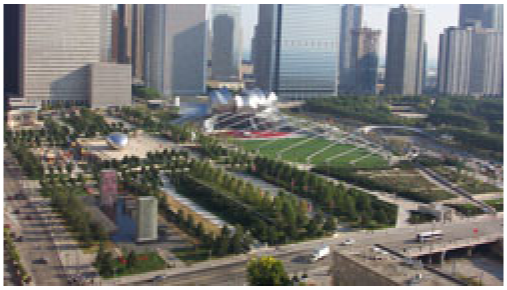

Figure 5. Millennium Park. Courtesy Green Roofs for Healthy Cities and Terry Guen Design Associates, Inc.

At 24.5 acres, Millennium Park is considered to be one of the largest intensive green roof projects in the world. The project was the result of a public-private partnership to transform an unsightly industrial area at the edge of historic Grant Park. The overall project objective was to create a free cultural venue for Chicagoans and tourists, with a focus on providing a new state-of-the-art outdoor music facility. The secondary goal was to remove (or cover) the train terminal, railway lines, and 800-space surface parking lot which occupied this prominent location in downtown Chicago.

Millennium Park holds many works of architecture, fountains, sculpture, and botanic garden spaces, as well as performance facilities, restaurants, and a skating rink. The green roof covers two new subterranean parking garages, a multi-modal transit center including a bridge over the existing railroad lines and station, and a 1,525-seat indoor performance theater. Numerous trees, shrubs, groundcovers, perennials, and annuals, along with growing media, absorb and polish storm water, clean the air, reduce the urban heat island, and provide multiple social, cultural, and economic benefits.

The centerpiece of the park is the Pritzker Pavilion and BP Pedestrian Bridge, constructed of enormous sculptural plates of curvilinear stainless steel. The 4,000-seat pavilion is home to the Grant Park Music Festival, which provides free performances throughout the summer. The pavilion is backdrop to the 7,000-seat Great Lawn: 95,000 square feet of reinforced natural turf, spanned by a grand steel trellis, which holds lighting and a state-of-the-art sound system. Designed for extreme traffic use and recovery through use of emerging turf technology, the Great Lawn includes a layered high performance drainage system.

Because the structural deck was designed to support four feet of growing medium, the park design is not limited by the pattern of the structural columns below. Growing medium for most park areas is a natural, locally available sandy loam or a blended soil based on a local sandy loam mix. The end result is varying profiles of growing media, with sand drainage throughout the project ranging from 8 inches to 4-foot depth.

The entire 24.5-acre deck was waterproofed with a hot-applied rubberized membrane system. Styrofoam fill was used to create landforms, which did not exceed the designed load capacity. Below the green roof, the subterranean parking areas provide direct pedestrian connections to the theatre and restaurants.

Project: 601 Congress Street

Seaport District, Boston, Massachusetts

Primary program goals: Achieve LEED certification; benefit building performance and environmental quality; provide visual amenity for building occupants

GRHC Award Winner, 2006: Sasaki Associates, Inc., Watertown, Massachusetts
Award Category: Intensive Industrial/Commercial
Architect: Skidmore Owings & Merrill, L.L.P
Landscape Contractor: ValleyCrest Landscape Development
Owner: Manulife Financial
Size: 11,000 sq. ft.
Estimated Cost: n/a

Figure 6. 601 Congress Street. Courtesy Green Roofs for Healthy Cities and Sasaki Associates

The intensive green roof at 601 Congress Street is on the 12th floor terrace of a 14-story office building across the harbor from Boston's Logan Airport. One of the building design goals was to achieve LEED certification. The terrace garden was created to be a sustainable design component of the project, as well as an amenity for the occupants.

It was decided for safety reasons that access to the planted area would be restricted to maintenance personnel. However, the terrace provides seating space with views of the surrounding urban landscape and harbor. A glass railing separates the paved terrace from the planted area without obscuring the visual impact of plant forms, colors, and textures, including seasonal changes in appearance.

Soil depth was limited due to structural loading limitations. Allowable depth varies from 6" at the perimeter to about 12" where low points occur in the sloped-roof drainage system. The lightweight soil mix for roof planting was specified as a custom pre-mixed blend composed of 55 percent rotary kiln expanded lightweight aggregate (expanded shale), graded sand, and treated compost derived from cranberry waste.

Drought-tolerant plant materials, including sedums and natural and ornamental grasses, were selected to cover and shade the ground plane. After the plants are established, maintenance is minimal. Annual pruning of the ornamental grasses to a 6" height in the spring, and soil nutrient replenishment once or twice a year via the drip irrigation fertilizer injector system are the only requirements.

A drainage/water storage/aeration system, manufactured by American Hydrotech, was installed over a layer of closed cell extruded polystyrene insulation. The drainage system consisted of lightweight panels of 100 percent recycled polyethylene, molded to form water-retention cups and drainage channels, and engineered to promote irrigation through capillary action and evaporation into the soil/vegetation layer.

The structural concrete roof slab was waterproofed with a hot, fluid-applied, rubberized asphalt monolithic membrane. The membrane was applied in two coats, with a layer of fabric reinforcement between layers. Hydrotech calculations indicate that approximately 70 percent of rainfall water is retained by the planting soil and drainage mat assembly. The retained water is taken up by plant root systems, reducing the need for irrigation.

