GREEN ROOFS:
SUSTAINABILITY FROM THE TOP DOWN

Rockefeller Center, New York City

DAVID STATER

GREEN ROOFS:
SUSTAINABILITY FROM THE TOP DOWN

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Abstract

This project will show that by incorporating green roofs into the design of buildings the built environment can provide the ecosystem benefits normally provided by the natural environment, including flood alleviation, cooling and insulation, and even biodiversity.

A brief history of green roofs will be followed by an explanation of some of the terms associated with their use. There will then be an extensive look at the benefits associated with green roofs, which will be categorized as physical, psychological, ecological, and economic.

Different policies from around the world will then be explored to better understand the relationship between policy and the implementation of green roofs. This will be followed by individual case studies that allow for a more detailed look at green roof types and construction costs.

The project concludes with the proposal of a green roof design for the Hunt Hall with some design recommendations.

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Introduction

A typical modern city has an ecological footprint (the area needed to maintain the population in terms of food, resources and waste disposal) of between 100 and 300 times the area of the city itself. When you combine that with the fact that sprawling cities like Phoenix, Arizona are losing open space to development at a rate of 1.2 acres per hour you can begin to see the urgency in changing how we approach urban design.

Chicago City Hall

The built environment must be altered to mimic the natural environment as a way of restoring ecosystems, reducing greenhouse gas emissions, and adapting to climate change. By incorporating green roofs into the design of buildings, the built environment can provide the so-called ecosystem services normally provided by the natural environment, including flood alleviation, cooling and insulation, and even biodiversity. The many acres of flat rooftop space in most cities can become new green space without altering land use or compromising development. The only limitation is roof structure (to be explained later).

History

The earliest known green roofs were turf roofs, a Nordic tradition still practiced today in many parts of Norway and Iceland. Turf was a durable and readily available building material known to have an insulating effect. There are several remaining examples of relatively sophisticated earth-sheltered and turf-roofed structures dating as far back as the Bronze Age, 3,000 years ago.

Turf Roof, Iceland

In warmer climates the first green roofs were roof gardens. Several roof gardens have been identified in the ruins of Pompeii, buried during the eruption of Mount Vesuvius in AD 79. There are many examples of roof gardens from the Middle Ages, including The Guinigi Tower in Lucca, which is currently the emblem of the Green Roof Organization in Italy.

"New materials were developed in the 19th century that gave rise to new styles of building which were better suited to creating the necessary load bearing and waterproofing characteristics required for roof gardens (Grant 10)." Further advancements came from Germany in the 1960's where still new materials were developed to create the green roof we still use today.

Guinigi Tower, Lucca, Italy

Green Roof Types

The term green roof is used to describe both ornamental roof gardens and roofs with more naturalistic plantings or self-established vegetation. Green roofs consist of three types of construction, design, and cost: intensive, simple intensive, and extensive. The intensive roof is closest to what is known as a roof garden. It has the appearance of a garden or park that you would see at ground level. Because of the amount of weight needed for a growing medium, plants, water, and visitors, these gardens are usually constructed over reinforced concrete decks. Because of the expense of roof structure upgrades these roofs are usually not an option for green roof retrofits, but if implemented at the design phase they can have a dramatic affect on the architecture of a building while adding green roof benefits to the structure.

The ACROS Building, Fukuoka, Japan is an intensive green roof.

The School of Art and Design in Singapore is an example of a simple-intensive green roof

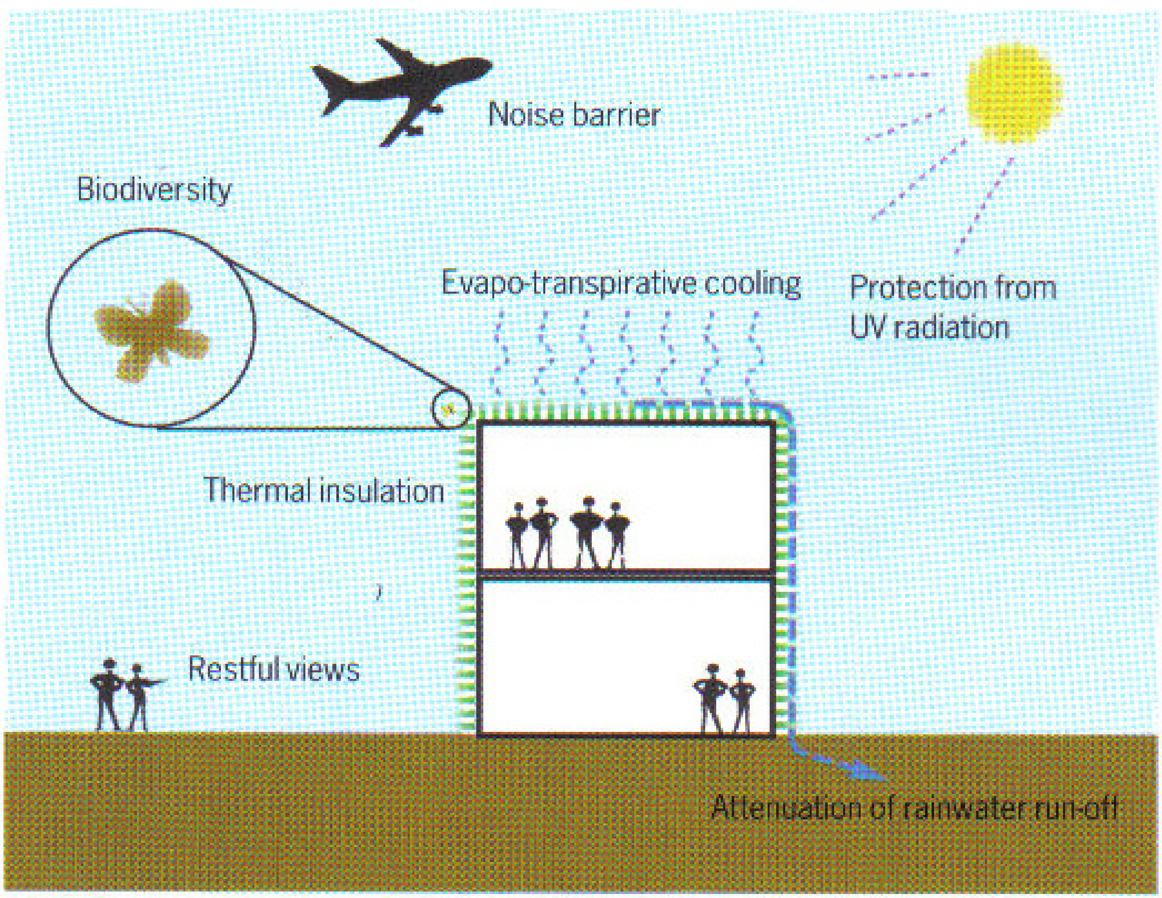
The second type is referred to as a simple intensive green roof. This roof is vegetated with lawns or ground covering plants, and requires regular maintenance, including irrigation, feeding and cutting. Demands on building structure are much more moderate than that of the intensive roof, making it much more affordable and a possible choice for retrofit green roofs. It is, however, more expensive and complex than extensive green roofs. These roofs are usually not meant to be accessible but they are often designed to be overlooked. A structure with a tiered roof system would be a great candidate for a roof of this type.

