PROMOTING SUSTAINABLE GREEN ROOFS THROUGH LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN (LEED)

by

AUBREY HAKE

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Approved by:

Major Professor
Dr. Tim Keane

Abstract

The multidisciplinary quality of green roofs involves landscape architects, architects, structural engineers, horticulturalists, and increasingly ecologists in design and implementation. A standard of measurement of green roof sustainability is necessary with increasing professional and public interest in green roofs and green roof impact on stormwater and urban ecology. Currently, green roof LEED (Leadership in Energy and Environmental Design) credits do not address the sustainability of green roofs. The intent of this research is to take a critical look at green roof sustainability in regards to the United States Green Building Council (USGBC) LEED green building standard credits. It is also my intent to be (at least) a small, yet integral part in advancing the LEED standards and environmental standards as a whole.

Precedent studies, archival research and professional interviews provide a solid foundation for the development of green roof LEED credits to measure success and increase green roof sustainability. Dialog with the USGBC and professionals provide a sound base for the development of the green roof criteria.

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CHAPTER 1 - Introduction

Society is at the threshold of a global sustainable movement. There is increasing demand for healthy environments from everyday products such as cleaners to protecting what is left of the natural habitats surrounding cities and towns. Designers, particularly landscape architects, have a responsibility to the land, plants, animals, and society. Many designers are aware of the harmful impacts that may occur as a result of built projects, but do not move forward to change common practice because it is too expensive, not the type of work they typically do, or their clients simply don't want it. Education regarding sustainable practices is crucial for designers and clients alike. Green roofs are one method to lessen the impact of buildings and help improve the environment.

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System is continuously developed and refined by the United States Green Building Council (USGBC) whose members come from every sector of the building industry. The standards were developed to define "green building," establish a common standard of measurement, promote integrated and whole building design practices, recognize environmental leadership, encourage green competition, raise consumer awareness of green building benefits, and to transform the building market (www.usgbc.org, 2006).

The LEED standards are based on scientific standards. State of the art strategies are emphasized for sustainable site development (SS), water savings (WE), energy efficiency (EA), material selection (MR), and indoor environmental quality (EQ). "Innovation in Design" points are available for projects that go above and beyond credit point requirements. Projects may be certified, professionals accredited, and training and practical resources are offered through USGBC, a non-profit organization (www.usgbc.org, 2006). The USGBC states, the LEED standards are “based on well founded scientific standards” that “emphasizes state of the art strategies” with a common purpose of transforming the building marketplace into a sustainable marketplace (www.usgbc.org, 2006).

Currently the USGBC has 7500 organizations spanning all building industry sectors with 75 regional US chapters, accredited professionals, emerging green builders, founding members and executives. There are roughly 35,486 accredited professionals (www.usgbc.org, 2007). The Emerging Green Builders is a collection of students and young professionals that promote integration of future leaders into green building (www.usgbc.org, 2007).

LEED and green roofs have one thing in common in the United States. Both are relatively new and are being tested by researchers and professionals. Some argue the difficulties of LEED and green roofs, saying they are too expensive and require too much effort on part of the designers and clients. Some place a great deal of faith in both systems to move the design professions and development industries toward more sustainable practices. Reality lies somewhere in the middle. Designers, policymakers, politicians, and the general public must work together to make sustainable design, in all aspects, effective. Those concerned with pushing sustainable design forward must keep trying. Every small step makes a difference.

Landscape architects and all design professionals impacting the built and natural environment are responsible for the effects of our actions upon the land and the processes used to create materials and products that we specify. "Since energy use in buildings is responsible for nearly half of the nation's greenhouse gas emissions, Mazria believes architects are primarily responsible for resolving the climate challenge," (Schendler, 2005). Edward Mazria is the author of Architecture 2030 and the 2030 Challenge that calls for the design of high performance and carbon neutral buildings and developments (http://www.architecture2030.org/open_letter/index.html, 2007).

Not only does it take energy to produce materials that make up the environments designers create, but it takes considerable energy to construct the projects. Therefore, it is critical that landscape architecture, as a profession, step up to meet the climate challenge.

Green roofs are one method to improve sustainable building that can have a positive impact on the surrounding environment by reducing the urban heat index and slowing the velocity and decreasing the amount of stormwater released into urban sewers. In *Green Roofs: Ecological Design and Construction* (2005):

> "By requiring heavy irrigation, herbicides and pesticides, or new plantings every season, many traditional roof gardens ***place a burden on their local environments***. In contrast, ecologically constructed roof gardens, known as green roofs or eco-roofs, have a net-positive impact: capturing rainwater to reduce stormwater runoff pollution, covering a large portion of the roof surface to insulate the building and cool the air, and creating habitat for native or migrating species. The design and construction of modern green roofs demands a holistic approach to maximize the benefits to the building and the community" (Earth Pledge, p.23).

Europe is decades ahead of North American green roof research, but the research currently available shows numerous benefits of green roofs for the environment. Green roofs are a valid best management practice (BMP) for sustainable design and are gaining acceptance in North America, including colder climates such as Illinois and Minnesota. The examples of green-conscious cities such as Chicago, Illinois and Portland, Oregon are increasing the knowledge and understanding of green roof systems and their benefits, and are beginning to influence cities and projects across the nation. While progressive cities and projects are appearing across the United States much of the general public and developers are still uninformed and reluctant to employ the green roof concept.

It is not the intent of this work to prove the validity of green roof benefits. Rather, I take a critical look at green roof sustainability in regard to the United States Green Building Council LEED green building standard credits in hopes that both the quality and image of green roofs will continue to improve and provide all of the environmental, ecological, and social benefits. It is also my intent to be (at least) a small, yet integral part in improving the LEED and other environmental standards as a whole. Developing dynamic LEED credits with requirements for certification that span initial installation and future green roof functions has the potential to change how environmental and sustainable design is perceived.

Research Question

The initial question for this research was “Why is it important to develop a LEED standard for green roofs?” This study began by addressing the question through archival research, an assessment of precedent studies, and professional interviews. Through gathering this information from archival research, precedent studies, and professional interviews, the research question shifted to “Why is it important to improve green roof sustainability within LEED?” The shift was a direct result of conversation with LEED Program Coordinator Deon Glaser. She advised against focusing on the development of a separate LEED standard for green roofs because it only focuses on one aspect of a building. For a building to be sustainable, the entire building must be considered. As a result, I decided to focus on existing LEED credits that include green roofs and how to improve the credits to include sustainable requirements for green roofs. Other credits may evolve as green roof technology improves and evolves. Green roof criteria outlining sustainable methods formulated from the literature, precedent studies and interviews is presented as a starting point for the development of specific green roof LEED credits.

General answers to the research question regarding the importance of LEED green roofs credits follows. First, there is relatively little current published or accessible information on guidelines for sustainable green roof designs in the United States. Recently published are the German FLL Guidelines or Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. known as The Landscaping and Landscape Development Research Society e.V. Developed in Germany, the research and FLL standards are specific to that region of the world and are a milestone in modern green roof development.

While North American designers and the green roof industry can benefit greatly from the FLL standards, specific standards for North America are necessary because of climatic differences from Europe and across the North American continent. Six ASTM (American Society for Testing and Materials) standards related to green roofs are currently available and are discussed in chapter two. The FLL and ASTM standards are a first step among many for the development of a solid base of standards for green roofs in North America. A LEED standard that incorporates more detailed credits for green roofs will promote guidelines specific to North America and would allow designers and clients to benefit from meeting the criteria and integrating the green roof into the whole building system.

A LEED certified building with a green roof provides great publicity for developers and owners in regards to marketing potential and real estate value; it has the potential to save the client money, and can lessen the impact of a building on the environment. Specific green roof credits would ensure a more sustainable product. Providing guidelines and LEED points to achieve for green roof performance criteria would help designers focus on methods to create sustainable green roofs and incorporate them into a whole green building system.

Most of the LEED credits are specific to building materials and functions with some regard to site functions. Green roofs do not fall specifically under landscape architecture, architecture, engineering, horticulture, or ecology – they relate to each of the fore-mentioned disciplines.

Research Intent

Initially my thought was that creating a LEED standard specifically for green roofs would offer an opportunity to emphasize and develop the dynamic and living quality of green roofs. However, because there are current LEED credits that address green roofs this research has taken a turn to focus on improving existing credits and suggesting more credits specific to green roof sustainability. While green roofs are man-made, they have the potential to function ecologically – and to become stable urban, suburban, or rural habitats – on a building structure. Credits developed with specific sustainability objectives would promote a direct human role in green roof ecology and natural processes. Mimicry of natural processes is a viable solution for green roof sustainability and creates a dynamic relationship between the man-made and natural environments.

The results of this work are intended to serve as a starting point for the development of a series of LEED green roof credits with the intention of integrating them into the “bookshelf method” USGBC is currently developing (Glaser, 2007). Other research results and benefits are expected to include a starting point for integrating developing greenroof standards (ASTM) in the United States into the LEED program as well as including updated information and requirements for green roofs.

Current LEED standards have several ways to obtain points in relation to green roofs, but do not determine whether a green roof is sustainable which is deleterious to the objective of supporting green roofs in the first place. Requiring a green roof but not placing guidelines for sustainable performance objectives leaves the sustainability of the green roof and the entire building in question. My goal is to provide the USGBC with information necessary as a starting point to improve green roof credits. I plan to submit the results of this work to a USGBC committee who may decide whether to develop new credits or to integrate the findings into existing credits as the USGBC seeks to review and improve its green building standards.

Several important questions of this study follow:

1. Where should professionals draw the line for a green roof that is LEED appropriate?

2. Can professionals pass judgment on green roofs that serve no ecological function?

3. Are there any “good” green roofs to base precedent studies on?

These questions are discussed in Chapter 4: Results.

Green Roof Sustainability

I believe a series of green roof LEED credits is necessary to improve the sustainability of green roofs within the LEED system and to create and maintain strong standards for green building. The issue of defining sustainability arises. Sustainability is difficult to define and in continuous debate by scholars and designers. Sustainable design can have different meanings to different people with varying objectives. For the purposes of this thesis I have chosen to use this definition presented by Sim Van der Ryn and Stuart Cowen as they summarize David W. Orr's characteristics of ecological sustainability:

> "These characteristics imply that the only long-term approach to building a sustainable world is to redesign the details of the products, buildings, and landscapes around us. Such redesign – attending carefully to scale, community self-reliance, traditional knowledge, and the wisdom of nature's own designs – requires patience and humility. It is a search for the nitty-gritty design details of a sustainable culture, one grounded in the texture of our everyday lives," (Van der Ryn, 1996).

This definition supports the USGBC's objective of transforming the building industry. I believe the definition of sustainability will evolve as the earth and its ecosystems have evolved over time and as we, as the human race and as designers, evolve with it. We will continue to learn the intricacies of nature and the scientists, designers and innovative thinkers of the world will unlock possibilities in the future unimaginable to us at the present time. As the sustainability debate continues in academia and in the "real world" it is my hope and goal as a future design professional that our technologies will emulate nature.

Thesis Format

The following chapters include: Background, Methodology, Findings, and Conclusions. The Background Chapter, a basis for the remainder of the thesis, presents and defines green roofs and related terms, history, standards involving green roofs, LEED, the history of LEED, and the precedent studies, and other researched green roofs affecting the results and conclusions. The precedent studies chosen were the Chicago City Hall in Chicago, the American Society of Landscape Architects Green Roof in Washington, D.C., and the Des Moines Public Library in downtown Des Moines, Iowa. Three other, less intensively studied green roofs are also considered: GAP Headquarters in San Bruno, California, Ford Dearborn green roof in Dearborn, Michigan, and The Life Expressions Wellness Center in Sugarloaf, Pennsylvania. Chapter Three, Methodology outlines the qualitative research methods including archival research, precedent studies, and professional interviews. Based on the research methods, I gathered and analyzed the findings, which are found in Chapter Four, Findings. From the findings I formulated conclusions and suggestions for green roof best practices and LEED credits which are found in Chapter Five, Conclusions.

CHAPTER 2 - Background

Introduction

Green roofs bring an awareness of the importance of fitting buildings into the landscape and working to enhance the connection of the built environment with the natural environment. According to David Yocca, Director of Landscape Architecture and Planning at Conservation Design Forum in Elmhurst, Illinois, green roof performance is dependant on the building program (Yocca, 2007).