Although there is no quantitative data available, it is clear that drainage, soil, and planting layers provide additional buffering of noise from planes passing overhead. Other benefits provided by the green roof include: reduction in the urban heat island effect; reduction in glare from the roof; decrease in energy costs; creation of habitat for birds, butterflies, and insect species; and improvement of air quality by reducing CO_2 levels, increasing oxygen output, and filtering and binding airborne dust and other particles.

Project: Phillips Eco-Enterprise Center (PEEC)
Minneapolis, Minnesota

Primary Project Goals: Demonstrate and research benefits to roof longevity and environmental quality; educate visitors about regional ecological identity and history

GRHC Award Winner, 2006: The Kestrel Design Group, Inc., Minneapolis, Minnesota
Award Category: Extensive Industrial/Commercial
Architect: LHB Architects
Owner: The Green Institute
Size: 4,000 sq. ft.
Estimated cost: $21.55/sq. ft.

Figure 7. Phillips Eco-Enterprise Center. Courtesy Green Roofs for Healthy Cities and The Kestrel Design Group, Inc.

The Phillips Eco-Enterprise Center (PEEC) in Minneapolis was constructed to serve as a model for comprehensive sustainable green building design. The PEEC's 4,000-square-foot extensive green roof provides the opportunity to both demonstrate and research the benefits of green roofs, including effects of the green roof on stormwater runoff, lifespan of roofing membrane, and temperature directly above the roof. The project also monitors establishment rate and survival of 18 native and 11 European green roof species in a Minnesota extensive green roof environment. The green roof's deck and seating area, constructed from recycled plastic, provide open space accessible to employees and visitors to the building. The roof was also designed to draw public attention from the adjacent elevated light rail transit line as well as provide educational opportunities.

To maximize regional identity and plant and animal biodiversity while minimizing maintenance requirements, a local native plant community, the Minnesota Bedrock Bluff Prairie, was used as a template to inform planting design. Bedrock bluff prairies are similar to many extensive green roofs in that they have shallow soil profiles and are exposed to considerable heat, drought, and wind. The same characteristics that help bedrock bluff prairie plants survive in their harsh natural environment were expected to help them thrive in the green roof environment. As the number of bedrock bluff prairies found on the Mississippi River Bluffs has greatly decreased, the PEEC green roof aims to provide an analog of this lost habitat within the Mississippi River watershed.

The PEEC planting design also called for traditional European green roof plants to be planted in swale-like depressions with 2" of growing medium, and oriented in the four cardinal directions. The roof design does not include an irrigation system. Sprinklers were used during the initial plant establishment period. Maintenance requirements include weeding and watering only during periods of extreme drought.

Accessible to the public and also visible from the adjacent elevated light rail transit line, the planting design targets both close-up viewing as well as quick glances from a distance. The orientation of the European species in the geometry of the four cardinal directions provides cues for guides leading tours of the green roof to begin their presentations, beginning with the relationship of the green roof to its context within its community. Wave-like groupings of one wildflower and one grass species in each group of native bedrock bluff prairie plants create concentrated masses of color and grasses waving in the wind, offering bold, dynamic, and ever-changing views.

Project: Ducks Unlimited National Headquarters and Oak Hammock Marsh Interpretive Centre

Winnipeg, Manitoba

Primary Project Goals: Provide rooftop habitat for native plants and wildlife and views of the surrounding landscape; mitigate the visual impact of the building

GRHC Award Winner, 2003: Number Ten Architectural Group, Project Architect
Award Category: New Intensive
Hilderman Thomas Frank, Cram & Associates, Landscape Design
Crosier Kilgourand Partners, Structural Engineers
MCW Consultants, Mechanical Engineers
AGE Engineering, Electrical Engineers
UMA Engineering, Civil Engineers
Size: 28,190 sq. ft.
Estimated Cost: n/a

Figure 8. Ducks Unlimited National Headquarters. Courtesy Green Roofs for Healthy Cities and Number Ten Architectural Group.

This building is home to the national headquarters of Ducks Unlimited, a non-profit organization dedicated to the conservation of waterfowl. Located on the edge of the Oak Hammock Marsh, an internationally designated wetland in southern Manitoba, the building was completed in 1992 and is home to the Oak Hammock Marsh Interpretive Centre. The Centre welcomes more than 200,000 visitors a year and provides education about wetlands and their preservation.

The 54,000-square-foot, two story concrete frame building is designed to blend seamlessly into its marsh and prairie surroundings through the use of two green roofs totaling 28,190 square feet. The design objectives were to reduce the visual impact from a “birds-eye” view, create maximum opportunities for observation of the marsh, and provide habitat. The green roof features include 16" of growing medium, wire mesh for rodent control, a two-ply SBS Soprema membrane system, high and low level drains, filter cloth on a granular drainage layer, and rigid insulation. A wide variety of native prairie grasses and flowers were planted including little bluestem, long headed coneflower, and western wheatgrass. Isolated sections of the green roof are home to numerous birds, such as piping plovers, as well as a few ground squirrels. The soil depth of the green roof and berming on the sides of the building eliminate the need for a chiller. Every three years, the prairie grasses are re-propagated through a controlled burn on the upper roof.