The third type is the extensive green roof. This type requires minimal maintenance and is usually not irrigated, although in some cases it can be during the time when plants are being established. The extensive roof has a very shallow planting media (low weight, sometimes soil-less) which helps minimize the cost and the structural load on the roof. This makes it an ideal candidate for retrofit green roofs. There are also disadvantages. The low-weight synthetic planting media is more susceptible to winds, drought, and high temperatures associated with an elevated surface. With this in mind, plant selection must consist of hardy, low-height drought resistant plants like succulents, herbs, and grasses. This roof would only be accessible for maintenance.

Canary Wharf, London, an extensive green roof.

Benefits

The many benefits associated with green roofs can be physical, psychological, ecological and economic. Rooftops, roads, and parking lots cover up to seventy percent of land area in dense cities like New York. By adding green roofs to buildings, the area available for leisure, recreation or wildlife can be increased. Aesthetically, green roofs provide the easiest way to screen equipment and soften a roofscape. Since large-scale architectural projects are often presented to clients and the public as models that are viewed from above, you can see how an attractive roofscape could add interest to a design.

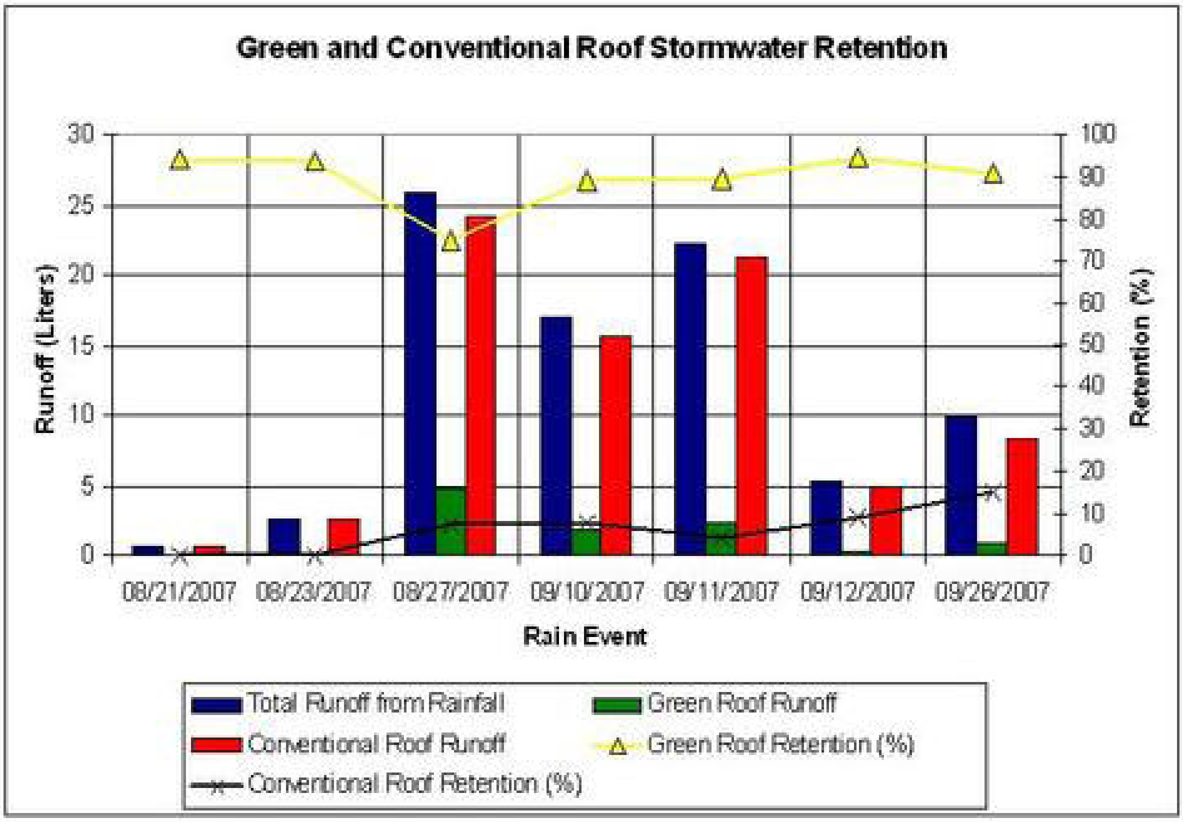


Some of the benefits of building-integrated vegetation

Being able to view and experience nature is excellent for mental health. Studies have shown that patients with natural views recover faster and need fewer pain medications than those that had a building view (Koss 357). With this in mind, therapeutic roof gardens are becoming popular in hospitals and care centers. They not only give the patients a more natural place to stroll but also provide a place to view. Frederick Law Olmstead once said, “Humans have psychological reactions to natural beauty and diversity, to the shapes and color of nature, especially to green, and to the motions and sounds of other animals”.

