Green Roofs as Urban Infrastructure

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Based on a presentation by Christian Werthmann

Introduction

The consequences of mass urbanization have created both costs and benefits for the human inhabitants of cities and the surrounding ecosystems. Some costs include poor urban air quality, heat islands, pervasive impervious surfaces leading to sinking groundwater levels and poor watershed health, declining ecological diversity in urban areas, and an often bleak, homogeneous landscape of concrete and asphalt that can negatively affect the human psyche.

The sustainability movement has often sought to join aspects of vernacular architecture with modern technology and design to achieve a more comprehensive design solution for the conditions presented by modern architecture and urbanism. Green roofs are one aspect of this approach to sustainable architecture and urban design. Green roofs offer numerous, albeit varied, benefits depending upon regional climactic and infrastructural variables. The desire to develop alternative sustainable infrastructures to better cope with issues such as urban hydrology, energy consumption, and overall quality of life helps to drive the green roof movement.

Green Roof History

Green roofs have long existed in the vernacular architectural traditions of Northern European and Scandinavian countries. In these cases the regional climate conditions necessitated that dwellings be insulated from external temperature extremes while offering few resources for the job. Thus sod, both abundant and effective, was utilized as a key insulation tool that proved to have additional benefits. A more recent, yet not quite contemporary, example is the American Midwestern use of dwellings roofed with sod.

The beginning of what we would today call modern green roofing originated through the study of spontaneously colonized rooftops in Germany during the late 1950’s. These early explorations prompted experimentation with green roofing designs and materials, most notably in Germany, the impacts of which can be seen on a much wider scale today.

In most modern cities, rooftops exist as barren wastelands populated with utility equipment and debris. Additionally, such premises seem to evoke images of society’s seedy underbelly, as depicted in popular culture and media. They certainly do not seem like an appropriate place for children to play, or somewhere that anyone would voluntarily choose to occupy. Though urban rooftops generally carry negative con-
notations, they have been a source of much joy and positive human experience. Often described as dramatic, scenic, romantic, and even poetic, rooftops offer a rarely glimpsed view of the urban jungle.

**What is a Green Roof?**

The National Roofing Contractors Association (NRCA) defines green roofs as “plantings/landscaping installed above a waterproof substrate at any building level that is separated from the ground beneath it by a man-made structure.” Simply put, a modern green roof is composed of several layers of material placed directly on the structural surface of a rooftop, allowing predetermined plant species to colonize the allotted areas. The typical layers that are placed onto the roof surface consist of a waterproof membrane to prevent leaks, a root barrier to prevent plant roots from causing structural damage, a layer of insulation, a drainage system to prevent the roof from becoming waterlogged, the growing medium, and finally the plants themselves. This set and order of components is a guideline, not a hard rule in green roofing. Although certain layers, such as the waterproofing and root barrier, must always be used, some projects may require more or less insulation, possibly an installed irrigation system, different types and depths of growing mediums, or different species of vegetation tailored to the specific project conditions and aspirations.

Green roofs offer a variety of benefits to building occupants, as well as to the building itself. The benefits derived depend heavily upon design, planning, and site specific conditions. Generally, green roofs have been shown to extend the life of the roof itself, reduce the urban heat island effect, reduce noise pollution, filter dust and smog, and provide habitat for local wildlife. In terms of hydrological benefits, green roofs provide a much higher level of water retention than a conventional rooftop during a rain event, reducing the peak flow from an area and therefore leading to a reduction of flood risks. Green roofs improve the water quality and watershed health of an area by increasing water filtration and reducing combined sewage overflow (CSO).