Project: Ford Dearborn Truck Assembly Plant
Dearborn, Michigan

Primary Project Goals: Benefit building performance and environmental quality, primarily through stormwater management and habitat creation; demonstrate sustainable design to visitors

GRHC Award Winner, 2004: William McDonough Partners, ARCADIS
Award Category: Extensive Industrial Commercial
Construction Manager: Walbridge Aldinger
Research Support: Michigan State University, Department of Crop & Soil Science and Department of Horticulture
U.S. Green Roof Consultant: Xero Flor America
Stormwater Consultant: Cahill Associates
Roof Membrane Installer: Christen, Detroit
Vegetation Consultant: Wildtype Native Plants
Vegetation Suppliers: Xero Flor America, LLC; Hortech, Inc.; and Walters Gardens, Inc.
Client/Owner: Ford Motor Company
Size: 454,000 sq. ft.
Cost: n/a

Figure 9. Ford Dearborn Truck Assembly Plant. Courtesy Green Roofs for Healthy Cities and William McDonough Partners, ARCADIS

At 454,000 square feet, (over 10 acres), the green roof atop Ford's truck assembly plant is one of the world's largest. The green roof is a part of a comprehensive effort to revitalize the historic Ford Rouge Center complex as a model for twenty-first century sustainable manufacturing. It is a significant component of a site-wide 600-acre stormwater management system. Other design objectives include the establishment of habitat at roof level, reduction in ambient temperatures, and protection of the roof membrane. The roof is key to Ford's visitor education program, highlighting environmentally beneficial site and building strategies.

A lightweight, easy to install Xero flor system was chosen. Lightness was a factor due to the 50-foot structural spans. Ease of installation was a necessity due to the complications of the roof size (requiring a crane and large staging areas) and the need to coordinate with remaining construction.

Researchers at Michigan State University tested a variety of plants under different soil depths and growing conditions. A mix of nine sedum varieties was specifically created to thrive in the upper Midwest climate. A growing medium of approximately 1" depth was used, consisting of 7–9 mm of porous stone, sand, and organic material with a total saturated weight of <10 pounds/square foot. This calculation includes a mineral wool fleece material that absorbs rainwater. Roots penetrate this water-retention layer.

The drainage layer is manufactured by Colbond and is a 3/4" thick nylon mesh with a geotextile fabric bonded to one side. The 100 percent recyclable nylon filaments are installed face down, creating an airspace through which drainage occurs. The rigidity of the mesh prevents its collapse and allows water to flow unimpeded. Another layer of this material, placed in an inverted position, serves as the vegetation carrier. When used as the medium/vegetation carrier, the spaces between the filaments contain planting medium. Seed and cuttings are then applied to the surface. The vegetation was pre-cultivated on the ground for over 12 weeks, after which the carrier and vegetation were cut into 3.28' x 6.56' pieces, palletized, and transported to the roof by crane.

An irrigation system was installed with the intent that it be used only while the vegetation acclimates and becomes established. The system is installed above the green roof surface. An organic liquid fertilizer was applied once during the initial year via the sprinkler system.

Waterproofing was provided by Siplast and consists of two layers, a modified bitumen product and a cap sheet made of a non-woven polyester mat, impregnated and coated with SBS-modified bitumen and a root-inhibiting agent. Xero Flor also supplied a 20-mm high-density polyethylene sheet to provide an additional root barrier above the membrane.

Current predictions anticipate a 7 percent decrease in energy use due to the green roof. Membrane life is expected to double from 25 to 50 years. It is anticipated that the green roof will also retain 447,000 gallons of water per year, amounting to 50 percent of the annual rainfall in Wayne County over the green roof area, or approximately one gallon/square foot/year. Ford identified this function as a savings due to the avoidance of a water treatment facility anticipated under new EPA regulations. Excess rainwater travels through a series of swales and wetland ponds, where it undergoes natural treatment before returning to the Rouge River.

A principal goal of the revitalization project was to attract wildlife (primarily birds and insects) back to the Ford site, which over its 90-year history had been denuded of vegetation. Dr. H.J. Liesecke of the FLL in Germany concluded that the green roof would provide 25 percent of the productive habitat of an undisturbed green site. The assembly plant's roof is also expected to improve air quality above the roof by 40 percent, in terms of dust absorption and the decomposition of hydrocarbons.

The proximity of the green roof to the Visitor Center's observation tower was a primary design consideration, and the plant's air houses, substations, and other rooftop elements were organized to present an orderly arrangement that framed the planted area. Ford has also established an apiary on the Visitor Center site adjacent to the Truck Assembly Plant. Honey produced by the bees is being collected and bottled. Honeybees have been identified gathering nectar from the sedum blossoms.

Project: The Church of Jesus Christ of Latter-Day Saints Convention Center

Salt Lake City, Utah

Primary Project Goals: Visually integrate the building with its surroundings; create outdoor public gathering space.