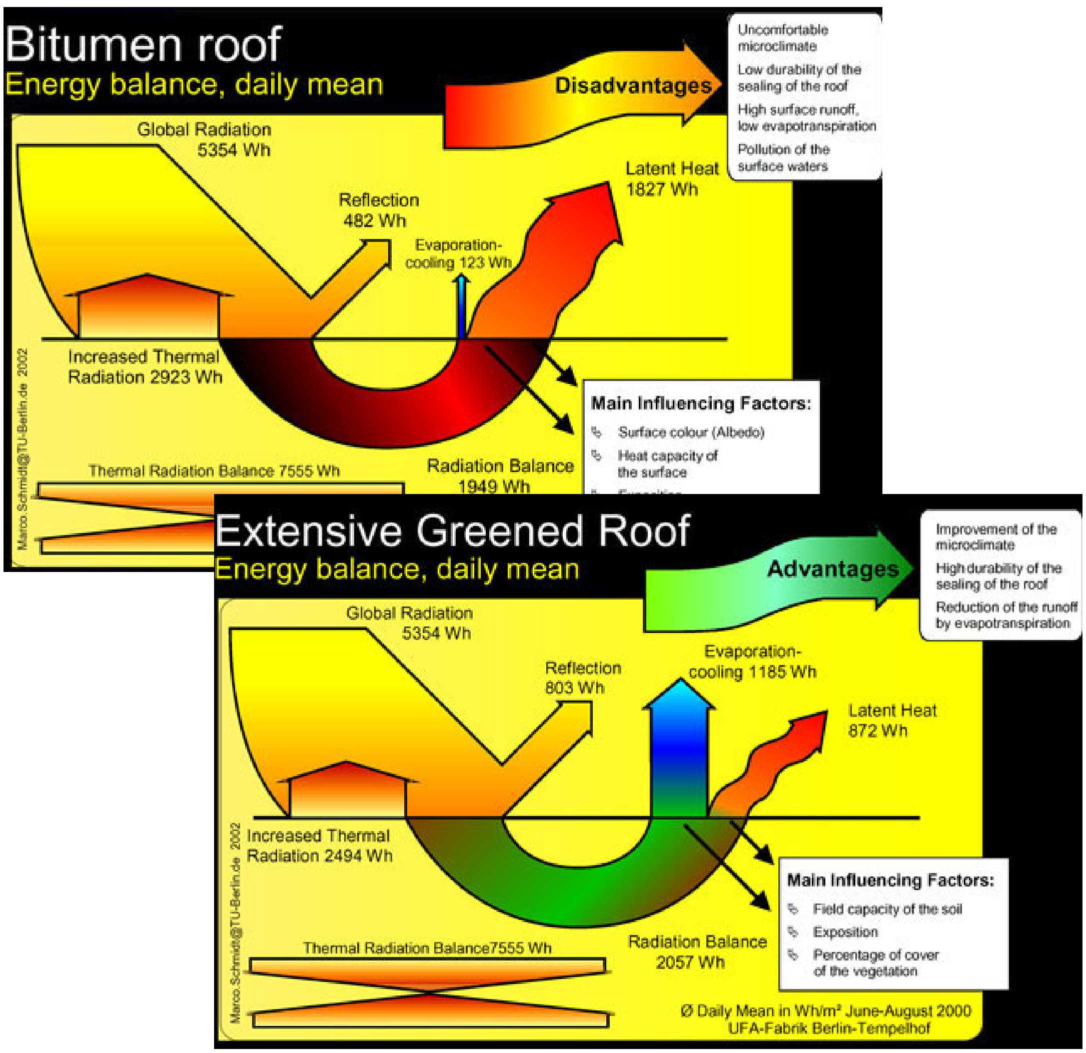
Schwab Rehabilitation Roof Garden, Chicago

Arguably the most important green roof benefits are ecological. "Green roofs make buildings more thermally efficient, ameliorate the extremes of temperature and humidity, moderate surface water run-off, and help reduce air pollution and noise (Grant 4)."



Conventional roofs have little to no stormwater retention capability. The permeable surface of a green roof allows for rainfall infiltration and greater water holding capacity. After a storm, water stored by the green roof is lost to evaporation and transpiration. As a result, green roofs can reduce total stormwater runoff volume on average by 50 % – 60 % (VanWoert et al., 2005; TRCA, 2006; Carter & Rasmussen, 2006) and in certain conditions can fully retain individual storm events (VanWoert et al., 2005; Bengtsson et al., 2005).

Storage water for evaporation and transpiration plays an important role on the urban heat island effect. The hard, heat-absorbent surfaces of cities retain more heat than areas with more vegetation and plant life. “This ‘heat island’ phenomenon is the result of ground-level air temperature being much higher than in surrounding rural areas, where the vegetation and plant life cool the air through moisture retention and subsequent evaporation and transpiration through their leaves (Lawlor 10).” New York and Chicago are both particularly concerned with urban heat island effect.



These graphics show the energy differences in heat loss between a conventional roof and a green roof (Marco Shmidt 2002). Notice the relationship between evaporation cooling and latent heat.