The intent of this thesis is to take a critical look at the Leadership in Energy and Environmental Design (LEED) green building standard credits involving green roofs. Currently, there is a shortage within the standards of specific criteria and guidance for green roofs and most of the standards focus on building elements. While the program of the building guides green roof performance there is a need to take a closer look at the promotion of green roof sustainability to produce more integrated design through LEED standards.

Before discussing the specifics of the LEED green roof credits it is important to understand the evolution of green roofs throughout history, green roof terminology, LEED, and the current green roof standards such as FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.) and ASTM (American Society of Testing and Materials). Development of criteria that may be used to create specific green roof LEED credits (dependent on the building program) is facilitated through archival research and precedent studies, and supplemented through professional interviews. After a discussion of green roofs and LEED, three precedent studies are presented.

Researchers in North America have conducted a significant amount of research showing the benefits of green roofs, but long term studies are needed before we will be able to see the real extent of green roof benefits. Green roofs serve multiple purposes, "The greatest potential of economic green roofs is not in material but in shaping human value," (Yocca, 2007). Green roof value extends beyond the physical and measurable benefits. The ability to use space not typically thought of as inhabitable opens up new possibilities for a green roof market and human space.

Designers can turn unused roof top space into an amenity. As Snodgrass describes, "It is easy to see how roofs are both a part of the current problem associated with urban heat island effects and stormwater runoff, but they could also be a part of the potential solution," (Snodgrass, 2006). Millions of square feet within our urban, suburban, and rural areas have the potential to improve the environment not only from a functional and ecological standpoint but from an inhabitable space and human value standpoint.

Green Roof Basics

The following terms are basic green roof references currently used in the market.

Definitions

Green roofs: Vegetation covered roofs that include three basic types: extensive, semi-extensive, and intensive. The term green roof implies that the vegetation is always green (Emilsson, 2006). A common plant used on many green roofs, sedum, has flowers in a variety of colors. The foliage may also change color depending on seasons and dormancy periods.

Extensive: Also known as eco-roofs, extensive roofs are low profile with thinner layers (drainage, media, and plants) than semi-extensive and intensive green roofs.

Low growing plants are established in .8 inches to six inches of growing media. These rooftops are usually less expensive and lower maintenance when compared to other types of green roofs (Dunnett, 2004).

Semi-extensive: These green roofs are designed to be low maintenance, but with deeper layers (drainage, media, and plants) than extensive but not as deep as intensive. Typical layers range four to eight inches. A larger variety of plants can grow on this roof when compared to an extensive roof (Dunnett, 2004).

Intensive: Intensive green roofs have the deepest layers (drainage, media, and plants) and a wider plant variety. The growth media is eight to twelve inches in depth. Many intensive roofs are designed to be at least partially accessible (Dunnett, 2004).

Rooftop Gardens: Rooftop gardens are accessible areas on the roof with containerized plants instead of layers of membranes and growth media that are installed directly on the roof deck (Dunnett, 2004).

Eco-roof: synonym for "green roof". Also used to distinguish vegetated roofs from roofs that have another ecological function, for example, a roof covered with photovoltaic cells (Dunnett, 2004).

Brown roof: a roof purposefully covered with substrate or a loose material such as urban development by-products like brick rubble, crushed concrete, and sub-soils. Vegetative colonization of the roof is possible but occurs without human intervention (Dunnett, 2004).

Vegetated roofs: " In my opinion, the term *vegetated roofs* is a more precise but at the same time less restrictive description of the system, as it focuses on the fact that the system includes vegetation and that it is installed on buildings," (Emilsson, 2006).

Plant-based Surface Systems: "An alternative scientific term, *plant-based surface systems* (PBSS), has been proposed by Tapia Silva *et al.* (2006)," (Emilsson, 2006).

To understand a green roof system, a basic knowledge of typical green roof components is essential. Every green roof starts with the base layer, the roof deck, and builds up from there. Osmundson gives a description of basic green roof components:

Roof Slab: The roof slab must be able to bear dead and live loads.

Dead Load: Dead loads are calculated as the weight of roof structure and permanent fixtures or elements including roof components, snow load, permanent utility structures and mechanical equipment (Osmundson, 1999).

Live Load: The live load includes occupants, furnishings, and temporary maintenance equipment (Osmundson, 1999).

Waterproof Membrane: Installed on the surface of the roof in liquid or sheet form, the waterproof membranes purpose is to keep outside water from leaking and creating damage inside the building structure. Caution during construction of a green roof is important to prevent mechanical damage and the membrane should also be protected from root penetration. Waterproof membrane specification is the responsibility of the architect, though all involved may be named if the membrane fails (Osmundson, 1999).

Protection Board: A rigid, durable material installed on top of the waterproof membrane that protects the membrane during construction (Osmundson, 1999).

Insulation: Typically a 2" layer of rigid extruded polystyrene foam board. The foam board has a measurable R-value (or measure of thermal resistance of the foam at a certain thickness), whereas other green roof layers are difficult to measure accurately because of variable moisture content (Osmundson, 1999).

Concrete Protection Slab: The smooth surface of a concrete slab can create ample drainage and protects lower layers from rapid temperature changes, mechanical damage, and Ultra-Violet rays. The 2 ½ to 4 inch thick slab may not be necessary or practical in cold climates where freeze/thaw cycles can cause cracking (Osmundson, 1999).

Drainage Medium: A porous material that is placed above the concrete protective slab and has the ability to support materials placed above it. The drainage layer can also be made of plastic with cells that hold water for plant uptake and openings which allow water to drain through. These plastic cell structures are available with filter fabric attached to one side (Osmundson, 1999).

Filter blanket: Placed over the drainage medium to prevent particles and debris from clogging the drainage medium. Water must be able to filter through and it must be rot resistant (Osmundson, 1999).

Planting Medium: The medium typically consists of porous, mostly inorganic media that is lightweight with water and nutrient holding capacity suitable to the plant selections. Examples of inorganic materials are: lava, volcanic scoria, Lelite, pumice, diatomaceous earth, sand, expanded and active clays, expanded shale, gravel, bricks, and tiles (Snodgrass, 2006).

Mulch/Erosion Control Mats: Osmundson recommends using mulch for roof gardens, but it should be used carefully on extensive green roofs, if at all. Any decayed humus on an extensive green roof will, over time, add up in extra load weight. Many extensive green roofs have low growing plants that cover the roof quickly, and there is also the possibility that spreading mulch over cuttings or plants that are just getting started will kill them. The American Society of Landscape Architects green roof used an erosion control vinyl matrix and a gravel material that acted as a mulch.

Plants: Plant selection for green roofs cannot be treated the same as projects at grade. Ed Snodgrass (2006) presents a solid explanation of plant selection in his book,

Green Roof Plants: Green roof plants are tougher and less nutrient reliant (Snodgrass, 2006). The same plants that may flourish on the ground may have a hard time surviving on a roof. Experts such as Snodgrass and university research conducted in the United States are valuable resources when selecting plants for a green roof. Snodgrass describes a general green roof plant as, "…the most successful green roof plants are low-growing, shallow-rooted perennial plants that are heat, cold, sun, wind, drought, salt, insect, and disease tolerant," (Snodgrass, 2006).

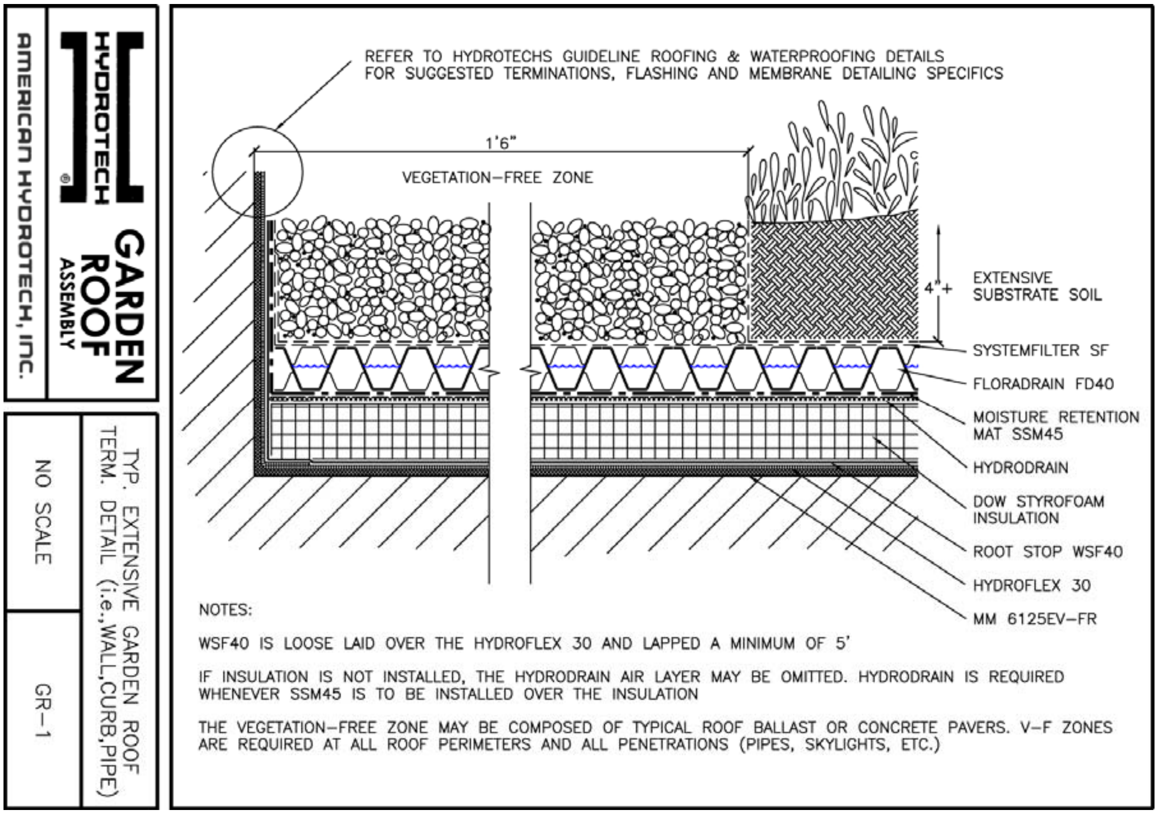
Green roof design follows the function of the building and site. Each green roof project has specific challenges. Many green roof systems are available from roofing companies and a growing number of green roof companies. Special care should be taken where there are any roof penetrations for elements such as roof drains, electrical cords, water supply, etc. Any penetrations should be limited as much as possible because they allow for the possibility of a leak, even if carefully waterproofed (Osmundson, 1999).

The following image is from Hydrotech's website and shows a typical section of one of their green roof assemblies, beginning with the concrete roof deck, Monolithic Membrane 6125-EV®, root barrier, moisture retention mat, Gardendrain/Floradrain, system filter, engineered soil (LiteTop®), and the vegetation (www.hydrotech.com).

Figure 2.1 Hydrotech Extensive Green Roof Assembly
(www.hydrotech.com).

This image represents a technical drawing of Hydrotech's extensive green roof assembly.

Figure 2.2 Hydrotech Extensive Green Roof Assembly Technical Drawing (www.hydrotech.com).