GRHC Award Winner, 2003: Olin Partnership, Landscape Architect
Award Category: New Combination
Owner: Church of Jesus Christ of Latter-Day Saints
Architect: Simmer Gunsel Frasca Partnership
Structural Engineers: KPFF
Theater Consultants: Auerbach + Associates
Size: 8+ acres
Cost: n/a

Figure 10. The Church of Jesus Christ of Latter-Day Saints Convention Center. Courtesy Green Roofs for Healthy Cities) and Olin Partnership

This 1.1-million-square-foot conference center, located in Salt Lake City, was completed in 2000. Design objectives were to integrate the building into the landscape of the Wasatch and Oquirrh mountain ranges, and to create a building that did not overwhelm the adjacent Mormon Temple. The roof is multi-leveled and over eight acres in size. The design includes planted terraces that step up 65 feet to roof gardens of firs, pines, and a meadow. The meadow planting involved more than a thousand volunteers who carried native plants up to the roof bucket-brigade style.

The green roof system includes a Hydrotech membrane and drainage mat, and geotextile filter fabric. The growing medium is composed of expanded aggregate and organic matter, with a depth that ranges from 2 inches to 4 feet. Coniferous trees such as Douglas fir and bristlecone pine are placed along free-standing walls anchored to the roof structure to accommodate the soil depths. The roof absorbs vast quantities of rainwater, lowering the peak rate of runoff for the site, and eliminates the extremes of air conditioning for an assembly hall of this size. The roof's vast expanse of meadows, firs, pines, and aspens creates an urban oasis and functions as a gathering point for the congregation.

Project: Life Expression Wellness Center

Sugar Loaf, Pennsylvania

Primary Project Goals: Express the building occupant's ecological ethic; visually integrate the building with its surroundings; enhance the building's aesthetics

GRHC Award Winner, 2004: Roofscapes, Inc.
Award Category: Extensive Institutional
Architect: Van Der Ryn Architects, Sausalito, California
Green Roof Installer: David Brothers Landscape Services, Worcester, Pennsylvania
Waterproofing Provider: Sarnafil, Inc., Canton, Massachusetts
Waterproofing Installer: Houck Services, Harrisburg, Pennsylvania
Owner: Ron and Joanne Gallagher
Size: 6,000 sq. ft.
Cost: n/a

Figure 11. Life Expression Wellness Center. Courtesy Green Roofs for Healthy Cities and Roofscapes, Inc.

In June 2001, a new holistic wellness center in central Pennsylvania installed a 6,000-square-foot Roofmeadow® green roof, an integral part of the center's architects' green building concept. The green roof was engineered by Roofscapes, Inc., as a 5-inch Roofmeadow® Type I: Flower Carpet system to satisfy the unusual deadload capacity and pitch of the roof as designed and the maintenance and aesthetic requirements of the architects and owner. The engineering challenges in this project were many: stabilizing vegetation on the steep slope, with deck pitches ranging from 14 to 30 degrees; detecting leaks on this sloped surface; protecting new plantings from severe mountain wind scour; and securing waterproofing at the gapped fascia.

The Wellness Center ranks among the steepest-pitched green roofs in North America. Several processes were used to achieve slope and dimensional stability for the vegetated cover. These techniques included the use of roof battens, slope restraint panels, and reinforcing mesh.

To protect the roof from wind erosion until the plants were established, the surface of the media was covered with a photo-degradable wind blanket mesh, fastened securely to the base of the green roof profile. The mesh has since disappeared into the cover vegetation.

Because the slopes make flood-testing the roof impossible, the green roof system is optimized for electric leak survey methods by using Sarnafil G-476 reinforced 80 mil single-ply PVC waterproofing membrane in a conventional configuration. The Electric Field Vector Mapping (EFVM) technique evaluates the water-tightness of waterproofing membranes without flooding and without disturbing vegetated cover systems.

The lightweight medium was engineered to absorb and retain rainfall while remaining fully drained, fulfilling the German FLL guidelines. Water drains freely by gravity due to the steeply-pitched roof. To create a curtain-like effect during rainfalls, the runoff is permitted to sheet off the roof along the length of the eaves. This was accomplished by gapping the fascia by half an inch. With the vegetation now mature, the rainfall escapes through the fascia and then drips down the tendrils of the overhanging plants. The vegetated cover reduces the rate and quantity of runoff, and also prolongs the duration of runoff, emphasizing the curtain effect.

Ninety-five percent of the plants are flowering sedum varieties from the classic German “green carpet” suite, providing a wide range of color. This drought-tolerant plant suite was selected to create a dense and uniform low groundcover. The cover was established from plugs installed on 12-inch centers, and was mature after 12 months. Weed pressure after the cover became established has been minimal. This resilience is a direct result of the xeric conditions on the roof, coupled with the dense groundcover. The roof requires minimal maintenance—typically a light spring and fall weeding.

The overall result of the green roof design has been to convert the building into a living structure that remains stable without active intervention and blends seamlessly into the surrounding landscape. It has attracted eco-conscious visitors from great distances, and is an example of a genre of green roof that can fit comfortably into suburban and rural developments.

Project: Feldman Residence

Santa Lucia Preserve, Carmel, California

Primary Project Goals: Visually integrate the building with its surroundings; create habitat; create attractive and usable open space; benefit building performance and environmental quality

GRHC Award Winner, 2007: Rana Creek
Award Category: Extensive Residential
Architect: Feldman Architecture, San Francisco, California
Landscape Architect: Blasen Landscape Architecture, Sausalito, California
Client: Dan & Sandy Feldman, Palo Alto, California
Size: 4,250 sq. ft.
Cost: $21/sq. ft.