Air pollution has long been an area of concern in urban areas. There have been many legislative solutions that have been successful, including auto emission standards and the phasing out of coal-fired electricity plants, but a "more recent approach is restoration of biological systems that help reduce airborne contaminants (Lawlor 10)". Vegetation has been shown to reduce atmospheric pollution by filtering particulates and absorbing gaseous pollutants (NASA). What better place to introduce this vegetation than the heart of the cities where the need is the greatest? "Some air pollutants that are filtered by plants are then adhered to the soil. This shows the mechanism whereby green roofs can reduce heavy metal and other pollution in stormwater run-off (Grant 37)."

Noise levels in cities are another hazard associated with the built environment. "Unpublished research by a roof manufacturer called Kalzip suggests that an extensive green roof can reduce sound within a building by 8 dB or more when compared with a conventional roof (Grant 38)." It is not the vegetation that insulates a building against noise but rather the substrate underneath it. Therefore the deeper the soil, the better the roof is at deadening noise. One of the reasons stated for creating the green roof at the Gap Headquarters in San Bruno was that it absorbs sound emanating from nearby busy highways and flight paths (Burke 2003).


Gap Headquarters, San Bruno, California

Although rarely seen as a primary issue in adopting a green roof design, an important by-product has been an increase in biodiversity. The expansion of urban spaces has led to habitat loss and fragmentation for many animal species. Green roofs can provide suitable habitat for many bird and invertebrate species by providing island habitats and stepping stone habitats that link habitat pockets with one another. However, there is current research in Switzerland and in London showing that green roofs need to be designed to meet specific local biodiversity conservation objectives (Livingroofs.org).

Chicago City Hall

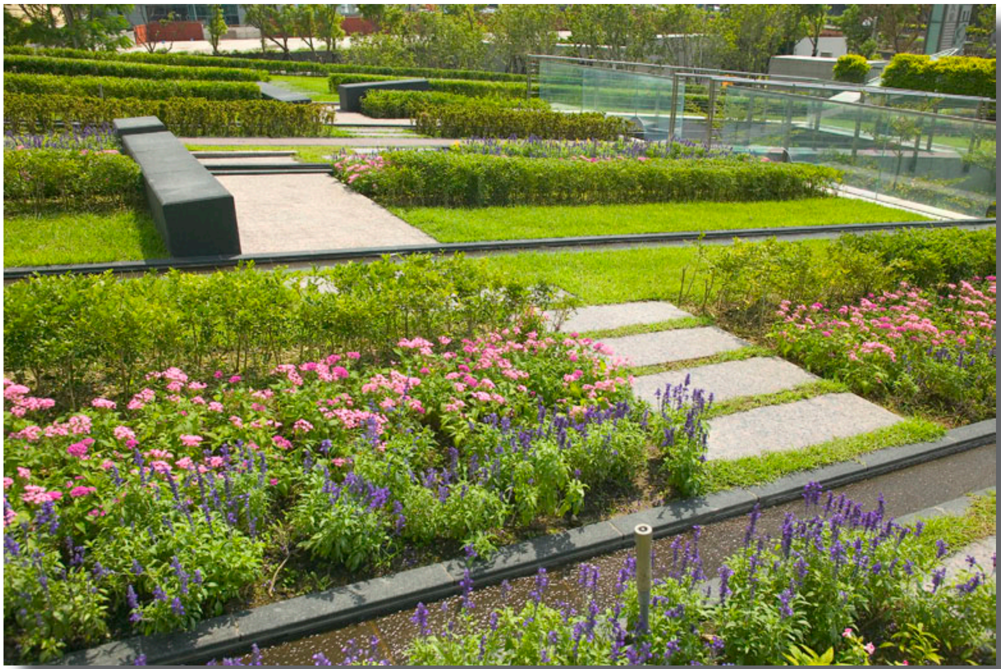
In addition to creating habitat for local animal species, green roofs provide an opportunity to reintroduce native plant species. The first green roof in Chicago has 150 different plant species.

Probably the largest driving factor in promoting green roofs is economic. "Studies have shown that on a summer day the temperature of a gravel roof can skyrocket to between 140 and 176 degrees F, but when covered with grass or other vegetation it is less than half as hot. The temperature inside the building stays cooler, saving energy on air-conditioning. In winter the building stays warmer, conserving energy on heating (Marinelli, 2008)." This effect is compounded by the evaporation and transpiration that takes place with the substrate retaining water. The hotter it gets, the more evaporation and transpiration takes place thereby cooling the air on the surface of the roof. Although energy savings vary with building type and geographical area, studies have shown reductions of up to 25% of air conditioning costs (Environment Canada).

Another cost saving benefit of a green roof is the increased life of the roof. A green roof system protects the waterproofing membrane from climatic extremes, UV light and mechanical damage and, in so doing, almost doubles its life expectancy. Therefore a good quality, root-resisting waterproofing system with a normal life expectancy when exposed to the elements for 30 years, can be expected to last up to 60 years, thus saving the client the cost of re-waterproofing during the average buildings expected life time (Livingroofs.org).

Waterproofing Membrane Protected by a Green Roof System

Green roofs also increase the value of the property and the marketability of the building as a whole, particularly for accessible green roofs. For example, American and British studies show that "good tree cover" adds between 6 to 15 per cent to the value of a home. Green roofs offer the same visual and environmental benefits. They also provide an opportunity for additional space for day care, meetings, and recreation. Studies have even shown a potential to improve employee productivity (GRFAC).