**Growing Mediums**

Green roof substrates are composed of aggregate materials such as gravel, expanded clay, or diatomaceous earth which is created by firing hydrated silica mineral at high temperatures to form a light and porous substance. In order to be appropriate for rooftop designs, the growing medium must perform a series of functions and embody specific characteristics. It must be capable of absorbing and retaining water, yet also of draining freely once a predetermined threshold of saturation is reached. This feature is vitally important for plant survival and prevention of leakages. The growing medium must be light weight and composed of materials that are capable of retaining their volume over time, that is to say, materials which will not decompose. Additionally, the mixture must be capable of absorbing and retaining nutrients. Generally, the composition consists of 30-40% substrate and 60-70% pore space. A growing medium is most often chosen based upon weight restrictions specific to the project being undertaken. For most green roofs, usually in temperate climate regions, the depth of the growing medium is between 4 and 6 inches, with a maximum weight around 33 pounds per square foot (PSF). When green roofs exceed these specifications, they are typically referred to as semi-intensive or intensive green roofs, or rooftop gardens.

**Intensive vs. Extensive**

Green roofs can be generalized into two distinctive categories: intensive and extensive. The differences amount to weight variations, plant species composition, irrigation needs, aesthetic and habitation possibilities, and depth of growing medium.

Extensive green roofs are composed of a shallow substrate supporting low growing, drought tolerant plant species (Figure 2). These green roofs are not typically designed for human traffic beyond that needed for occasional maintenance, although there are exceptions. From a functional standpoint, extensive roofs are the most cost efficient, since they are much cheaper to install than intensive green roofs and produce maximum ground cover, which results in greater benefits for the performance of the building itself. When an extensive green roof is installed, the entirety of the rooftop surface is covered with green roofing materials, growing substrate, and living plants. Generally it is best if the roof has a very shallow slope, since steep slopes complicate installation and may cause maintenance problems. However, extensive green roof designs are the most effective in successfully dealing with the complexities of slope, since they maintain a continuous bed of low growing vegetation with minimum potential for erosion and wind related problems.

Intensive green roofs typically have a deeper growing substrate, higher weight requirements, and a wider variety of plant species, such as small trees and other vegetation requiring deeper soil (Figure 3). These roofs are most often intended for human interaction, as they are frequently designed as fully usable landscapes. Roof gardens can fit into this category, although there can also be roof gardens that are not intensive green roofs.
All green roofs require watering during the initial period of plant colonization and root system establishment. In temperate climates an irrigation system can be avoided in most cases. In Mediterranean, hot and dry climates, an irrigation system is often necessary to keep the plants alive during long periods of drought, or if a certain visual aesthetic is to be maintained throughout the year.

Green Roof Plants

Contrary to their name, green roofs are not always green. The color may differ based upon the species composition selected or the local climate and seasonal conditions. In temperate climates typically succulents, such as sedums, are chosen for their high degree of drought tolerance, their tendency to grow and spread close to the ground, their ability to withstand temperature extremes, and the wide variety of aesthetic choices they offer (Figure 4). Other types of species, such as grasses and wildflowers, can also be chosen and may actually prove to be more suitable depending on the intentions of the design project. Vegetation can also be selected to attract butterflies and other types of wildlife.

Green Roof Economics

The material cost of installing a green roof varies greatly around the world. For example, in Germany installing a green roof would be considerably cheaper than installing the exact same design in the United States, due to a well established green roof industry. These reduced costs result from the effect that the mass production of green roofs and economical green roofing technologies have on market economies. This is an important factor when considering the greening of an urban landscape, since a minimum 20% of existing rooftops should be greened in order to have a measurable positive impact on local hydrology and watershed health.

The Harvard University Graduate School of Design’s Green Roof Initiative provides a case study on green roof economics in action (Figure 5). The specific costs per square foot of a green roof ultimately vary from project to project. In general, greater weight, depth of growing medium, and elaborateness of additional design features will result in increased overall construction costs. The design at the GSD consisted of a waterproof membrane on top of the roof decking, which happened to also serve as a root barrier, a gravel and mushroom compost mix as the growing substrate, and sedum cuttings harvested from other existing projects. Three studies were undertaken using different design intensities. This project was implemented to survey the effectiveness of different approaches to green roof installation in an effort to reduce the overall installation costs of a green roof. The project estimates a cost of around $2-$3/ft², as a result of intensive preconstruction planning and investigation of onsite conditions.