Figure 12. Feldman Residence. Courtesy Green Roofs for Healthy Cities and Rana Creek.

This newly constructed residence was designed to integrate itself back into the land at the private Santa Lucia Preserve in Carmel, California, which integrates low-density residential development with conservation. Design goals included low water use, solar power, and habitat enhancement. Green roofs cover three small buildings built into a hillside, with the hill seamlessly continuing onto the roofs. Plant material for the roofs consists mostly of locally adapted, indigenous plants already found thriving onsite prior to building. The focus was on stabilizing all disturbed soils by planting grasses and forb mixes approved for the Santa Lucia Preserve, controlling non-native species, and simply allowing natural regeneration of the local plant assemblages.

The 6” depth of growing medium is composed primarily of sand, lava rock, and amendments that allow for both moisture retention and drainage. The growing media included inoculants for mushrooms that appear in the cool, wet winters. The roofs were installed with irrigation to support the initial establishment of the plants and for minimal summer maintenance. The waterproofing membrane is American Hydrotech MM6125 followed by a Hydroflex30 Protection Course and Root Stop WSF40. The drainage system is Floradrain FD40 underneath the growing medium layer, and ¾" to ½ " gravel with perforated pipe and surface drains at the roof’s edges.

Perennial plant species selected for the roof, such as sand sedge, Pt. Joe fescue, yarrow, and wild strawberry, are typical of the oak woodland understory and representative of the Monterey Peninsula regional flora. A host of annual wildflowers were over-seeded in the fall, and by springtime, tidy tips, lupine, poppies, and goldfields surprised the owners with a colorful spring bloom. These annuals continue to sprout and flower each spring.

The green roofs are designed to provide usable landscape, filter and store rainwater, attenuate sound, increase thermal insulation, and provide site sensitive beauty for the home. The owners benefit by reducing their energy consumption up to 30 percent during the summer months from the insulation of the green roofs. With a growing media depth of 6", the sound is reduced by approximately 43 decibels. The sounds from the humans and their activities within the buildings are also being buffered to protect the wildlife, given the sensitive nature of the habitat in the preserve.

The 33 species of native plants used on the roofs have helped the site recover from the disturbance caused by the initial building activities on the site. The ecology of the site is expected to become more complex and to resemble the natural analogs that were emulated in the design.

Expanded Project Profile: The Story behind ASLA's Green Roof[4]

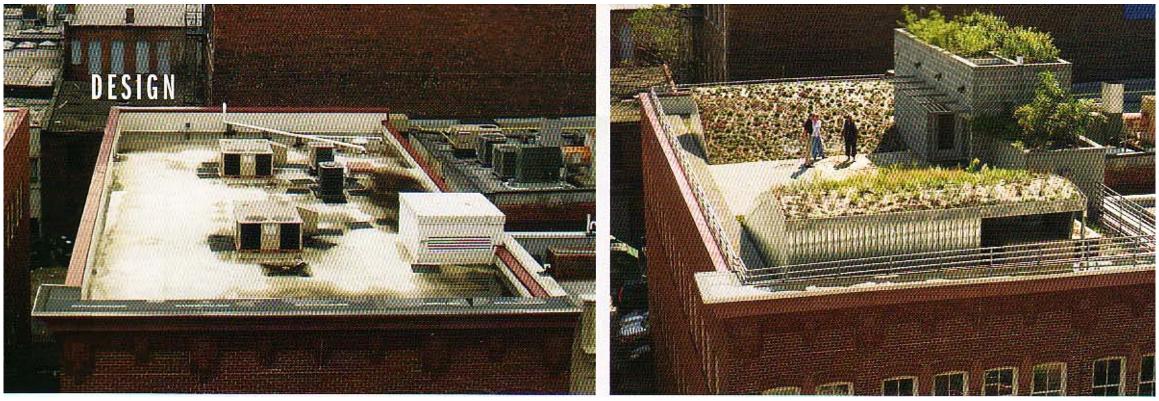

Figure 13. Before and after photos of the ASLA Headquarters building's roof. Courtesy Sam Brown

When the American Society of Landscape Architects (ASLA) decided to "green" the roof on its headquarters building, the primary goal was to showcase landscape architecture's ability to unite environmental performance with high-value, usable outdoor space, even in the least likely environments.

Green roof design was initially dominated by architects and/or roofing contractors who were interested primarily in performance. ASLA wanted to encourage the profession of landscape architecture to play a leadership role in uniting the useful aspects of green roofs with their spatial and experiential potential. The Society wanted to demonstrate the unique value that landscape architects could bring to this new medium. The program required not only that the green roof perform, but also that it communicate and inspire.

The landscape architecture firm, Michael Van Valkenburgh Associates Inc. (MVVA), selected to lead the design team, agreed with ASLA that green roofs had an unrealized potential to become useable spaces. The landscape architecture team was very excited to embark on a project that was seeking a larger role for the next generation of green roofs. The team wanted to create an inspiring and memorable landscape experience that is possible in this location only through the use of green roof technology.

A Designer's Perspective on What Makes Green Roof Design Different

The paramount technical challenge of green roof design is the need to minimize weight. Traditional roof gardens are tremendously heavy and often cost prohibitive. The breakthrough of green roof technology is a system for growing plants based on lightweight materials used sparingly. The need to remain within tight weight tolerances is one of many unique elements of green roof design.