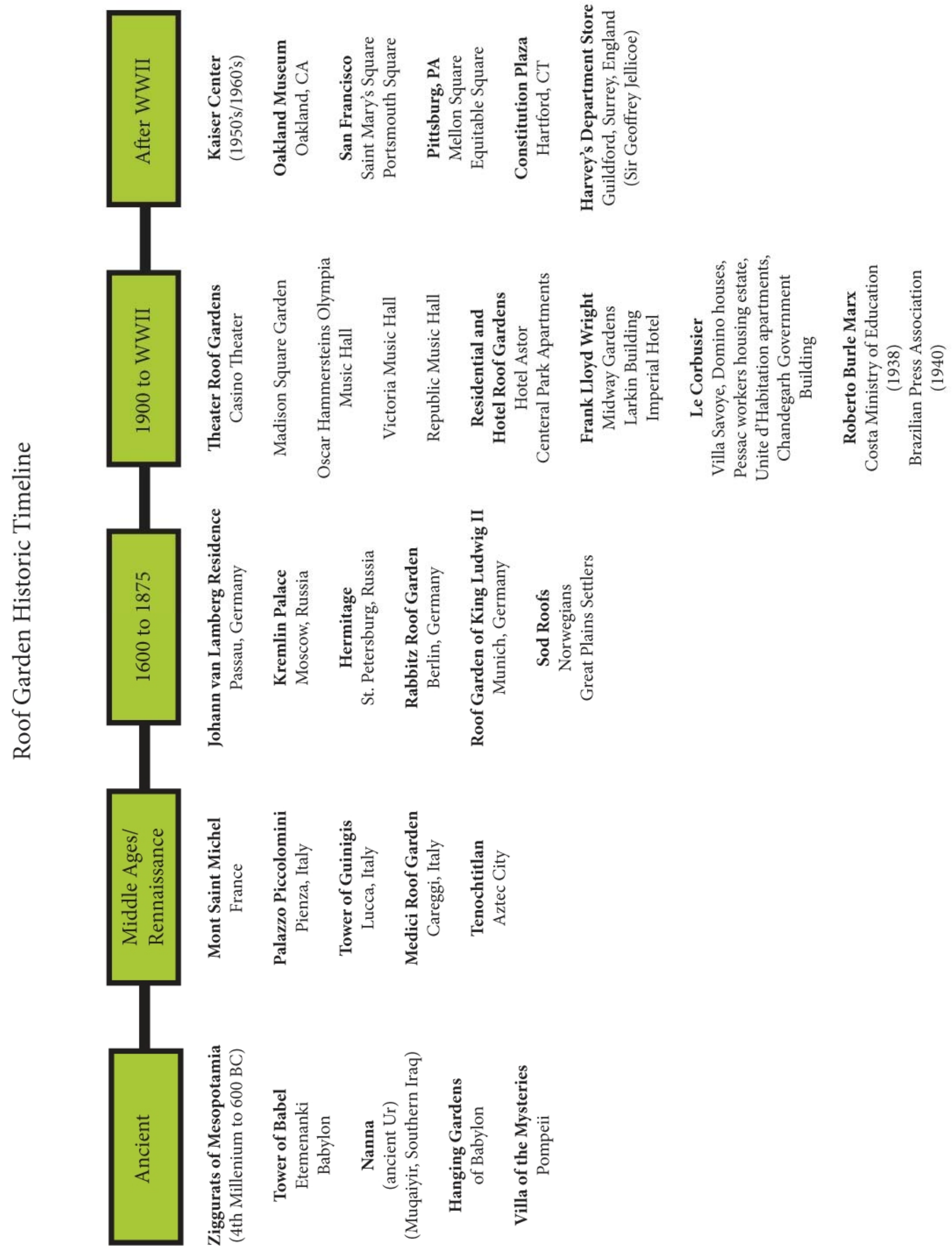


Green Roof History

The timeline on the following page is a general expression of green roof history according to Osmundson (1999). This timeline focuses on the progression of green roofs from ancient times, the Middle Ages and Renaissance, 1600-1875 AD, 1900 to WWII, and after WWII.

Figure 2.3 Historic Green Roof Timeline

(Osmundson, 1999).



Materials

Several differences between ancient roof gardens and modern roof gardens are apparent. Ancient roof gardens were mostly a display of wealth and power. Materials included deep layers of soil with trees and shrubs. The hanging gardens of Babylon are believed to be built up in tiers, vaults, and terraces. Stone beams supported the roofs where a layer of reed in tar, two courses of backed clay brick with cement, and a lead covering for a waterproofing layer was used. Conduits brought irrigation water from the river (Osmundson, 1999). The hanging gardens and many ancient and historic gardens were elaborate and formal.

Lead was a common material used to waterproof historic roof gardens. A German builder used vulcanized cement as waterproofing during the mid-1800's. Another German green roof attempted to use copper plates to waterproof one green roof, but the plates caused so much leaking that the gardens were demolished in the late 1800's. Sod roofs were popular in Norway and among the Great Plains settlers (Osmundson, 1999).

The 1950's and 60's brought materials such as broken drain rock with no filter which caused the planting medium to wash into open spaces. As a result, filter fabric was added in the mid-1960's. Grass-Cel, a honeycomb-shaped high impact plastic used for parking areas and walkways, also worked well for green roofs when turned upside down and used for drainage. As green roof technology progressed, many companies produced versions of Grass-Cel with filter fabric attached.

Since the 1970's modern green roofs have focused on functional and ecological benefits as opposed to displays of wealth and power. Garden roofs from the ancient to the 1970's primarily focused on recreation and displaying wealth and power, (Emilsson, 2006). The first modern drainage materials were pebbles, broken rock and clinkers or burned bricks which were not used after WWII. These materials worked well but were heavy (Osmundson, 1999).

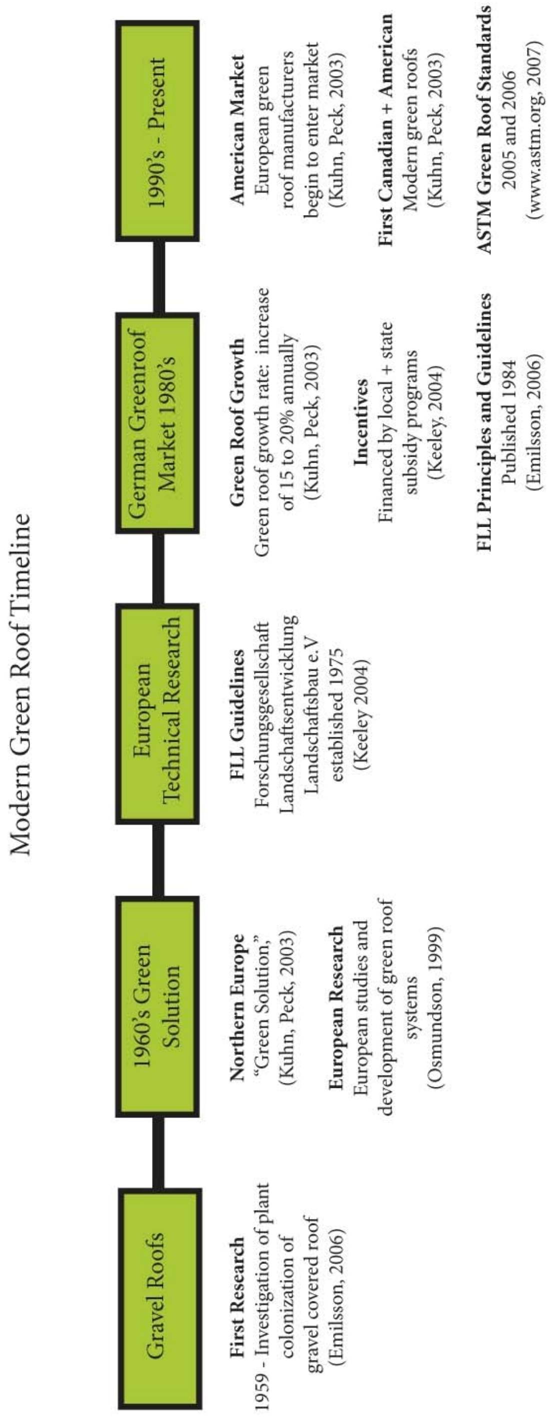
Connecting the links between historic and modern green roofs provides a basic knowledge of green roof development over time. While historic garden roofs focused on the aesthetic, modern green roof evolution (in the last century) has found benefits beyond the visual.

> "The argument for planting the cities of the United States has been largely based on aesthetics, with little thought given to the broader effects of overall environmental quality. We would do well to take note of the European experience and to adopt similar corrective programs to improve the environment of our cities," (Osmundson, 1999).

While this is a valid point, it is still important to emphasize the shaping of unused space for human habitation.

The modern green roof timeline (Figure 2.4) represents the development of modern green roofs from 1959 to the present. It includes key events and research that led up to the developing green roof technologies of today.

Figure 2.4 Modern Green Roof Timeline



Modern greenroofs are linked to German gravel covered roofs with spontaneous germination of plants.

> "One of the first investigations of a system similar to the modern extensive vegetated roofs was carried out as early as 1959, on 1- to 94-year-old spontaneously vegetated sand and gravel covered roofs, so-called *holzzement* (wood concrete) roofs (Bornkamm, 1959). The gravel was placed on the roof to protect the tarpaper sealing membrane from degradation by UV-light, wind, rain and fluctuating temperatures. The unwashed clay-sand-gravel mix that was used was rapidly colonised and developed into several different stable vegetation systems ranging from *Poa compressa* communities on thicker sites to *Sedum* spp. and bryophyte-dominated systems on thinner eroded edges (Bornkamm, 1959)," (Emilsson, 2006, p10).

As scientists observed the gravel roofs with vegetation, many began to study the impacts these roofs could make for the building and surrounding environment. With the "Green Solution" movement in Northern Europe during the 1960's, green roofs were studied for efficient installation and weight issues. European technical research increased during the 1970's. "One of these movements was led by scientific researchers who re-discovered the historic German green roofs of the 1880's (which had been unintentionally implemented for fireproofing) and began to study their ecological benefits," (Keeley, 2004).

With the onset of green roof research, the Landscaping and Landscape Development Research Society or the German FLL (*Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V)* was established in 1975 (Keeley, 2004).

The German green roof market took off in the 1980's as the growth rate increased 15 to 20% per year and from one million to 10 million meters square. Many German and Northern European cities used tactics through state legislation, grants and incentives to encourage green roofs (Kuhn, 2003). In 1984 the FLL published principles and guidelines for green roofs called *Guidelines for the Planning, Execution and Upkeep of Green-roof Sites* (Emilsson, 2006).

"Green Roofs for Healthy Cities" began as a small private and public organization network founded in 1999 due to a research project on green roof benefits called "Greenbacks from Green Roofs" by Steven Peck, Monica Kuhn, Dr. Brad Bass, and Chris Callaghan (www.greenroofs.net, 2007). In 2004, the association officially became a not-for-profit industry association known as Green Roofs for Healthy Cities – North America, Inc. (www.greenroofs.net, 2007). By 2005, 2.5 million square feet were built by GRHC members, in comparison to 11 to 12 million square feet per year in Germany (Eisenman, 2006). More information may be found at the association's website, www.greenroofs.net. The American green roof market has rapidly progressed since the 1990's due to promotion through associations such as GRHC and through research at several universities.

Another milestone for modern green roofs was published green roof standards. The American Society for Testing and Materials (ASTM) International published four green roof standards in 2005 and one in 2006. Two more standards are currently being evaluated. ASTM International is a voluntary standard development organization which provides technical standards for materials, products, systems and services. The standards are developed by about 30,000 members and technical experts including producers, users, consumers, government and academics (www.astm.org).

Standards Involving Green Roofs

The FLL Guidelines for the Planning, Execution and Upkeep of Green-roof Sites are ground breaking for green roof design guidelines, but the standards are based on research in Europe, not North America. As research in North America continues, it is important to update guidelines and standards on a continuous basis in order to ensure green roof sustainability. As mentioned above in the modern green roof timeline, the four ASTM green roof standards were published in 2005 and one in 2006. Currently two are under development. The following tables list the ASTM standards, the year they were published, and the title. The second table shows the two standards in progress.

Table 2.1 Table developed from standards listed at www.astm.org.

Standard	E2396-05	E2397-05	E2398-05	E2399-05	E2400-06
Released	2005	2005	2005	2005	2006
Title	Standard Test Method for Saturated Water Permeability of Granular Drainage Media	Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems	Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems	Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems	Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems

Table 2.2 ASTM Standards In Progress www.astm.org.

Standard	WK4236	WK7319
Title	Practice for Assessment of Green Roofs	Guide for Use of Expanded Shale, Clay or Slate (ESCS) as a mineral component in Growing Media for Green Roof Systems

LEED

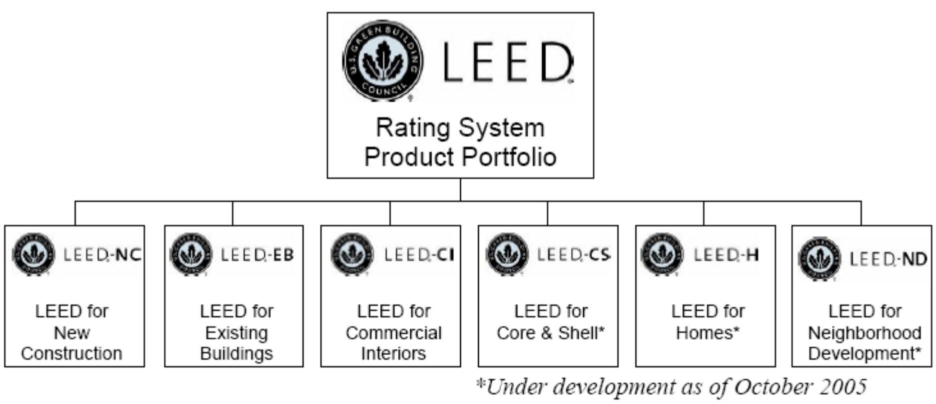
History of the USGBC and LEED

The United States Green Building Council was created in 1993 with a pilot version of the LEED green building rating system released in 1999 (Solomon, 2007). A pilot version, or test version that was reviewed by professionals, of LEED-NC 2.0 was released in March of 2000 and LEED 2.1 in November of 2002 which streamlined the documentation process. The written versions are available online. The USGBC filed for ANSI accreditation to become an ANSI (Accredited National Standards Institute) Developer (USGBC Press Release, 2005). Currently LEED Version 3.0 is in the works.