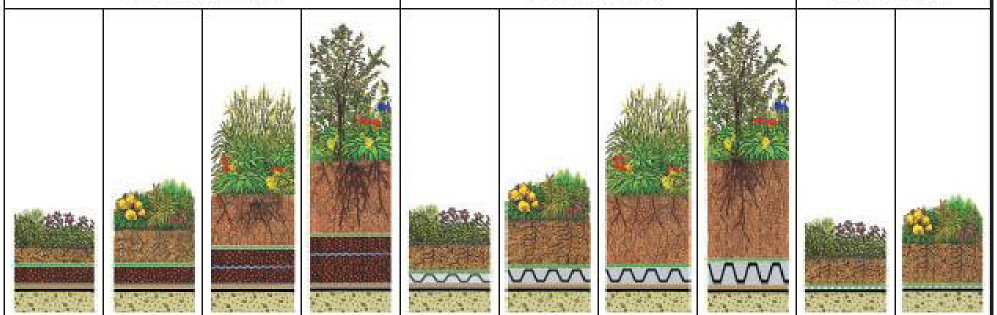


Green roof garden with employee access
Lite-On Corporate Headquarters, Taipei, Taiwan

The largest economic benefit comes from local policy makers that can encourage and even legislate the implementation of green roofs. This is where the U.S. has fallen behind other countries. Policy benefits include the development of more floor space if green roofs are installed, or offering a reduction in drainage charges in line with falling rates of runoff.

Design & Construction

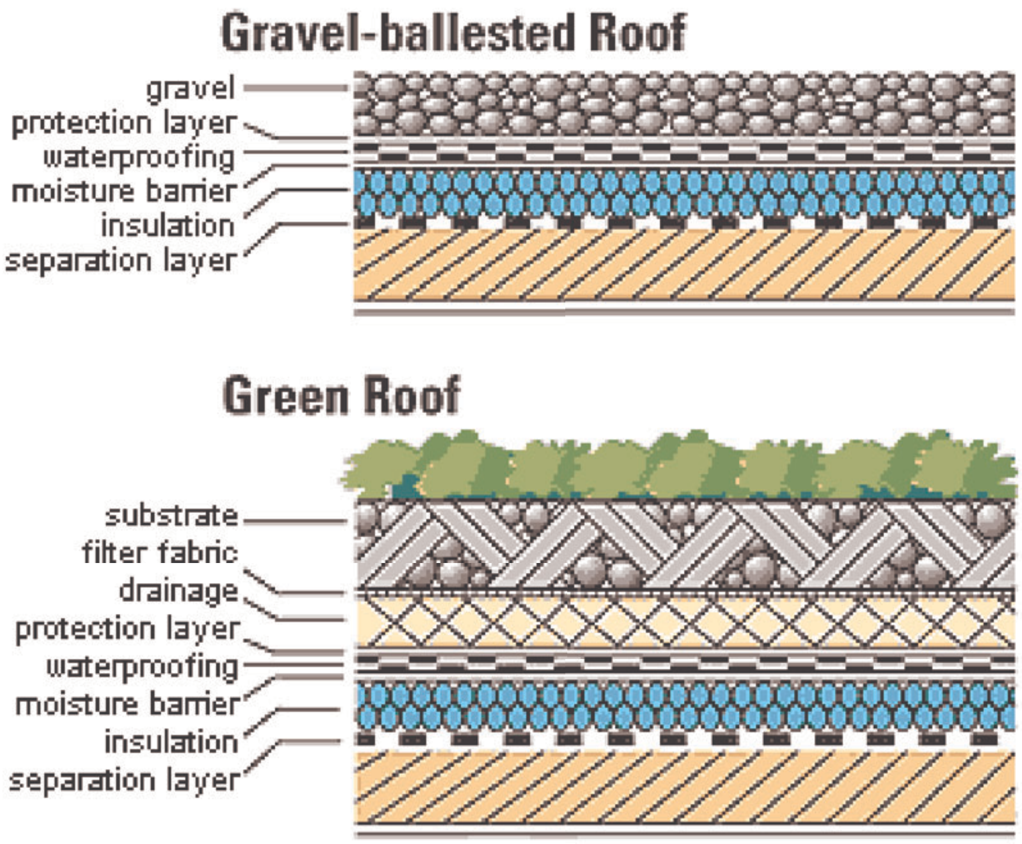
When considering a green roof, landscape architects, architects, and engineers must take into account the dead load of wet soil, plants and other materials and the potential for live loads of people or moving machinery. "The lightest standard residential roof constructed from sawn timber and supporting tiles is normally designed for loading of between 100 and 150kg/m2. The weight of sedum roofs 50mm thick may be 70kg/m2 wet and when the soil-less geotextile blankets are used, saturated weights can be as low as 30kg/m2 (Grant 46)." With these low weights it is possible to retrofit green roofs to most structures without additional strengthening. However, the advice of a structural engineer should always be sought and local building codes checked beforehand. The chart below shows the wide range of options available. There is a trade-off between plant selection and structural support needed.