Weight, plant height, soil depth. Some rooftops are composed of segments with varying weight-bearing capacities, which can then allow for some variation in soil depth. For the most part, however, a green roof's soil profile is minuscule—just a film of 2-4 inches. The soil can't support trees and other massive vegetation, the major spatial elements that landscape architects usually use to give shape, depth, and character to a space. In many cases, plant height will barely reach

[4] This section is based on a series of interviews with Chris Counts, ASLA, of the east coast firm Michael van Valkenburgh Associates. Counts served as project manager and associate in charge of ASLA's green roof project on its headquarters building in Washington, DC.

8–12 inches. Neither can the soil be graded to create topographical interest: the roof surface is typically evenly sloped or even level, and generally capable of supporting soil weight only if it is evenly distributed to a uniformly shallow depth.

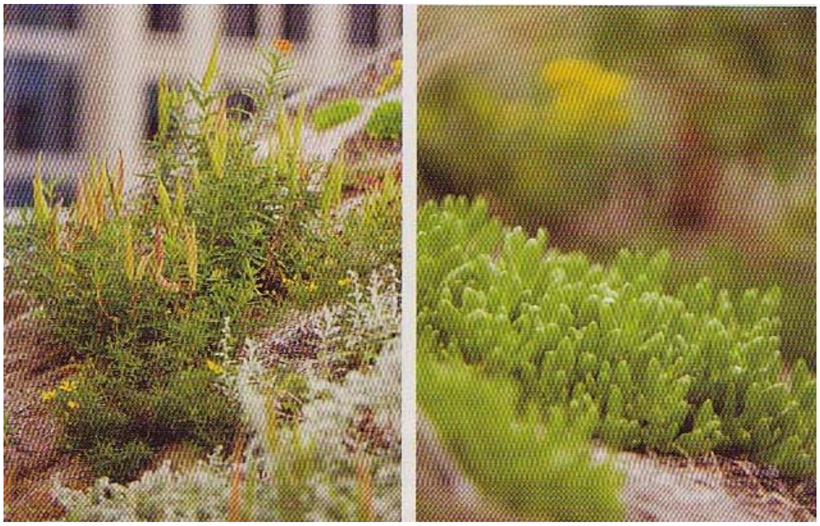

Figure 14. Typical green roof plants. Left: Asclepia tuberosa (butterfly milkweed); Right: Delosperma nubigenum (ice plant*). Courtesy Sam Brown*

Aspect, elevation, wind. On a flat roof, aspect will be more or less constant, but other taller structures nearby may shadow the roof unevenly, resulting in varying exposure to light across the roof surface, with levels of soil moisture decreasing with longer exposures to the sun. The elevation and exposure of the rooftop can make it a windy place at least some of the time. Wind can have particular significance on a rooftop, where lightweight materials are more likely to become airborne.

Machinery. Rooftops have long been the favored location for a building's mechanical systems. A green roof's design must be compatible with the operation of HVAC units, elevator exhaust shafts, pumps, and drains, while somehow not allowing these elements to dominate the space. This machinery is bulky, and OSHA requires maintaining additional clearances for all machinery that must be serviced. Intake and exhaust systems also create microclimates that may favor some plant species while hindering others.

Rooftops can be surprisingly complex environments, with structural and climatic variations that drive design in a number of ways. The type of microclimatic diversity that is created by differences in slope, aspect, soil depth, and proximity to equipment was something that we were very interested in exploring through the design of the ASLA green roof. The major topographic elements of the design, the "waves," were introduced in part to create greater variety in order to better understand its effects on plant survival and human comfort.

Design Development for the ASLA Green Roof

ASLA's green roof began as many green roof projects do: the roof needed replacing. In this case, the roof was a modest 3,300 square feet of space atop ASLA's headquarters building, a 1980s three-story structure in the city core of Washington, D.C. Because the building belonged to ASLA, it was important that the green roof design provide a powerful and memorable experience to visitors that communicated the values of the organization and the profession.

The simplest “green” design, a “big carpet,” would not offer much to visitors, even if improved with interesting planting schemes and inviting pathways. Seeking the power to engage the visitor, ASLA’s green roof design team drew as much inspiration from “roof” as it did from “green.” The focus on the concept of “roof” inspired a number of concepts that drove the design.

A green roof, like a regular roof, is *utilitarian*. The difference is that the green roof is useful in more ways. An extensive green roof system is a bioengineered machine. Like a race car, it is designed to maximize function and performance. The soil is the lightest it can be, and the plants must be able to thrive in heat and drought. The utilitarian nature of green roof components is conceptually harmonious with the modern approach to roofing in general. You don’t find anything extravagant.

All roofs have a *“behind the scenes”* quality. Rooftops have a peculiar context—they are very much in the city but also removed from the network of familiar urban locations and activities. The rooftops of the city offer both a retreat and a privileged vantage point. This intrinsic quality captures the imagination, giving visitors a rare perspective on the operations of city life. The mystery and excitement of being safely out of the city while still observing its comings and goings is something to be captured and enhanced.

The site’s context is *urban*. ASLA’s multistory brick building is one of many arranged in a tight grid. The neighborhood’s street-side sidewalks are punctuated sparely with young trees. In this city environment, all plants are magical, even those that might not impress most gardeners. Robust species that colonize harsh urban environments come across as rugged and raw. Their vitality is welcome in the city, where nature is otherwise so sparse or controlled.