LEED Rating System

The following figure shows the LEED Rating System Product Portfolio.

Figure 2.5 LEED Rating System Product Portfolio
(www.usgbc.org, 2005).



Product Development Process

The development of LEED products is a c*onsensus process* in decision making across the diverse membership of USGBC. Standard approval requires a two thirds majority vote. There is a LEED Steering committee that "develops detailed policies and procedures governing the LEED product line," (www.usgbc.org, 2007).

The layout and presentation of the standards are based on a specific format that includes:

- Intent
- Requirements
- Technologies and Strategies
- Documentation requirements and supporting "Letter Templates"

Building Certification Process

To certify a building the first step is to register the project and obtain all necessary materials through the USGBC to begin the process of working through and applying for credits. The following table shows the numbers of registered and certified LEED buildings for each product. The initials in the top column correspond with the LEED Rating System Products in Figure 2.5. (NC: New Construction, CI: Commercial Interiors, EB: Existing Buildings, CS: Core and Shell).

Table 2.3 Registered and Certified Buildings
(www.usgbc.org, 2007)

LEED	NC	CI	EB	CS	Total
Registered	4,049	495	252	364	5,160
Certified	546	99	42	28	715

LEED is based on a points system of 69 points. A checklist (see Appendix A) is available to guide designers and project team members as they apply for LEED credits.

There are four levels at which a building may be certified. LEED Certified is the first level and applicants must achieve 26 points. LEED Silver may be achieved with 33 points. LEED Gold is the third level with 39 points and LEED Platinum is met with 52 points.

The following table is a breakdown for LEED-New Construction, which all other LEED products are developed from and what the LEED Accredited Professional Exam focuses on.

Table 2.4 LEED-NC Sections and Points per Section
(www.usgbc.org, 2007).

LEED-NC	Section Points
Sustainable Sites (SS)	14
Water Efficiency (WE)	5
Energy and Atmosphere (EA)	17
Materials and Resources (MR)	13
Indoor Environmental Quality (EQ)	15
Innovation and Design Process	5

Part of the submittal process for LEED certification includes filling out letter templates for each credit provided as online PDF's by the USGBC once a project has been registered and appropriate fees are paid. The letter templates include various requirements and submittals for the credit.

LEED issues a professional exam for individuals that have interest in green building. Typically those who study for and take the exam are in professional fields related to green building. As the USGBC states on their website, "LEED Accredited Professionals (LEED AP's) have demonstrated a thorough understanding of green building practices and principles and familiarity with LEED requirements, resources, and processes," (www.usgbc.com, 2007).

Criticisms of LEED

The USGBC and LEED have come a long way since their inception, but there are many criticisms of the system. This section is not meant to point out negative aspects, but to bring to light what others who have worked with the system have identified. This section is meant to make the reader aware of disadvantages and that LEED is working diligently to respond to feedback.   Constructive criticism by professionals and related industries is important for the LEED green building standards to improve and integrate more stringent sustainable strategies. The following table, adapted from Schendler and Udall's *LEED is Broken, Let's Fix It* (2005) compares advantages and disadvantages of LEED.

Table 2.5 LEED Advantages and Disadvantages

Adapted from “LEED is Broken, Let’s Fix It” (Schendler & Udall, 2005).

Advantages	Disadvantages
Promotes green building	Complicated
Well-known standard	Personnel Issues: confrontational, brutal process, crippling bureaucracy, catch-22’s
Points keep track of mitigated impacts	Points Chase
Structured standard	Confusing
Policymakers are writing LEED certification as requirements	Few Certified buildings
Building professionals participation	Lack of Science
Information provided to professionals	Time consuming
Weeds out those who aren't serious about green design	Cost
Setting examples	Mostly wealthy owners
Property value increase	Architects chase $
Public education	Professionals can't afford to certify
Documents green building methods	Fosters "greenwashing"
Advertising/PR benefits for involved parties	PR benefits drive design process
Market transformation	All credits are equal (not weighted for cost, time, or benefits)
Energy strategies benefit long term savings	Energy modeling is complicated

Alternative Green Building Standards and Organizations

The following table identifies and provides basic information about alternative green building standards. The table is meant for use as a quick comparison. The World Green Building Council was established to expand LEED into other countries. BREEAM was begun in the United Kingdom and has weighted credits. Green Globes began in Canada and is rated through awarding up to four green globes according to green building methods utilized by the project. The Athena Institute also began in Canada and provides products such as green building software, life cycle analysis (LCA), and consulting services. Currently a major goal of the Athena Institute is to integrate LCA software use for green building systems (www.athenasmi.ca/about/challenge.html, 2007).

Table 2.6 Current Green Building Standards
(www.usgbc.org, www.greenglobes.com, www.athenami.ca/about/challenge.html, www.worldgbc.org, www.breeam.org, 2007).

Standard	LEED	WorldGBC	BREEAM	Green Globes	Athena Institute
Founded	1993	1998	1988	2000	--
Acronym	Leadership in Energy and Environmental Design	World Green Building Council	Building Research Establishment Environmental Assessment Method	N/A	N/A
Country	United States	9 countries	United Kingdom	Canada	Canada
Products	Rating systems	Rating systems	Standard BREEAM and Bespoke	Self Assessment and 3rd Party Verification	Software, LCA, consulting services
Buildings	Certified	Certified	Certified	Verified	N/A
Rating System	Points and checklist	Points and checklist	Assessment and scale	Awarded one through four green globes	LCA assesses environmental performance
Quick Comparison	In market more than any other green building system	Expansion of LEED to other countries	Weighting of credits	Based on self assessment and voluntary verification	Working to facilitate the use of LCA software in green building systems

LEED Evolution

While there are areas of LEED needing improvement, particularly in bioregional sensitivity and Life Cycle Assessment (LCA) methods, the USGBC is currently updating the standards for a LEED Version 3.0, (Glaser, 2007). LEED 3.0 is not necessarily a new product, but a new way of distributing and improving the products LEED already has available. The new version focuses on continuous improvement in order to quickly incorporate knowledge into the program as technology develops (Sackett, 2007).

With an increasing demand for the USGBC's products and services, it is difficult for USGBC to keep up with the demand for improvements, though they are interested and listening to feedback. LEED 3.0 brings structural changes to the system. It can be described more like a bookshelf model and therefore there would be no new individual rating systems for specific project types though it is still being developed (Glaser 2007).

> "LEED is moving toward Continuous Improvement which involves aligning the existing credits across building types and developing new and important credits to the bookshelf (one large pool of credits that projects can choose from). The idea is that instead of a project team having to fit its scope into a rating system with the closest fit, it will be able to use a customized system based on its own personal project type," (Glaser, 2007).

According to Nancy Solomon in her article "*How is LEED Faring After Five Years in Use*," Nigel Howard, vice president of LEED and international programs at USGBC, expects LEED 3.0 to establish bioregional weighted credits, (Solomon, 2007). This will have a significant impact on green roofs and specifically water credits, which are linked to green roof integration.

LEED 3.0 seems to be what the USGBC intends as an avenue to update and add credits. Without the release of the new version, it is difficult at this time to recommend exactly how green roof credits should be aligned, but I take a critical look at the role of green roofs in LEED and how those credits may be improved and built upon. By incorporating green roofs into the LEED credits, the USGBC can and is making a significant impact on the market of green roofs. It is at this crossroad of green building standards and the rise of green roofs in North America that I raise the issue of preserving green roof sustainability within the LEED green building standards.

Precedent Studies

Six precedent studies serve as a basis for determining the criteria for the LEED green roof credits. The first three studies are developed from research gathered from archival sources and include: Ford Dearborn in Dearborn, Michigan, the GAP Headquarters in San Bruno, California, and the Wellness Center in Sugarloaf, Pennsylvania. The studies offer important lessons regarding green roof sustainability. Three intensively studied green roofs are the remaining precedents: Chicago City Hall in Chicago, Illinois, the American Society of Landscape Architects (ASLA) green roof in Washington D.C., and the Des Moines Public Library in Des Moines, Iowa. These studies focus on two key aspects: ecology and function. Green roofs provide numerous aesthetic and spatial definition benefits but the subjective nature of these benefits would prove difficult to measure. Aesthetic and spatial design decisions may be left to the designer'(s)' creativity and ingenuity.

While the precedent studies are not full case studies, the Case Study Method for Landscape Architecture (Francis, 1999) is used as a guide for gathering information. Mark Francis presents a case study methodology and explains its limits and benefits. His work was a part of a research project commissioned by the Landscape Architecture Foundation in 1997, whose goal was to develop a case study method for landscape architecture (Francis, 2001).

Before each precedent discussion, an overview table highlighting the green roof's context, design development, program elements, maintenance, benefits, and lessons is presented. The first three studies (A, B, and C) provide information gathered solely from archival research. The last three studies (I, II, and III) were first studied through archival methods and then developed more intensely with phone interviews, in person interviews, and site visits. Appendix B provides a table of specific details about each of the six green roof precedents discussed.

Study A: Ford Dearborn Plant

Table 2.7 Ford Green Roof Overview

(Earth Pledge, 2005) and (www.greenroofs.net).

Precedent Study A	Ford Dearborn Plant
Context	Redevelopment of 1917 plant Largest green roof in the world
Design Development	Green space Habitat Reduce temperatures Visitor education program Energy savings Stormwater
Maintenance	Entire green roof irrigated, weeding
Benefits	Turned industrial site into green space Habitat established on roof Reduced ambient temperatures Protects roof membrane Part of visitor education program Energy model prediction: 7% decrease and doubling of roof life from 25 to 50 years Stormwater retention - no need for water treatment facility Improved air quality above roof by 40%
Lessons	All 10.4 acres are irrigated due to thin membrane Coordination: long roof spans led to need for easy installation, staging Placed plant orders 1 year in advance Turned large industrial site into green roof technology

Context

The green roof is located on the Ford Dearborn Truck Assembly Plant in Dearborn, Michigan. It is part of the ninety year old complex commonly known as the Rouge. The Ford Motor Company developed the Rouge at the confluence of the Rouge and Detroit Rivers as part of Henry Ford's vision for an assembly line that could take raw materials and produce complete products, in one place. The plant was built between

1917 and 1928, and during the 1930's employed more than 100,000 workers (www.thehenryford.org/rouge/history.asp, 2007).

After Ford's death in 1947, the company began to shift to globalization and the amount of work at the Rouge began to decrease. The plant was near closing in the early 1990's but due to the community's sense of identity and requests to save the plant, the company made an effort to keep the Rouge open. Generations of families had worked at the Rouge. The recent restoration is now known as the Ford Rouge Center which includes six factories on 600 acres. The Dearborn Truck Factory is where the 10.4 acre vegetation covered roof is located (www.thehenryford.org/rouge/history.asp, 2007).

The assembly line was innovative technology at the time of its invention by Henry Ford. One of Ford's goals was to have self sufficiency. While globalization has changed manufacturing and much of how products are produced in modern times, Ford's goal of self sufficiency can still be realized through sustainability. The company's commitment to sustainable design is evident in their investment of the Dearborn Truck Factory green roof and stormwater management over the grounds (www.thehenryford.org/rouge/history.asp, 2007).