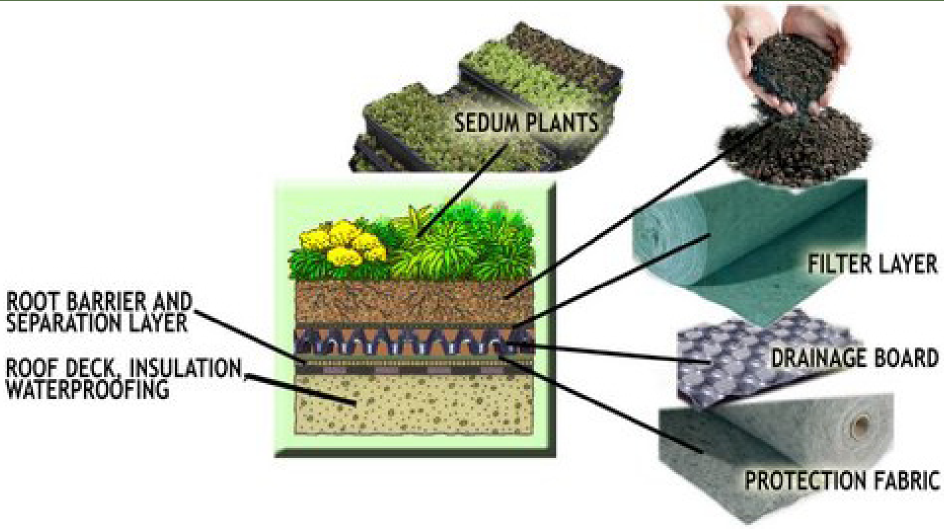
GREEN ROOF SYSTEMS	SYSTEMS WITH GRANULAR DRAINAGE				SYSTEMS WITH DRAINAGE PLATES				SYSTEMS WITH DRAINAGE MATS	
system designation	G1	G2	G3	G4	P1	P2	P3	P4	M1	M2
typical plants	sedum herbs	sedum herbs perennials	perennials grasses shrubs	grasses shrubs trees	sedum herbs	sedum herbs perennials	perrenials grasses shrubs	grasses shrubs trees	sedum herbs	sedum herbs perennials
extensive soil mix	2"	4"	-	-	3"	5"	-	-	3"	5"
intensive soil mix	-	-	6"	9"	-	-	8"	12"	-	-
separation fabric	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	-	-
granular drainage	2"	2"	4"	6"	-	-	-	-	-	-
drainage plate	-	-	-	-	1"	1-1/2"	1-1/2"	2-1/2"	-	-
drainage mat	-	-	-	-	-	-	-	-	3/8"	3/8"
protection mat	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	-	-
nominal thickness	4"	6"	10"	15"	4"	7"	10"	15"	3"	5"
dry weight	19 lbs/ft^2	28 lbs/ft^2	45 lbs/ft^2	69 lbs/ft^2	14 lbs/ft^2	23 lbs/ft^2	34 lbs/ft^2	52 lbs/ft^2	14 lbs/ft^2	22 lbs/ft^2
saturated weight	26 lbs/ft^2	41 lbs/ft^2	70 lbs/ft^2	105 lbs/ft^2	23 lbs/ft^2	37 lbs/ft^2	57 lbs/ft^2	85 lbs/ft^2	23 lbs/ft^2	37 lbs/ft^2
minimum slope	0:12	0:12	0:12	0:12	1/4:12	1/4:12	1/4:12	1/4:12	1:12	1:12
maximum slope	1:12	1:12	1:12	1:12	1:12	1:12	1:12	1:12	3:12	3:12
water retention	50%	60%	70%	80%	50%	60%	70%	80%	50%	60%
irrigation system	-	-	subsurface	subsurface	-	-	surface	surface	-	-

Green Roof Systems and Setups, Resource Conservation Technology Inc.

Materials: Manufacturers will sometimes refer to there roof components as a system because it consists of many layers that all have a relationship to one another. "There are seven basic elements to any green roof: waterproofing membrane, root barrier, insulation, drainage layer, filter fabric, growing medium, and plants. These components allow for vegetation to grow on a built surface while protecting the underlying structure (Earthpledge 134)."



This graphic shows the subtle differences between a conventional roof and an extensive green roof.

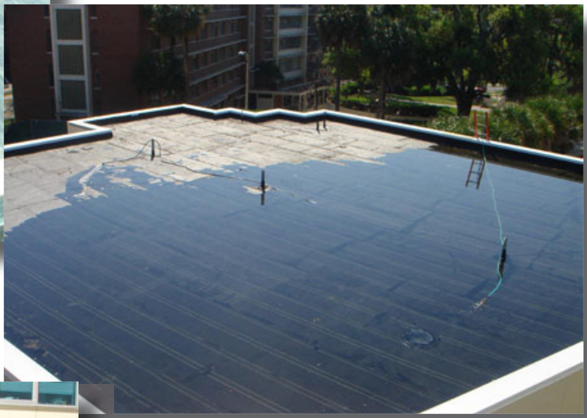


Typical Setup of Extensive Green Roofs.
Designed by Jörg Breuning, Green Roof Service LLC

The waterproofing membrane safeguards the roof from leakage and, therefore, is one of the most important elements of any roof, green or not. After membrane application, a leak detection test must be performed before applying additional layers. The next layer is the root barrier which protects the waterproofing membrane and the roof deck from penetration by aggressive roots. Insulation is not a structurally necessary component of a green roof, but most building codes require it in standard roof construction to prevent heat loss. Although a green roof minimizes energy use in the summer it is not an effective insulator in the winter. The insulation layer can be placed above the waterproofing membrane or below it. It may even be below the roof deck entirely. The drainage layer prevents over-saturation, ensures that roots are ventilated, and provides roots with extra space to grow. A filter fabric must be placed between the drainage layer and the growing medium to keep the substrate in place. The growing medium for a green roof is made from different components than you would find in your average topsoil, a mineral base with minimal organic material. This is why it is often referred to as a substrate. “The composition of the substrate is determined by water retention capacity, weight, aeration, and nutrient retention (Earthpledge 135).” The following page shows the step-by-step procedure involved in installing these layers.

Green Roof at University of Florida
Charles P. Perry Construction

Waterproofing Membrane



Leak Detection Test

Root Barrier and Drainage Layer

Filter Fabric

Materials Hoisted with Crane

Distribution of Substrate

Once the growing medium is placed it is time for planting or seeding. Green roof plants need to be able to thrive in shallow soils, resist drought, survive heat and exposure and require low maintenance. Sedums are the plants most usually specified on extensive green roofs. As succulents they can store water to enable them to survive high temperatures and drought. These plants can be established by seeding or from cuttings. They can also be pre-grown on geotextile mats that can be easily delivered and installed to produce an instant effect.