One strong image guiding the design for ASLA’s roof was a romantic vision of wild nature overtaking abandoned areas in the midst of the concrete landscape. The architectural materials in the roof design would provide the transition from the polished interior and hard architecture of the building to its rooftop’s grit, mechanics, harsh environment, and rugged vegetation.

Finally, the roof needed to be *“green.”* No fertilizer, pesticide, ongoing irrigation, or other intensive maintenance would artificially sustain the roof plants. This specification further proscribed against a lush and gorgeous carpet. Plants had to be selected to survive the harsh roof environment without supplemental care. The roof would facilitate casual cohabitation by urban plants and human city-dwellers. The design would invite the forces of nature to freely occupy and enliven contrived human space.

The Design

ASLA’s green roof is a place where visitors do not need to tread lightly in order to avoid compacting soil or crushing vegetation. The rooftop’s scant 3,300 square feet provide a place for complex ecological function and human activity to overlap and coexist, a double duty made possible by a few simple design moves.

The design of ASLA’s green roof uses typical green roof materials, but layered and exaggerated to create a space that is visually engaging and multi-functional. The spatial engine of the design is an extreme vertical exaggeration of the roof insulation (Styrafoam) to create two large, sloping landforms (“waves”) that rise to a height of eight feet. These large landforms are covered with a thin soil profile to support plant life. The height of the landform on the north side of the building was calibrated to be viewable from the sidewalk below.

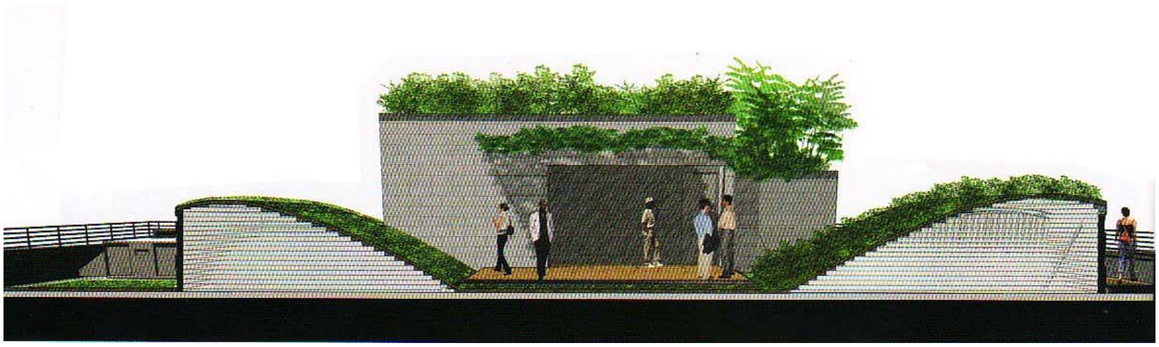

Figure 15. Elevation drawing of the ASLA Headquarters building's green roof. Courtesy MVVA

The waves immerse visitors in a green valley that creates a textured contrast with the buildings of the city. The two landforms rise from grade at a 2:1 slope, a north-facing slope and a south-facing slope converging on the entry path and together creating a green valley. The slopes assert mass and (perceived) weight, as well as creating microclimatic diversity and a gradient of growing conditions, forming a kind of demonstration garden of which plant species will survive in which locations.