Design Development

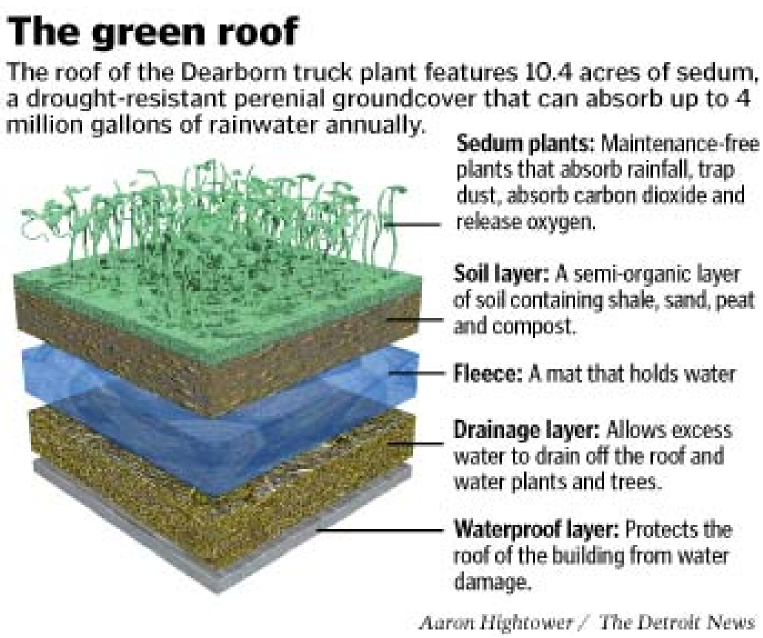
As part of the revitalization of the Rouge Complex, the Ford Motor Company chose to implement a green roof on the new Dearborn Truck Factory. Michael McDonough, world renowned sustainable architect, worked with the company to design the 10.4 acre green roof and the building. Several influential factors of the green roof design were the size of the roof and 50 foot structural spans. Because the roof is so large, the installation method needed to be as simple as possible to allow for cranes and large staging areas. The 50 foot structural spans required a lightweight green roof.

Visitor education was an important factor to promote sustainable buildings. The arrangement of rooftop elements and the location of the green roof near the observation tower of the Ford Rouge Center were critical to allow visitors a view of the roof (www.greenroofs.net, 2007).

Maintenance

The one inch growing media requires that the entire 10.4 acres be irrigated by a sprinkler system which incurs its own maintenance schedule. The green roof was fertilized one time through the irrigation system during the first year with Rosasoil, a 100 percent organic product.

Figure 2.6 Ford Green Roof Layers
(http://www.detnews.com/2004/project/0405/04/r04-140473.htm, 2004).



Benefits

The green roof adds a significant amount of open green space on an industrial site that for years has been without vegetation. The green roof build-up and vegetation helps reduce ambient temperatures above the green roof, mitigates stormwater runoff, reduces energy use and attracts wildlife. “Dr. H.J. Liesecke of the FLL in Germany concluded that the Ford roof would provide 25% of the productive habitat of an undisturbed green site; a 25% improvement over existing conditions.” In addition to the habitat benefits, an improvement of 40% in air quality above the roof is expected in regards to dust absorption and hydrocarbon decomposition (www.greenroofs.net, 2007).

The Ford Company is going beyond building sustainable by teaching the public about the sustainable practices and green roof technology used in the Ford Rouge Center. An observation tower adjacent to the Truck Assembly Factory allows visitors to view and learn about the green roof.

Lessons

All 10.4 acres are irrigated due to a thin membrane, but the green roof is expected to retain about 50 percent of the rainfall over the green roof (www.greenroofs.net, 2007). The ability of the green roof to retain water resulted in not having to use a water treatment facility that would have cost in the tens of millions of dollars (www.greenroofs.net, 2007).

Mechanical engineers that worked on the project, according to www.greenroofs.net, planned to conduct energy modeling in order to compare the performance of the Truck Assembly building to others of similar use. They predict a seven percent decrease in energy use because of the green roof (2007).

Michigan State University conducted research for the green roof and Ford Motor Company. "Researchers at Michigan State University tested a variety of plants under different soil depths. They investigated drought and freeze resistance, density of growth, weed control, fertilization, and irrigation requirements," (www.greenroofs.net, 2007). Teaming universities with green roofs for research is an effective way to generate information about green roofs.

The size of the Ford Dearborn green roof raised two issues. One, coordinating the staging of the materials and two, the plants had to be grown in mats on the ground 12 weeks prior to installation. The green roof has an irrigation system intended for use only during the time needed for the vegetation to become established (www.greenroofs.net, 2007).

The ability of the architect and the client to turn a large industrial site into a demonstration for green roof technology and stormwater benefits is a prime example of the potential for green roofs. The following figure shows part of the green roof on the Truck Assembly factory.

Figure 2.7 Ford Green Roof

(http://images.businessweek.com/ss/06/07/wow_green/image/4riverrouge.jpg, 2007).

Study B: The GAP Headquarters, San Bruno, California

Table 2.8 GAP Green Roof Overview

(www.greenroofs.net, 2007).

Precedent Study B	The GAP Headquarters
Context	Designed to blend into savannah foothills above the San Francisco International Airport
Design Development	Undulating greenroofs blend with regional landscape Design had effect on the building and surrounding landscape through mechanical, acoustical, thermal, and stormwater performances as a whole Rainfall recycled onto roof for irrigation Roof mass attenuates sound
Maintenance	Minimal annual maintenance
Benefits	Energy savings projection: 11 year payback Sound attenuation: up to 50 Db
Lessons	Eliminated need for water treatment facility Projected decreased energy use Connection to Michigan State University Size: Large industrial site; provides habitat

Context

Completed in 1997, the GAP Headquarters green roof was one of the first of its kind in the United States. Michael McDonough's environmentally attuned design responded to the context of the site, the rolling hills of the northern California coast and the proximity to the San Francisco International Airport.

> "Blanketed in soil, flowers and grasses, the roof's undulating terrain echoes the ancient local landscape, re-establishing several acres of the surrounding coastal savannah ecosystem" (McDonough, 2003).

Design Development

The 69,000 square foot green roof has undulating forms with up to a 25% slope. The interesting form of the roof blends into the surrounding savannah foothills and native grasses and wildflowers grow in a six inch deep media. The project began by asking unconventional questions: "What would native birds hope to see as they fly over the site?" and "Wouldn't it be marvelous if the birds could see the habitat with which they evolved?" These questions opened up the design to other professional disciplines such as ecology, botany, conservation biology, and environmental history, (www.mcdonough.com/writings/field_of_dreams.htm, 4.17.07).

The green roof is integrated into the building, which is designed to create, "a productive, comfortable, culturally rich workplace," (www.mcdonough.com/writings/field_of_dreams.htm, 4.17.07). The green roof was designed to be self-sustaining and low maintenance with the use of native grasses.

Benefits

The undulating forms of the green roof mimic the nearby rolling hills of the California coast. The roof mass provides thermal properties and reduces the amount of temperature control needed for the building. Rainwater is collected on the roof and used for irrigation of the vegetation. The green roof is well integrated with the building and the site, thanks to Michael McDonough, Chairman and Founding Partner of William McDonough and Partners and Paul Kephart, Executive Director of Rana Creek. Attention to detail and integration of building and site led to the award winning GAP Headquarters project and it is also one of the most energy efficient buildings in California.

> "By setting out to create a positive, regenerative human footprint, by tapping local energy flows and integrating building and landscape, the design outperforms buildings that set energy efficiency as their highest goal," (www.mcdonough.com/writings/field_of_dreams.htm, 4.17.2007).

The GAP green roof is also able to reduce noise in the building by up to 50 dB according to Paul Kephart of Rana Creek in Caramel Valley, California, (http://www.montereycountyweekly.com/issues/Issue.02-23 2006/cover/Article.cover_story_2, 2006),

> "'Gap's headquarters are located right next to 280, 380, the 101 [highways] and it's right by the San Francisco airport,' Kephart says. 'The roof attenuates low-frequency noise. Despite everything going on outside the building, we've created a very quiet environment.'"

Lessons

The GAP Headquarters green roof demonstrates how green roofs can be aesthetically pleasing, integrated with the site and surrounding landscape and provide numerous environmental and cost benefits.

> "Although challenging in nature, the successful establishment of native grasses on the GAP headquarters' roof plane provides valuable documentation specific to soil composition, plant species and management guidelines for long term green roof establishment and maintenance," (www.ranacreek.com, 2007).

The GAP green roof is one of the first in a Mediterranean climate and provides habitat for local wildlife and insects (www.ranacreek.com, 2007). According to McDonough, it also allows the inhabitants to be a part of the local ecology and connection between "human creativity and the abundance of the nature," (McDonough, 2003).

The figure shows the undulating forms of the GAP Headquarters green roof.

Figure 2.8 GAP Inc. Headquarters Green Roof

(airhead.cnt.org/images/gap_green.jpg, 2007).

Study C: Life Expressions Wellness Center, Sugarloaf, Pennsylvania

Table 2.9 Wellness Center Green Roof Overview

(www.greenroofs.net, 2007).

Precedent Study C	Life Expressions Wellness Center
Context	Holistic wellness center/chiropractic center Green building concept proposed by Van Der Ryn
Design Development	Green roof integral part of design Creation of living structure blended with environment Energy conservation Steep pitch: 3:12 and 7:12
Maintenance	Minimal spring and fall weedings
Benefits	Stormwater retention Drainage Aesthetic - curtain effect of water running off plants on roof edge
Lessons	Unconventional details to secure waterproofing for fascia gap Slope stability: roof battens, slope restraint panels, reinforcing mesh Media: engineered to absorb + retain water + remain fully drained

Context

The holistic chiropractic wellness center is located on sixteen acres of meadow in a mountain valley region known as Sugarloaf Valley, Pennsylvania. Mr. and Mrs. Gallagher, the owners, wanted to have an office that responded to the needs of a family and have state-of-the-art equipment in a non-toxic environment. The building was designed by Sim Van der Ryn, a leading green architect and principal of his firm. The green roof is part of the whole building design that includes passive solar design, natural daylighting, limitation of harmful chemicals in finishes and building materials. Charlie

Miller of Roofscapes, Inc. designed the technical aspects and facilitated installation of the green roof (http://www.lifeexpressionchiro.com/, 2007) and (www.greenroofs.net, 2007).

Design Development

The slope of the wellness center roof responds to the forms of the mountains surrounding the valley. The design program of the green roof required unconventional details to secure waterproofing for the fascia gap. The fascia was gapped one half inch to create the curtain effect when water drained off the roof (www.greenroofs.net, 2007).

> "The maximum slope of the Life Expression Wellness Center roof is 30° (7:12 pitch). The unique roof design allows runoff to discharge along the length of the eaves, creating a curtain effect. The vegetated cover reduces the rate and quantity of runoff, and also prolongs the duration of runoff, further emphasizing this curtain effect. This project also incorporates an integrated leak detection system furnished by Roofscapes, Inc." (http://www.roofmeadow.com/projects/project3.shtml, 2007).

The unique pitch of the roof also presented design challenges. Special attention to slope stability was required. Roof battens, slope restraint panels, and reinforcing mesh kept the soil media in place. A photo-degradable wind blanket mesh was fastened to the green roof profile base. The sedums grew in and covered the mesh, stabilizing the soil with their roots (www.greenroofs.net, 2007).

Engineered by Roofscapes, Inc., the green roof system contained the Roofmeadow Type I: Flower Carpet, a green roof planting option. This system helped satisfy the deadload, pitch, maintenance and aesthetic requirements through a colorful planting palette. The media was engineered to fulfill the German FLL guidelines. The waterproofing membrane used was Sarnafil (a manufacturer) G-476 reinforced 80 mil single-ply PVC (polyvinyl chloride, a type of plastic). An Electric Field Vector Mapping

(EFVM) test was conducted and replaces a traditional flood test because of the slope of the roof (www.greenroofs.net, 2007). EFVM tests can detect small leaks without having to flood a roof.

The following plants were selected for the wellness center roof and are included in the Roofmeadow Type I: Flower Carpet: *Allium schoenoprasum*, *Dianthus deltoides*, *Sedum acre*, *Sedum album* 'Coral Carpet', *Sedum floriferum, Sedum oreganum*, *Sedum reflex, Sedum sarmentosum*, *Sedum sexangulare*, *Sedum spurium* 'Fuldaglut', and *Sedum spurium* 'Tricolor' (www.greenroofs.net, 2007).

The Life Expression Chiropractic Center was the winner of a 2004 Green Roofs for Healthy Cities North American Green Roofs of Excellence Award.

Maintenance

Initial weeding was done until the sedums grew thick enough to keep most weeds at bay. Minimal spring and fall weedings are done as shown in Figure 2.9 (www.greenroofs.net, 2007).

Benefits

The steeply pitched roof demonstrates how the designer and green roof engineer solved the unique design requirements to create an effective green roof technically and aesthetically. The green roof demonstrates the use of the waterproof membrane testing technique, EFVM on a steeply pitched roof when traditional flood testing was impossible to conduct (www.greenroofs.net, 2007).

Drainage of the roof was solved technically and incorporated with aesthetic design to create a unique feature using gravity that adds to the holistic quality and concept of the Wellness Center. Though steeply pitched, the green roof still slows the velocity and quantity of stormwater runoff (www.greenroofs.net, 2007).