The estimated cost of the first study was $0.25/ft² (plus labor) for sedum cutting and unamended gravel ballast. The second study consisted of sedum cuttings and gravel ballast with a 5% addition of organic compost at a cost of $1.25/ft² (plus labor). The final and most successful study cost $2.60/ft² (plus labor) for sedum cuttings placed in a mix of 80% lightweight aggregate and 20% organic compost. In the first study all the sedum cuttings died, in the third study the sedums survived but grew sparsely, and in the second study they grew quite well due to the increased amount of nutrient rich compost.

Inhabiting Green Roofs

With an ever expanding global population increasingly migrating to cities to live and work, the goals of sustainable living necessitate that urban areas be built more densely. However, this goal can never be realized if the urban city is not made more habitable at the same time that it is made more dense.

Rooftops are a dramatically underutilized resource in the urban environment. A large percentage of outdoor space in dense urban settings, up to 30% in many cases, consists of rooftop surfaces. Green roofing provides a way to reclaim the experience of outdoor space high above within an urban environment, meshing utilitarian and egalitarian functions. Intensive green roofs and rooftop gardens are commonly designed with human habitation and interaction in mind. Access to greened rooftops improves the psychological disposition and productivity of those who choose to take advantage of them. An example of a habitable green roof can be seen at the American Society of Landscape Architects (ASLA) in Washington DC (Figure 6). This green roof, by Michael Van Valkenburgh and Associates, features two raised areas with shallow lightweight soil depths and a third raised area over the entryway with deep lightweight soil depths. This design incorporates aspects of both green roofs and roof gardens to arrive at a habitable, functional, and aesthetically rich rooftop space.

Humans are not the only ones inhabiting green rooftops. Whether intentionally or unintentionally, green roofs often attract a variety of wildlife to their scarce natural space. Usually the attraction is intentionally developed through plant selection and species composition. Insects (such as butterflies) and their predators (such as birds and lizards) are frequent guests of green roofs.
Unconventional Green Roofs

Sedums and other succulents dominate the green roof landscape, yet offer little ecological value themselves. They provide a high degree of functionality, which is why they are so commonly used. Certain species may attract insects and their predators, but do not provide any substantial wildlife habitat. Planting native grasses is one way to create a functional green roof while providing habitat for insects, birds, and other wildlife. Although grass roofs require more maintenance, like mowing and weeding, they can also increase the ecological value and experiential quality of the green roof. Green roofing can also work in concert with integrated energy production systems like photovoltaic panels. These systems provide further benefits for the buildings operation as well as providing additional shading for the green roof plants.

Food production potential can be incorporated as an aspect of a green roofing project (Figure 7). This application depends heavily on local climate conditions, since food plants are typically seasonal plants and often need to be replanted each season. This aspect of green roofing is additionally limited by the depth of the growing substrate on the rooftop. Many food producing crops need relatively deep soil to reach maturity and produce fruit. Clever solutions can be found to help solve this problem. For instance, locating points on the rooftop that may be able to carry greater loads, such as above columns or other load bearing structural areas, can provide locations to install planters with deeper substrates.

Green Roofs in Arid Climates

Green roofs are still a new infrastructural tool in dry climates, but their effect on local hydrological conditions and their cooling benefits can make their application desirable. A region can be considered arid if it receives 20 inches or less of rainfall a year. Ground water recharge and runoff quality are major concerns for dry areas (Figure 9). Austin, Texas, for example, receives an average of about 31 inches of rainfall annually. Though it is not an ‘arid’ region, it does certainly deal with issues of water scarcity and drought, which lends validity to the use of native plants in green roofing (Figure 8).

Green roofs must be irrigated in regions receiving less than 500 mm (about 20 inches) of rain annually. If an irrigation system must be installed, the source of the water should be derived from recycled onsite sources as much as possible and applied via a slow drip watering system. Harvesting the condensation from air conditioning units can be useful for retrofit green roofs, though there are more effective means of harvesting water for new construction if proper planning is done. Installing large underground cisterns to retain collected rain water for use onsite can be a very effective tactic for new development. Methods of watering are equally important to the overall success and sustainability of a green roof in these regions.