Sedum flats grown specifically for green roof installation

Color variations of a sedum roof.

Another planting technique that is increasingly popular is establishing native communities with the use of wildflower and grassland seed mixes. The exact composition of seed mix will depend on the substrate used, the local climate and the area in which the roof is located. Although there is also a trend for the use of native plants, these plants may not do as well as non-native species on a rooftop environment.

In the case of intensive roof gardens the sky is the limit. With the deeper substrate one is only limited by there own planting zone requirements. The down side to these roof gardens is that they will require an irrigation system. When this is necessary it is preferable to use stored rainfall or recycled gray water.

A green roof planted with wildflower and grassland seeds, Barclays Headquarters, London

Policies

The largest driving factor in the implementation of green roof construction is policy. The popularity of green roofs around the world has a direct correlation to local government involvement whether it is requiring them to be used on government buildings or giving tax breaks to those who choose to build with them. For a general overall view we will look at policies from Europe, Asia, and North America.

Europe. The impressive advances in roof greening in Switzerland and Germany have been attributed to the positive policy environment. “Most green roof advocates believe that they will need to persuade their governments to adopt similar regulations or incentives before roof greening techniques become mainstream in their own countries (Grant 23).” In Switzerland, land use regulations require all federal agencies to apply the ‘Swiss Landscape Concept’ when commissioning or rehabilitating buildings and installations. This means that facilities must be compatible with natural settings and landscape (SAEFL 1998). Nearly half of all cities in Germany offer incentives for green roofs (German Roof Gardening Association). “Direct financial support ranges between 25% and 100% of the installation costs. Indirect subsidy is also provided by some German states and cities where drainage charges are reduced for developments with green roofs (Grant 25).”

Berlin, Germany

Asia: With China's rapid economic growth, increased car ownership, and increases in industry they have experienced a serious increase in air pollution in their cities. With the need for change and the eyes of the world on Beijing for the 2008 Olympics, there have been a number of initiatives to green the city. "Since Beijing is too densely populated to add parks the Beijing Municipal and Forestation Bureau has set a target of greening 30% of high-rise buildings and 60% of low-rise (less than 12 story) buildings by 2008. The official news agency Xinhau has reported that, by the end of 2006, Beijing plans to have between 80,000 and 100,000 square meters of roof gardens with this rising to 300,000 by 2008 (Grant 27)."

Beijing, China

Japan has had similar problems due a the post-war building frenzy, making Tokyo the most densely developed metropolis on earth. The result has been an increasingly severe 'urban heat island' problem. In 2001, the Tokyo authorities finally recognized that something needed to be done and recommended tree planting and new parks, and set a target of creating 30 square kilometers of green roofs (Earth Pledge). Also in 2001 the Tokyo metropolitan government amended its Nature Conservation Ordinance to compel developers of new private buildings with a footprint larger than 1000 sq. meters, and new public buildings with a footprint larger than 250 sq. meters, to green 20% of their roof areas, or face an annual fine. This new law had an impressive effect with the area of green roofs almost doubling in a year and several green roof construction companies being established including some by leading car manufacturers like Toyota.

Toyota Plant, Tokyo

Tokyo Municipal Offices

North America: In 2002 the Toronto City Council adopted a policy that recognized the value of green roofs in tackling the urban heat island effect and, following a discussion paper in 2005, adopted a green roof strategy. This strategy includes the production of technical booklets, grants for pilot projects, and planning agreements to secure green roofs. The city is also considering the possibility of reducing water rates for properties with green roofs.

Portland, Oregon, is considered to be one of the leading authorities on green roofs in North America. The city was encouraging roof gardens through planning incentives as early as the 1980's. There are currently over 30 green roofs downtown with plans of expansion. "There are new regulations requiring green roofs on public buildings and all new buildings developed in the city must have a roof with at least 70% vegetation cover (Grant 28)."

Louisa Residential Complex, Portland

Another major player in green roofs is Chicago, Illinois. Their driving force has been concerns over the urban heat island effect and air quality. Policies that have encouraged green roofs include an Energy Conservation Code requiring roofs to have a minimum solar reflection of 0.25. While this policy does not specify green roofs, the city authorities accept green roofs as a way of meeting this requirement. There is also a 'building green' policy that allows a higher density of development for buildings with 50% vegetated roof space. As a result of these policies, by 2004, Chicago had about 80 green roofs covering 100,000 sq. meters.

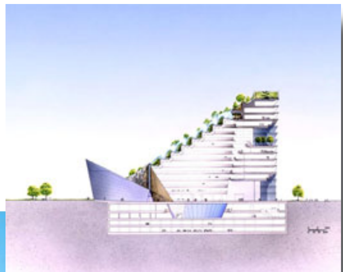
Chicago City Hall

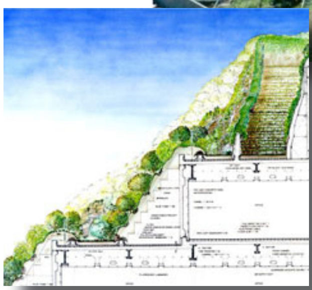
New York City is another downtown area with a serious urban heat island problem as well as storm water runoff issues. With 29% of Manhattan being flat roofs the potential is there to green an area twice the size as Central Park but green roofs are still a relatively new concept to New Yorkers. Earth Pledge, a local non-governmental organization often quoted in this project, created a green roof on their headquarters building and launched a green roofs initiative in 2001 that led to the establishment of a green roofs policy task force and the New York Ecological Infrastructure Study in 2002. Fifteen state and federal agencies and departments have participated in the initiative.