Lessons

The Wellness Center demonstrates that a steeply pitched roof can still retain stormwater and provide aesthetic benefits through the curtain effect as the water drips off of the plants at the edge of the roof.

There was considerable effort to stabilize the slope and overcome the unique design program requirements in order to have a functioning green roof. The green roof has "…attracted eco-conscious visitors from great distances, and the owners have graciously served as passionate advocates and "green roof ambassadors," and "…is an excellent example of a genre of green roof, rarely seen in North America, that can fit comfortably into suburban and rural developments," (www.greenroofs.net, 2007). The following figure demonstrates how the green roof is maintained.

Figure 2.9 Maintenance of the Wellness Center Green Roof

(http://www.roofmeadow.com/projects/project3.shtml, 2007).

Study I: Chicago City Hall Green Roof

Table 2.10 Chicago City Hall Green Roof Overview

(www.greenroofs.net, 2007).

Precedent Study	Chicago City Hall
Context	12 story building, downtown Chicago one square block; funded by Urban Heat Island Initiative Act Study heat reduction effects in urban area Experiment with diverse vegetation
Design Development	Two designs: one from existing loads, one a redesign of the first with structural reinforcement of the skylights sunburst pattern Varying thicknesses of material 150 plant varieties Irrigation - roof collection + integration into greenroof layer
Maintenance	Drip over surface for initial - use during drought
Benefits	Air intakes on roof - energy reduction Reduces UHI Demonstrate green roof technology Aesthetic view from 33 surrounding buildings Verticality through skylights, diverse plants Seasonal plant palette interest Helped city rework building permit program Pioneering project
Lessons	Green roof influences 1/12th of building No monitoring for first 2 years Experimental plants Public interested and concerned (dormant plants) Weather Station: above green roof was cooler than above control roof

Context

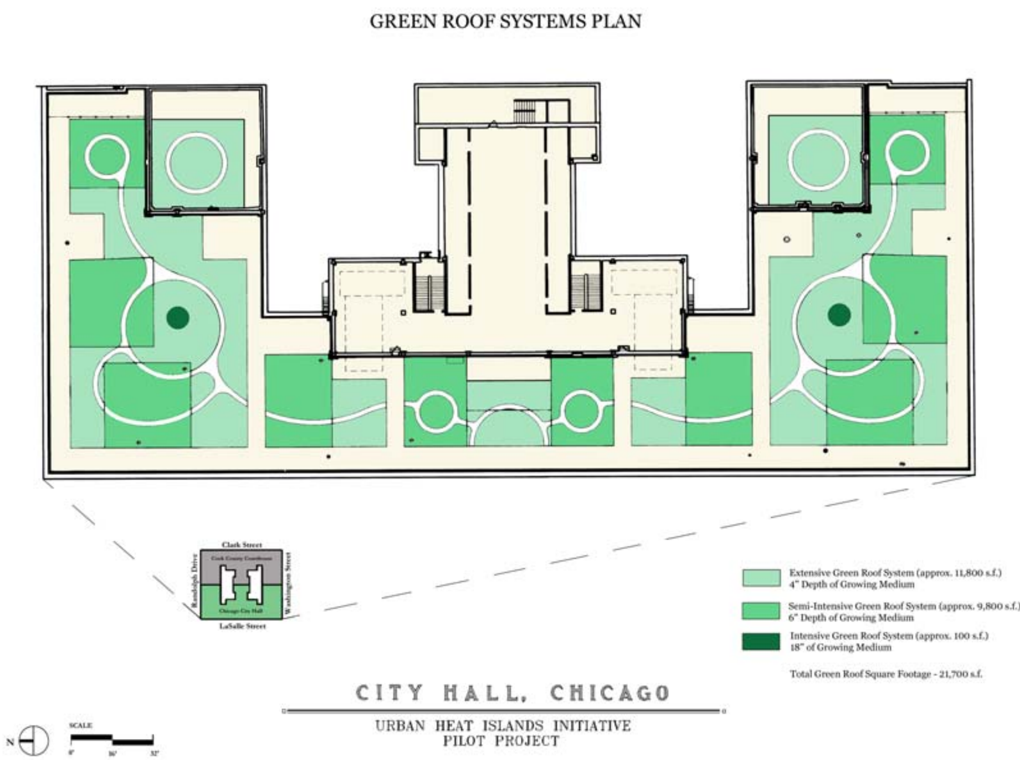
The Chicago City Hall is located in downtown Chicago and surrounded by 33 taller buildings. The city is now well known, with the help of Mayor Daley, for being green and for the increasing amount of green roofs in the city. City Hall was, according to Dvorak and de la Fleur of Conservation Design Forum, developed as a study of heat reduction in urban environments and as an experimental demonstration of plants and their adaptability to Chicago rooftops (De la Fleur & Dvorak, 2006). The roof top is not accessible to the public or building occupants but is visible from the 33 surrounding buildings.

The retrofitted 20,300 square foot green roof is located on the 11^{th} story roof deck. The building is one square block in area and about 100 years old. The green roof was funded by the EPA's urban heat island initiative act. In 2002 the project won an ASLA Professional Merit Award. The green roof acts as a demonstration to help bring green roof technology to the city. It was designed to deploy the widest range of materials and planting palette as well as communicate an artistic composition that reads as a whole, (Yocca, 2007). The Chicago City Hall green roof was dedicated September 20^{th}, 2000 (Chicago DOE, 2001). Since the installation, 2 million square feet of green roofs have been installed in Chicago.

Design Development

Two designs were developed. One was from existing loads without additional structural support and was mostly extensive with some semi-intensive and two intensive areas that were six feet in diameter over the structural columns of the building (shown in the following figure) (De la Fleur & Dvorak, 2006).

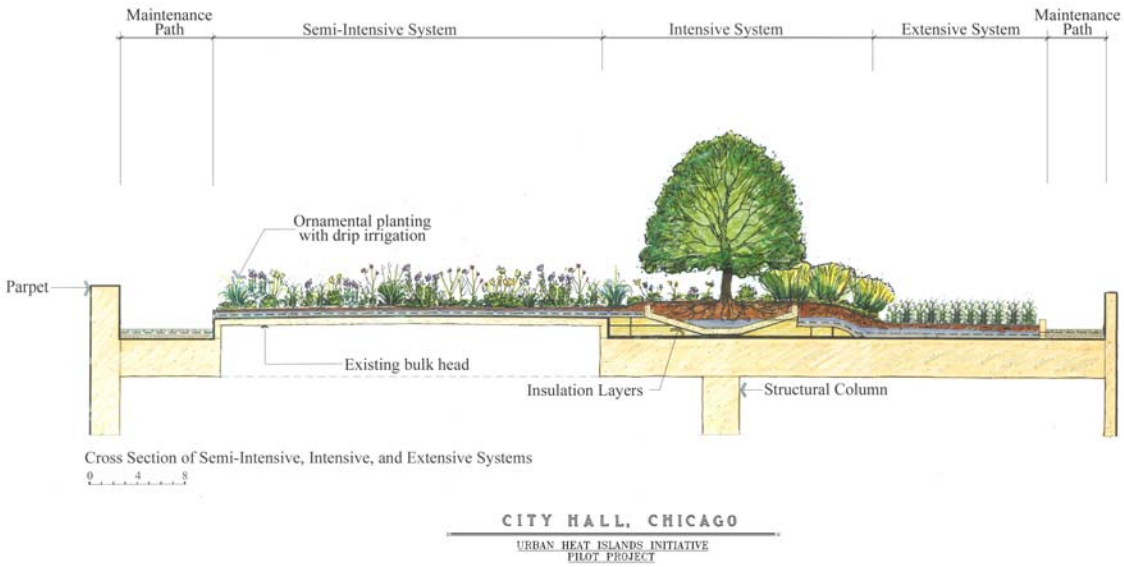
Figure 2.10 Extensive, Semi-intensive and Intensive Areas
(Courtesy Conservation Design Forum).



The second redesign consisted of structural reinforcement of the abandoned skylights for semi-intensive gardens (De la Fleur & Dvorak, 2006). The increase in semi-intensive area added to the diversity allowing for the 20,000 plants, including about 150 species (De la Fleur & Dvorak, 2006) and (Chicago DOE, 2001).

Figure 2.11 Section Showing Green Roof System Relationships

(Courtesy Conservation Design Forum).



The existing structural capacity was about 30 pounds per square foot. The two areas above the structural columns were able to support additional loads, therefore the hawthorn trees were placed above them. The old skylight areas were able to support loads for semi-intensive plantings.

Retaining walls are used for the edges of the green roof and the existing drainage system for the building was kept in place for stormwater in excess of what the green roof can handle. The rooftop was designed to store water in the drainage layer and growing medium up to what the structural loading of the roof structure is able to support. The system should be able to support a one inch rain (Chicago DOE, 2001).

A unique aspect of the Chicago green roof as opposed to many extensive green roofs is the Chicago design has verticality through the skylight areas that were built up. This changed the experience of the green roof by bringing the plants closer to eye level, though the green roof is now closed off due to liability issues. The plants are placed in a sunburst pattern which allows for a colorful and attractive pattern and variant media depths and different species of plants, visible from surrounding buildings.

The concrete decking of the city hall was sloped for strategic removal of excess stormwater (Yocca, 2007). Columns and skylight areas with extra structural support provided areas for semi-intensive and intensive green roof. Styrofoam was used to build up areas and bring them closer to visitors, (Yocca, 2007).

The Chicago green roof is irrigated through water collection on either side of the penthouse. The water is directed to tanks which, when needed, is integrated into the green roof layer. Initially drip irrigation was installed over the entire surface. This is only used in the summer when it is dry and there is threat of drought.

Maintenance

Drip irrigation was installed on the green roof for initial establishment and for use during periods of drought. Water is collected from the penthouse roof into water tanks located near the downspouts of the penthouse which is used for drip irrigation. Overflow is released into the green roof media (Chicago DOE, 2001).

Lessons

The green roof was planted in October due to a construction schedule delay. A snowfall after planting helped the survival of the plants. The following summer, the plants went dormant due to heat and drought and looked brown which caused concern from neighboring building occupants.

The whole building does not benefit from energy savings. The upper floor benefits from a reduction in heat gain during the summer but the green roof only influences 1/12th of the building where a one story building is 100% influenced by a green roof (Yocca, 2007). There are still economic and energy benefits. The air intakes for the cooling system are located on the roof therefore the benefits of the cooling properties of the green roof helped reduce the temperatures on the roof from which the HVAC must draw and cool the air. The air over the green roof was 90 to 100 degrees Fahrenheit instead of 170 degrees Fahrenheit on the control roof (Yocca, 2007).

Conservation Design Forum (CDF) suggested monitoring for the green roof from the initial installation. Though this was planned, the city did not install the equipment to monitor stormwater runoff and plant survivability. For the first two years, there was no monitoring. Since there was no monitoring, there has not been the opportunity to study plant growth. Of the 160 species of plants, some have thrived and some have not survived (Yocca, 2007). With monitoring, specific information could have been gathered and been very useful to types of plants and their growth and survivability rates.

A weather station is temporarily set up on the roof as well as on the other half of City Hall that does not have a green roof. On the hottest days, the ambient air temperature was roughly 95 degrees Fahrenheit outdoors and 100 degrees Fahrenheit over the green roof. The non-green roof was 170 degrees Fahrenheit on a hot day (Yocca, 2007).

A PDF from the City of Chicago's website provides information on monitoring the green roof. According to the PDF a temperature measurement was taken on August 9, 2001 showing a 50°F difference between the green roof and the conventional black tar county roof on the other half of the building (Chicago DOE, 2001). The outdoor temperature was in the 90's.

Paved City Hall Roof: 126 - 130°F

Planted City Hall Roof: 91 - 119°F

Black Tar County Roof: 169°F

The city calculated the projected energy savings due to the green roof:

Avoided energy cost $3600/yr.

Total direct savings: 9272 KW hours per year

Natural gas savings: 7,372 Therms per year (Chicago DOE, 2001).

The windy climate of the Chicago area in addition to the height of the building resulted in the need to use a bio-degradable netting to prevent wind erosion (Yocca, 2007). Green roofs in similar windy situations should use some form of wind erosion control for the green roof media until the plants become established and can hold the soil.