In dry climates the root systems of rooftop vegetation need to be encouraged to grow as deep as possible. Encouraging deep root systems allows the plants to maintain access to a larger amount of moisture, helping them survive droughts with less help from irrigation. To best provide for this root depth, the growing medium depth is increased to 12 inches rather than 6. Not only does this greater depth provide moisture in its lower levels for plants, but it also can cool the building better as the plants will grow larger and shade a greater area. However, the delicacy of conditions in dry climates can often result in unforeseen challenges. For instance, a non-irrigated green roof can actually be worse for the interior microclimate of a building than a conventional roof. When exposed to full daytime sun due to a lack of continuous plant cover, the rooftop substrate can act as a thermal blanket, making it more difficult to let the building cool out at night.

Urban “heat islands are created when dark-colored, impermeable surfaces absorb heat energy and radiate it back into the air”. This can be an especially severe problem for cities in hot, dry climates. For instance, during summer months it is often 16 degrees Fahrenheit hotter in the center of Mexico City than in surrounding outlying areas. A well planned green roof is one tool that can be used in conjunction with many others in order to have a substantial impact on urban environmental problems like heat islands and poor water quality.

Dust accumulation can have a large negative impact on ground water quality in dry regions. When long periods of time pass without any substantial precipitation, dust and soot accumulate on rooftops, green or otherwise. When rain finally does come, all this accumulated particulate matter is discharged with the runoff water. Green roofs can substantially reduce this negative effect by filtering the runoff water and trapping some of the airborne pollutants. Green roofs can also reduce the severity of

Figure 8: Austin, TX residential green roof with native plants
Figure 9: Sample green roof runoff performance chart
peak flow conditions in dry regions by retaining a large percentage of annual rainfall, about 70% in most cases. This increased retention can help mitigate flooding, which can cause millions of dollars in property damage and result in injuries or death.

Though green roof applications do exist in dry climate regions around the world, their development has been a recent occurrence, so it is not yet clear how well they will perform. Only time will tell.

Conclusion

Green roofs offer a multitude of benefits for building occupants, building operators, and the surrounding environment. These benefits include greater stormwater retention and filtration, increased ground water quality, increased wildlife habitat, reduced noise and air pollution, and increased internal and external thermal stability. Worker productivity, physical health and mental well-being also stand to benefit from a properly installed and maintained green roof.

The importance of planning properly for a green roof project must be stressed. In order for a green roof to provide the maximum amount of benefit while remaining economically viable, green roofing professionals ought to be brought into the planning and design processes. Hiring a green roof consultant can address many of these issues when they are most readily impacted: the beginning phase of project planning. Tailoring a project to the specific regional and infrastructural conditions will help to achieve the most ecologically viable and sustainable results.

Notes


Biography

Christian Werthmann is currently an Associate Professor of Landscape Architecture as well as the Department Director at the Graduate School of Design at Harvard University. Throughout his research, he has focused on implementing alternative landscape infrastructures in heavily urbanized areas. Christian Werthmann is a co-founder of “TransUrban”, an interdisciplinary research group devoted to the investigation of built experiments in sustainable urbanism. His profile may be viewed at the following address: http://www.gsd.harvard.edu/people/faculty/werthmann/index.html

Further Reading


Figures

Figure 1: MEC’s Green Roof. Chicago, IL. http://flickr.com/photos/sookie/156954114/
Figure 2: Extensive Green Roof. http://www.roofmeadow.com/images/Fencing_colors.JPG
Figure 3: Solaire Building Intensive Green Roof, New York. http://greenroofs.wordpress.com/contact-us/
Figure 4: Sedum Varieties. http://www.florico.com/images/2inSUCCULENT.JPG
Figure 5: GSD Green Roof Initiative. http://www.gsd.harvard.edu/people/faculty/werthmann/research.html
Figure 6: ASLA Green Roof. From Christian Werthmann’s GR presentation 10-27-08: Courtesy of Sam Brown
Figure 7: Sam Brown
Figure 8: Austin, TX residential Green Roof with native vegetation. http://www.penick.net/digging/?cat=34
Figure 9: Green Roof Runoff Performance. http://www.wbdg.org/resources/greenroofs.php