Earth Pledge Headquarters, New York City

Case Studies

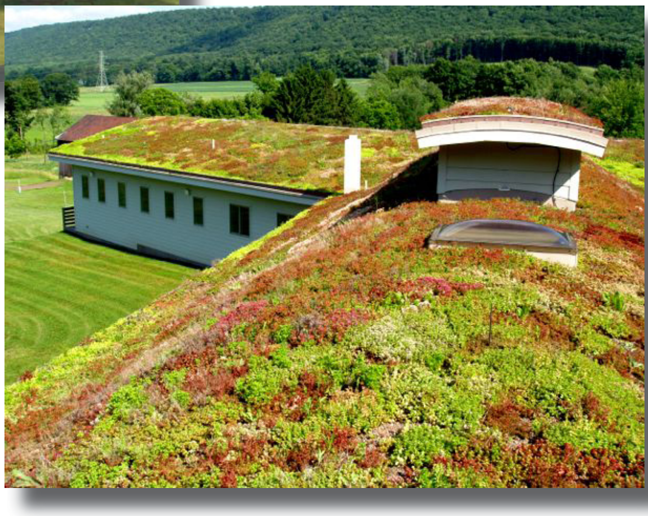
One of the most beautiful and dramatic green roofs in the world is the Asian Crossroads Over the Sea (ACROS) building in Fukroka, Japan. The project is a fusion of both public and private space, which more than doubles the size of the adjacent Tenjin Central Park. It is an elaborate series of stepped roofs that create over one million square feet of multipurpose space, including a museum, a theater, shops, and offices. Built in 1995 this intensive green roof is 100,000 square feet and has a soil depth of 12-24 inches. A special feature of this roof is a rainwater catchment system with sensors for irrigation and water reuse.





Chicago now claims more green roofs than any other U.S. city, proudly calling themselves the 'greenest city in America'. One reason for there success is the elaborate green roof on the century-old City Hall. "Built in 2001 it is one of this country's oldest green roofs and is now an important research and demonstration site for studies on the benefits of green roofs, comparisons of green roof technology, and the survivability of both native and non-native species (Earth Pledge 58)." Over 150 Varieties of trees, vines, grasses, and shrubs are the subjects of ongoing experiments. Plants are organized into bands of different colors, which change as the season progresses. These bands are not merely aesthetic, but allow the same plant material to be tried in various soil depths, slopes, and drainage patterns. Soil depths are 4 in., 6 in., and 18 in. with saturated weights of 30lbs/s.f. to 90lbs/s.f. Installation costs were calculated to be $45.50/s.f.

The location of the third case study is the Life Expression Chiropractic Center in Sugar Loaf, Pennsylvania. This green roof , built in 2001, shows a thriving sedum extensive green roof and demonstrates the ability to plant on sloped surfaces. It has proven to regulate interior temperatures while controlling runoff. There is a 5 inch soil medium which consists of 90% mineral and 10% organic matter giving it a saturated weight of merely 28 lbs/s.f. The roof was said to cost only $7/s.f. It's excellent design and energy efficiency helped it to win the 2004 Green Roofs Award of Excellence. Note how the roof changes color throughout the year. This roof is a great example of what can be expected for the Hunt Hall with both energy efficiency and cost effectiveness without adding significant load bearing issues to a green roof retrofit.



Hunt Hall

The Landscape Architecture department is moving to Hunt Hall in September 2008. Due to the move there is an excellent opportunity to install a green roof at the new location. This roof would provide both an example of emerging technology and an educational tool for future Landscape Architecture students to embrace. The lecture hall at the west end of the building provides a roof at a lower level than the rest of the building. This would allow for a viewing area from the second story hallway windows at the top of the staircase. Additionally, roof access is located at the second story hallway for ease of installation and maintenance.

From top left, clockwise: Google Earth image shows location of the lecture hall, front photo shows stepped roof heights, back side shows location of hallway windows, view of roof from windows.

The cost of a green roof depend upon the design, climate, and plant selection. For an extensive green roof, costs range between $8-20/s.f. In the case of Hunt Hall I would suggest using a 4 inch substrate and planting with sedum, a base rate of $10/s.f. would be appropriate for the Hunt Hall calculations. The roof of the lecture hall is approximately 3500 square feet, an estimate installation might cost around $35,000. These costs will be offset by the extended life of the roof and the savings in energy costs associated with cooling such a large interior space.

The greater benefit is the opportunity for Landscape Architecture students to envision a built roof as a living example. It will be a constant reminder of the significance of sustainable design in our built environment and will be a practical component in design studios.

While this is not a detailed estimate of the overall costs of installation, this project is designed to sell the idea of it's implementation. This is a challenge for future students to use this senior project as a springboard to facilitate the construction of a green roof on the Hunt Hall and use the roof for a case study within the Landscape Architecture program.

Comparing the existing Hunt Hall roof on the left and the Swathmore Building on the right you can see the potential for a dramatic demonstration green roof.

Conclusion

In conclusion, the many acres of flat rooftop space in most cities can become additional green spaces while also mimicing the natural environment in a way that restores ecosystems, combats the urban heat island effect, controls stormwater runoff, and conserves energy.

There should now be enough evidence and successful examples worldwide to be able to convince more legislators, planners, architects, landscape architects, engineers, developers and builders that green roofs have real benefits, at local and city-wide scales. It is predictable that attitudes towards green roofs will change and that they will become more commonplace and mainstream following further adoption of new guidelines on urban design by central and local government. Green roofs will make the cities, homes, and workplaces of the future, greener, cleaner, cooler, and more tranquil, with people sharing space with nature.

Millennium Park in Chicago is a 24 acre green roof that sits over a parking garage.

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