Irrigation was installed and kept in to make sure the plants do not go dormant. Yocca expressed that many people from the surrounding buildings called City Hall asking if they knew the plants were brown, out of concern for the success of the green roof (2007). Another benefit of the pioneer green roof project was the chance for CDF and other consultants to work through the building permit program. This helped the city to rework their policies to encourage green roofs. The following two images are of the plan prepared by Conservation Design Forum and a photograph of the constructed design.

Figure 2.12 Chicago City Hall Green Roof Plan

(http://www.asla.org/awards/2006/medals/images/da_01.jpg, 2007).

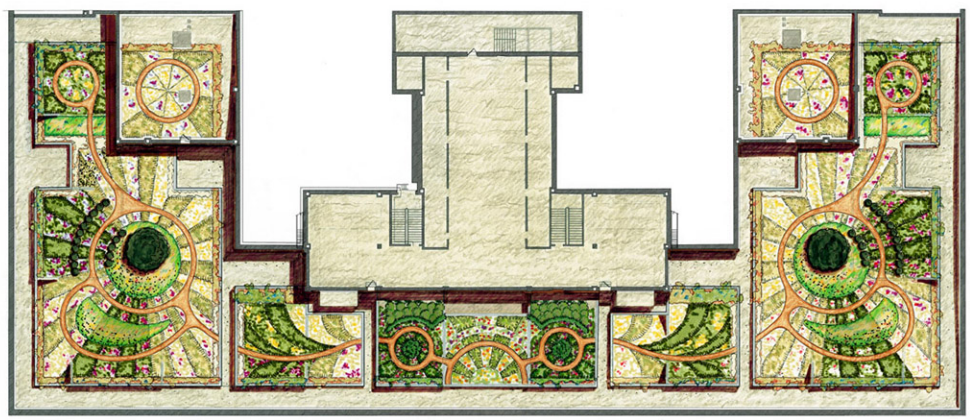


Figure 2.13 Chicago City Hall Green Roof Aerial

(http://www.asla.org/awards/2006/medals/images/da_03.jpg, 2007).

Study II: American Society of Landscape Architects Green Roof

Table 2.11 ASLA Green Roof Overview

(Yocca, 2007), (www.asla.org, 2007) and (Eisenman, 2006).

Precedent Study	ASLA Green Roof
Context	Green roof demonstration project Promote environmental + structural benefits + landscape architect involvement Retrofit
Design Development	Two large waves define space Metal grating over extensive sedum allows for more usable space that is functional
Maintenance	Weeding, irrigation (temporary)
Benefits	Metal grating - people walk over and give sedums a "haircut" - usable space while maximizing green roof coverage and stormwater benefits High profile Monitoring for plant growth, stormwater retention capacity, water quality, temperatures Greater potential for energy conservation through green roof layers because fewer floors
Lessons	South side plants harder to establish because slope faced north, also has greater number of experimental plants Space shaped by waves Shows range of design applications Showcases that landscape architecture profession is most well suited for design of human habitation on rooftops

Context

The American Society of Landscape Architects (ASLA) green roof, completed April 26th, 2006, is located in Washington D.C. in the area known as China Town just to the north of The Mall and the Gallery Place China Town metro station. The three story building is next to another building with roughly the same square footage of roof space as the ASLA building. The green roof was retrofitted on top of the existing ASLA structure.

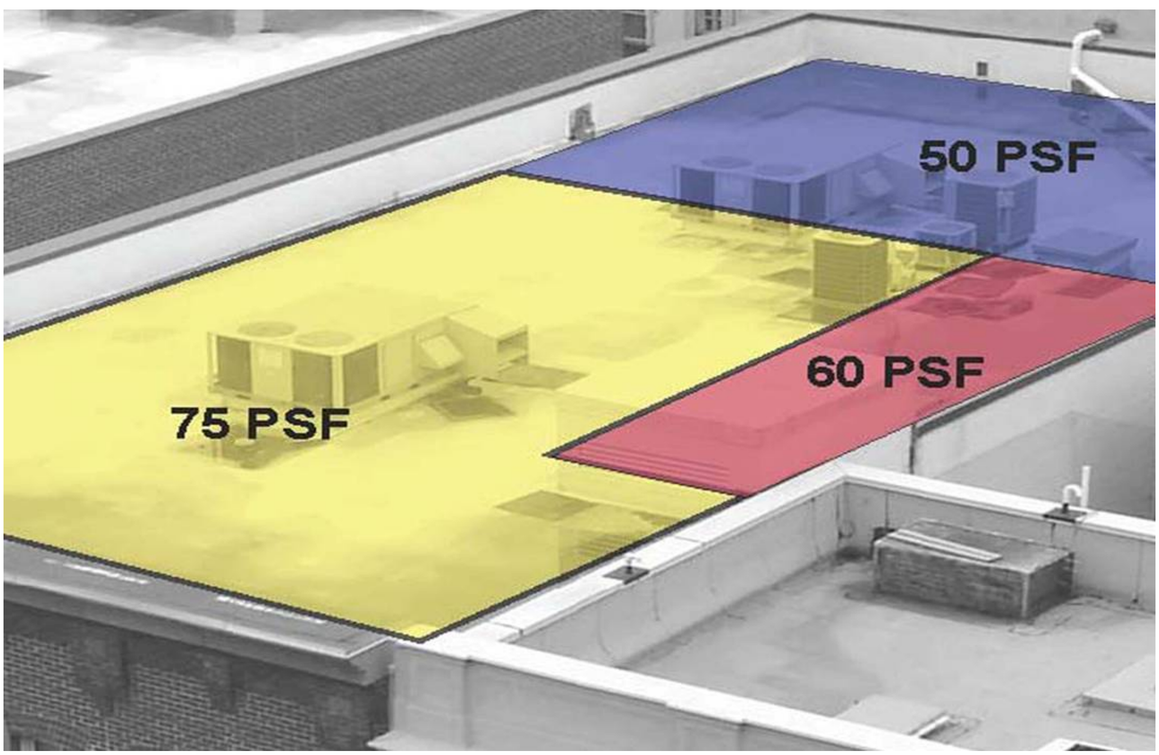
Washington DC is 57 miles square and contains 46% impervious surface which includes asphalt, concrete and roof tops, (K. Swann, ASLA green roof tour, March 22, 2007). One benefit of green roofs is retention and slowing the release of stormwater volumes. ASLA reports their green roof retained 76.7% of 11.83 inches of rainfall in its first season, (www.asla.org, 2007). Green roofs in the DC area could help reduce the amount and velocity of stormwater released into the city's combined sewer outlet (CSO) system. The cost for DC to separate the stormwater and sewer systems is estimated at $2.6 billion. Currently, about 2.5 billion gallons of CSO outflows are released into the Anacostia River (Swann, 2007).

The old roof of the ASLA building needed replacement in 2004 after only 10 to 12 years. The Society Board voted to replace the roof with a green roof to maximize environmental benefits, demonstrate green roofs, and promote how landscape architects contribute to green roof projects, (www.asla.org, 2007). The idea developed to replace the roof with a green roof as a demonstration of landscape architect's ability to manage all aspects of a green roof.

Design Development

Initial design challenges consisted of the existing HVAC (Heating Ventilation and Air Conditioning) units in the middle of the roof. In order to create a useable space, these units would need to be removed. It was not cost feasible to move the roof drains, but they are currently "hidden" under the grating (K. Swann, ASLA green roof tour, March 22, 2007). The most costly aspect of the green roof construction was the addition of a stairwell for roof access. The method of access before the green roof was through two trap doors. The load bearing capacities for the green roof were determined and outlined (Figure 2.13). Structural elements such as the elevator shaft and on top of the stairwell could accommodate greater loads.

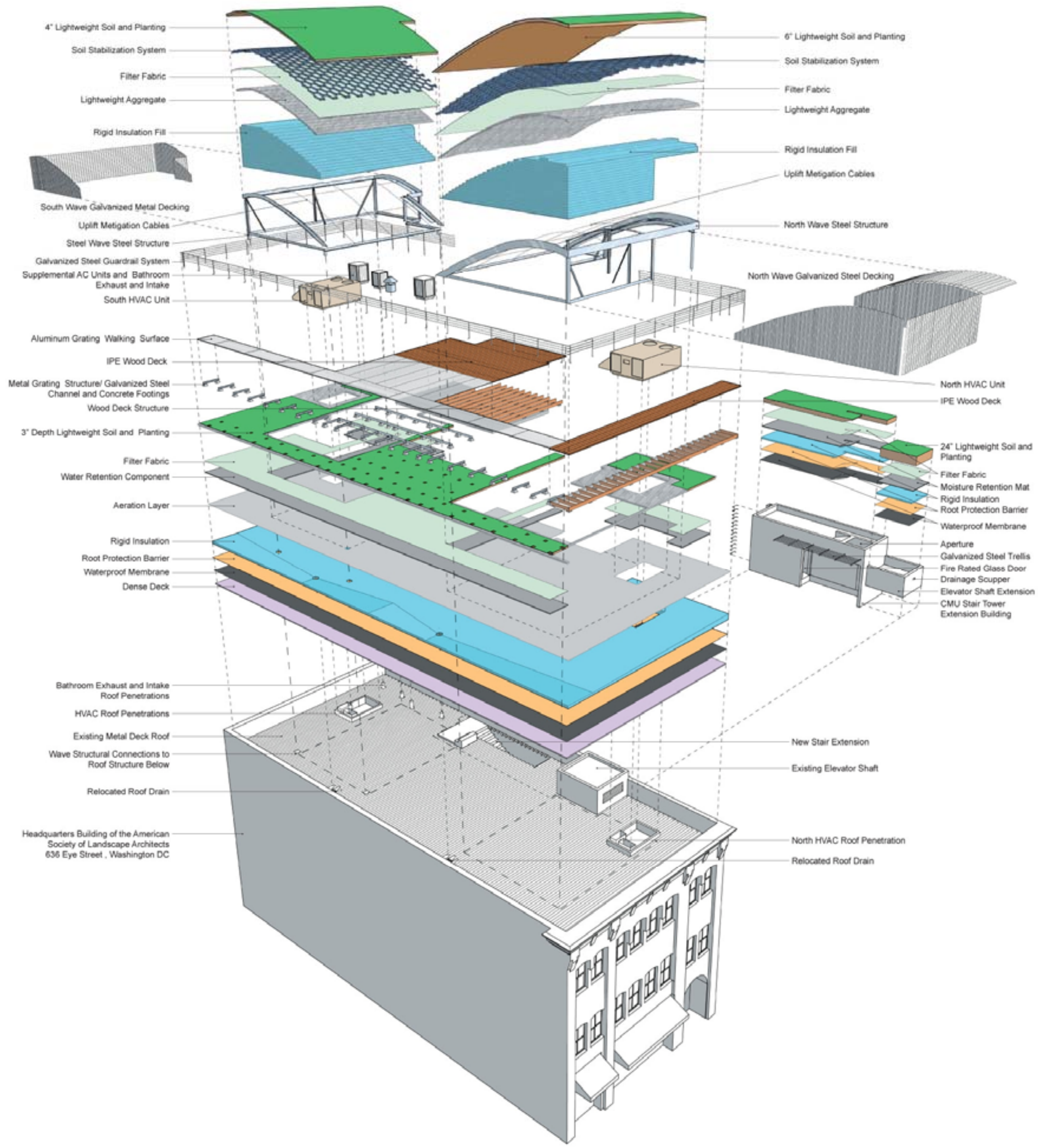
Figure 2.14 ASLA Load Capacity
(Courtesy MVVA and ASLA).



Michael Van Valkenburgh Associates (MVVA) was hired as the lead designer and landscape architect with Conservation Design Forum as the consulting landscape architect. DMJM was hired as the architect, Forrester the general contractor and Robert Silman Associates as the structural engineer. The green roof space was shaped through two wave structures shown in the following figure, designed to give visitors the feeling of being in a meadow. Corrugated metal supports the sides of the north and south facing waves which are filled with foam rigid insulation and supported by a steel structure with uplift mitigation cables incorporated. Each wave is structurally connected to the roof structure (www.asla.org, 2007).