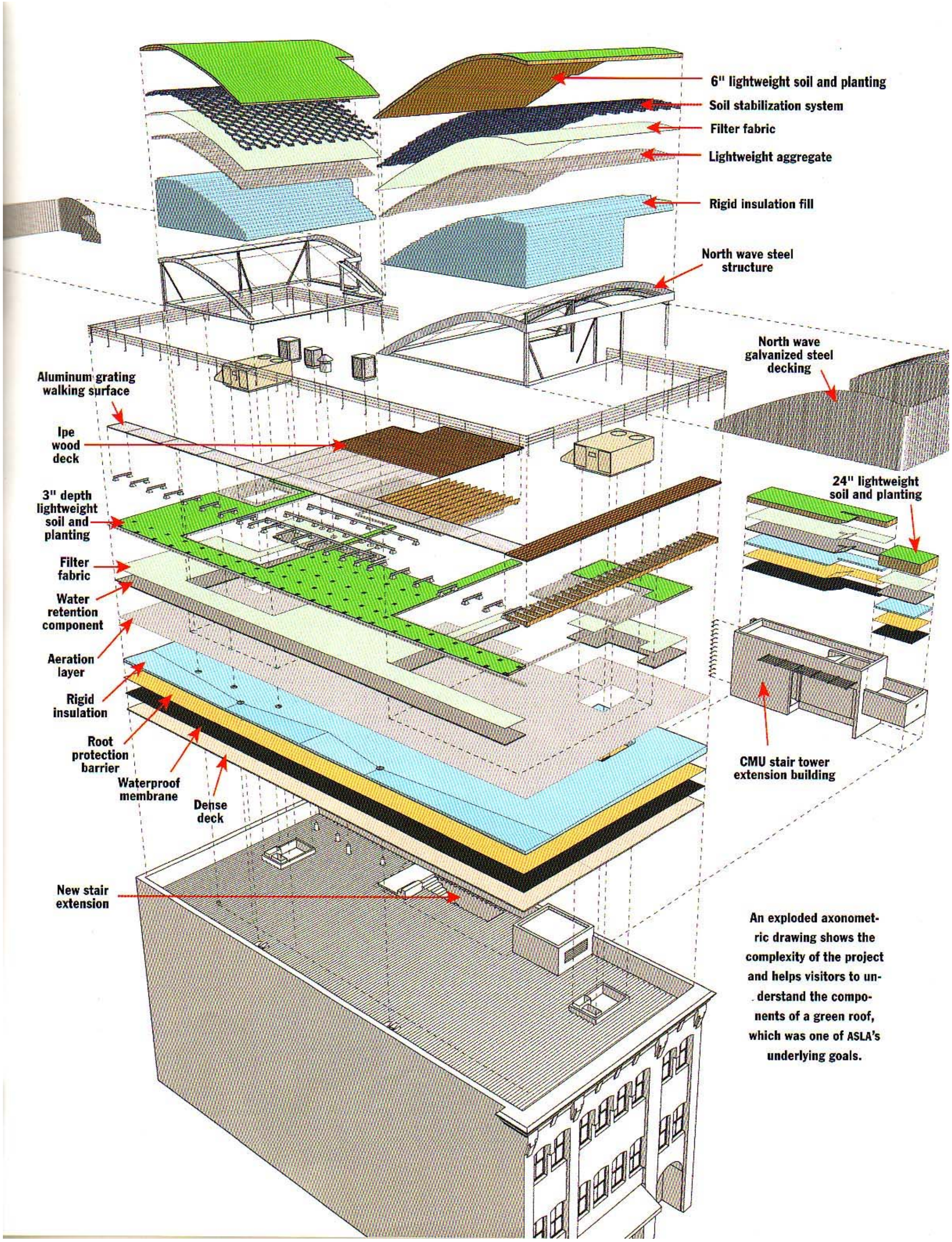

Figure 16. Exploded axonometric drawing. Courtesy MVVA

The landforms posed technical challenges. Strong winds on the small roof threatened to shear the lightweight foam from its anchors, and the shape and angle of the landforms' walls compounded this threat. Robert Sillman Associates, the structural engineer, devised an ingenious solution that used the arcing steel frames of the landforms as armature. A net of steel cables elegantly secured the two foam objects to the roof trusses below, preventing the foam from blowing off the building.

Another innovation of the ASLA green roof is the metal grating walkways over some of the green roof plantings. For the most part, sedum and green roof plants can not be walked on, suggesting a spatial trade-off between having a green roof and a place for people. The experimental system floats a super lightweight aluminum grating, low in heat conductivity, 3" over a thin green roof system of sedum. The sedum selected will grow approximately 6" in height, so that it will extend through the aluminum grating above. In the areas of high traffic, the plants that emerge through the grate will be trampled down. This will regenerate, rather than destroy, the plant and have the added benefit of recording a second order of circulation pathways along the aluminum terrace.

Figure 17. Two illustrations of grating used as a walking surface over planted sedums. Courtesy MVVA

A major challenge in the design of this and many green roofs is the obnoxiously large and noisy HVAC and utility equipment. The ASLA building's two large HVAC units were located directly in the middle of the roof. It was determined early on that the units had to be relocated. The south HVAC unit fit conveniently behind the south landform, but the north HVAC required a more innovative solution. The thin profile of the green roof media allowed for carving out the northwest corner of the north landform (where the slope peaked) to create a discrete space for the HVAC unit. In this position, the HVAC unit accommodated service and exhaust requirements while not compromising the gesture of the "wave."

Another critical issue was access. The existing roof access consisted of only a ladder and trap door. The decision was to extend the building's internal staircase vertically and create a modest structure ("pavilion") where the staircase extension terminates at the roof. The pavilion is a simple concrete masonry block structure that sits directly on the structural walls of the existing bearing wall below.

Figure 18. Computer rendering of the ASLA Headquarters building's green roof. In this picture, south is roughly 11 o'clock. Courtesy MVVA.

The extra bearing capacity of the walls of the stairwell and elevator shaft allowed for significantly deeper soil profiles on the roofs of both of these structures: 12" and 20" soil depths respectively. Elsewhere on the roof, soil depths range from 4" on the south landform, 6" on the north landform, and 3" under the grating. Together, this range of soil depths creates a kind of encyclopedia of green roof types and growing conditions. The result is a visually rich environment that displays and demonstrates the versatility of green roof technology.[5]

[5] Designed to be a demonstration project, ASLA's green roof is open to ASLA members and the public by scheduled tour through ASLA staff. ASLA's website, www.asla.org, also provides access to images collected live through a 24-hour webcam.

Reflections and Outlook

Technology and new materials now allow landscape architects to build lightweight landscapes in places that 20 years ago would have been left barren. Green roofs are both exciting new territory for landscape architects and an opportunity to demonstrate what landscape architects do best as a profession. A particular set of design constraints is clearly at play, but in the end, green roof design is still design, and the spatial and experiential challenges of place-making are not novel. The opportunity for landscape architects both to increase the environmental health of cities through green roof development and to reclaim roofscape for human enjoyment and excitement is truly extraordinary.