Figure 2.15 ASLA Green Roof Isometric

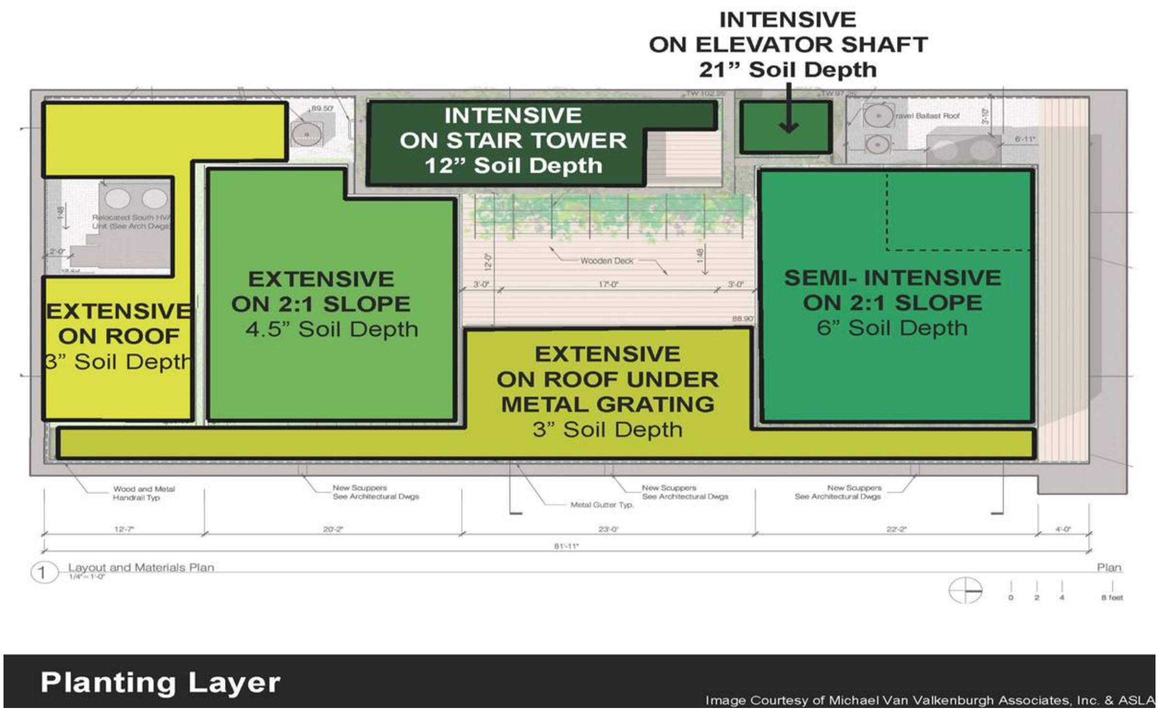
(www.asla.org, 2007).



Based on the structural load accommodations and soil media depths, plantings were chosen for the different areas of the green roof. The varying soil depths allow ASLA to demonstrate different media and types of plants that can be grown on green roofs. Such variety also allows for monitoring and testing of plant growth and stormwater retention. The following figure demonstrates the planting depths and types of green roofs used.

Figure 2.16 ASLA Green Roof Soil Depths

(Courtesy MVVA and ASLA).



Plants were selected for the ASLA green roof to be self-maintaining and drought tolerant. The ASLA Green Roof Plants table lists the plant species used on the green roof and what section of the green roof the species are located. There are some species that are planted in more than one area.

Table 2.12 ASLA Green Roof Plants

(Beaulieu, 2007).

	Sedums	Perennials	Grasses	Vines	Shrubs
North Wave	*S. floriferum* 'Weihenstephan Gold'*; S. album* 'Murale'*; S. reflexum*	*Talinum calycinum; Delosperma nubigenum* 'Bautoland'*; Artemisia ludoviciana* 'Silver King'*; Asclepia tuberosa; Achillea millefolium; Tradescantia bracteata; Solidago nemoralis; Coreopsis verticilatta* 'Zegreb'*; Rudbeckia hirta; Allium ceranuum*	*Elymus viginicus; Sporobolous heterolepsis; Bouteloua gracalis; Eragrostis spectabilis*		
South Wave	*S. telephioides; S. lanceolatum;*	*Silene caroliniana; Optuntia humifusa; Phlox subulata*			
Terrace	*S. kamtschaticum; S. spurium* 'White Form'*; S. spurium* 'Fuldagut'*; S. spurium* 'John Creech'*; S. sexangulare; S. reflexum*	*Talinum calycinum; Delosperma nubigenum* 'Bautoland'			
Elevator Shaft				*Campsis radicans* 'Balboa Sunset'	*Rhus copallina*
Stairwell					*Rosa carolina; Ceanothus americanus; Rhus aromatica; Comptonia peregrine*

Plants on the edges of the wave structures struggled because they did not receive water from the hand placed sprinklers. The AC unit on the north side dried out and stressed plants located on the north terrace adjacent from the AC unit. There are plans to use a shield or a deflector for the wind created by the AC fan (Swann, 2007).

Maintenance

Currently, a maintenance schedule does not exist. Through monitoring done by MVVA, a maintenance schedule will be developed. The major issue is seedlings because the rooftops are closer to the ground and catch airborne seeds.

The HVAC unit under the north wave allows the unit to be hidden from view but still remain accessible for maintenance. ASLA is considering option for installing a deflector for the AC fans to redirect the air flow on the plants in the north terrace. The force of the wind caused plant stress and desiccation. Temporary sprinklers are installed and connected to a water source through garden hoses to help the plants become established. In the first season, the water did not reach the edges of the green roof and many plants did not survive. From plant growth monitoring research, Richard Hindle suggested the edges be replanted with more drought tolerant plants (Swann, 2007).

Tools such as metal prongs are used to weed the cacti and through the metal grating for isolated weeds. If there are a large number of weeds under the metal grating, the grating is removed to weed the area and then replaced (Beaulieu, 2007).

Lessons

Initially a portion of the waterproofing membrane was installed prior to the staging of steel for the stairs. Due to construction work with the steel, the damaged membrane had to be replaced though an exact amount and whether all of the membrane was installed and then had to be replaced was not specified in an interview with Gerry Beaulieu, ASLA CFO (Beaulieu, 2007). Plants along the edges of the waves struggled and burned out from lack of water from the temporary irrigation with lawn sprinklers.

The HVAC units under the north wave caused plant burn out on the north terrace. Careful consideration of air flow and wind from the fans for future green roofs is an important factor.

IPE wood used for part of the roof deck without grating and an extensive green roof system was mistakenly stained. The wood is so dense it will not rot and therefore does not need staining.

A stormwater monitoring program with flow gauges was implemented by Gerald Beaulieu, ASLA CFO. The monitoring program was begun in July of 2006, three months after the completion of the green roof. From data collected by Beaulieu, the following table indicates the storm events from July of 2006 to early January of 2007. It is difficult to tell the ability of the green roof to retain certain percentages of water until more data is collected and the plants become established. The orange color under “Inches of Rain” indicates a rain event greater than one inch.

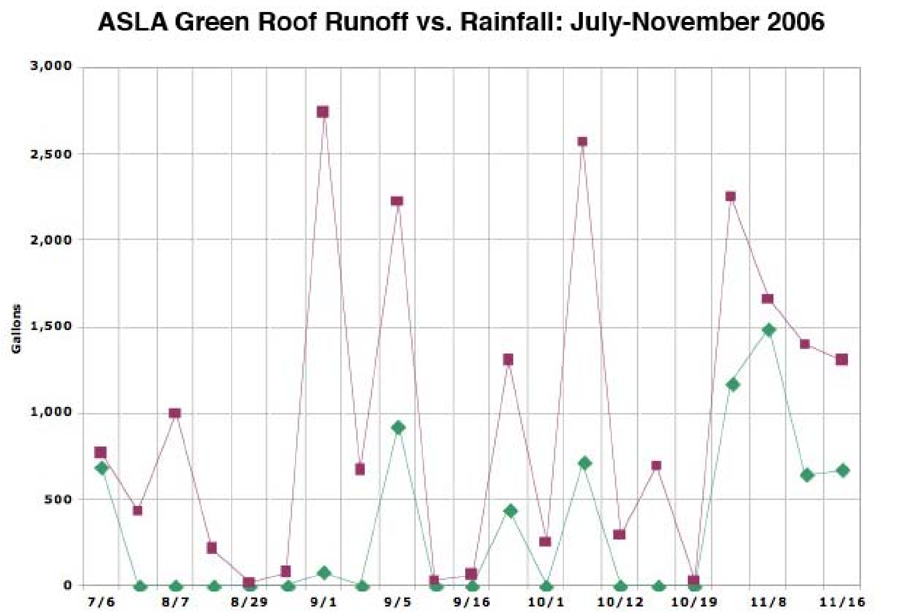
Table 2.13 Storm Events: Percent of Stormwater Retained (gal)

(Beaulieu, 2007).

Date	Inches of Rain	Run-off (Gal.)	Total Rainfall (Gal.)	% Retained
07/06/06	0.61	684.366	766.3471	10.6976
07/22/06	0.34	0	427.1443	100
08/07/06	0.79	0	992.4823	100
08/10/06	0.17	0	213.5721	100
08/29/06	0.01	0	12.56307	100
08/30/06	0.06	0	75.3784	100
09/01/06	2.18	72.694	2738.748	97.3457
09/02/06	0.53		665.8425	100
09/05/06	1.77	925.497	2223.663	58.3796
09/15/06	0.02	0	25.12613	100
09/16/06	0.05	0	62.81533	100
09/28/06	1.04	442.175	1306.559	66.1573
10/01/06	0.2	0	251.2613	100
10/06/06	2.04	712.529	2562.866	72.198
10/12/06	0.23	0	288.9505	100
10/17/06	0.55	2.269	690.9687	99.6716
10/19/06	0.02	0	25.12613	100
10/27/06	1.79	1171.05	2248.789	47.9253
11/08/06	1.32	1490.062	1658.325	10.1466
11/12/06	1.11	640.017	1394.5	54.1042
11/16/06	1.04	667.11	1306.559	48.9415
11/22/06	0.81	418.928	1017.608	58.8321
11/23/06	0.07		87.94147	100
12/01/06	0.06		75.3784	100
12/13/06	0.09		113.0676	100
12/22/06	0.7	0	879.4147	100
12/23/06	0.06	103.151	75.3784	-36.844
12/25/06	0.49	35.188	615.5903	94.2839
12/26/06	0.1		125.6307	100
12/31/06	0.06		75.3784	100
01/01/07	1.03	784.231	1293.996	39.3946
01/02/07	0.02	0	25.12613	100
01/05/07	0.19	0	238.6983	100
01/06/07	0.02	0	25.12613	100
01/07/07	0.02	0	25.12613	100
01/08/07	0.5	0	628.1533	100

A graph from the ASLA website shows a representation of the storm events and the retention of water by the green roof. The red line shows the rainfall in gallons and the green line shows the amount of stormwater runoff from the green roof.

Figure 2.17 ASLA Green Roof Runoff vs. Rainfall: July – November, 2006 (www.asla.org, 2007).



ASLA has committed to monitoring the performance of the roof over time for: stormwater retention; water quality; temperature; and plant growth. Flow meters and rain gauges are in place; the roof retained 76.7 percent of the 11.83 inches of rain that fell during the first data collection period. Temperatures on the ASLA roof will be tracked against temperatures on the roof of a neighboring building. An environmental engineering consultant has been retained to analyze and compare water quality collected on the roof and runoff collected from roof drains. The water quality analysis will follow U.S. Environmental Protection Agency standards, and will include pH, suspended and dissolved solids, dissolved oxygen, chemical oxygen demand, nutrients, and heavy metals. In addition, light meters have been placed in different areas and a number of plants tagged so that data on plant growth and growing conditions can be collected. The report will form the baseline for ongoing research during future growing seasons.

Gerald Beaulieu, CFO of ASLA, has also set up a system for monitoring the buildings energy usage. Based on cooling and heating days and kilowatt hours he was able to correlate energy uses statistically with degree days, (Beaulieu, 2007). Though the roof is only in its second growing system, an assumption can be made based on comparing data of 2005 and 2006 and the two months so far in 2007. The results for 2006 so far have not shown much difference from the KWH/Unit in 2005, but the

January and February 2007 consumption seems significantly less than that of the same months in 2006. At this point it is too early to determine the actual validity of energy savings related to the green roof because the plants have not fully established and more data collection is needed. Going back several more years (or even to date of building construction) prior to 2005 and averaging energy consumption and then comparing the data to 2006 and 2007 as more data is collected may help indicate any real differences. The calculation of heating and cooling degree days acts as a constant between years and fluctuating weather patterns.

Heating and cooling degree days are calculated to relate a day's temperature to energy demands for heating and cooling. A base temperature is used and subtracted from the average temperature for the particular day for cooling degree days. The same base temperature is used for heating degree days except that the average temperature for the day is subtracted from the base temperature.

Example: The high is 90 and the low is 70 for a summer day. The average temperature is 80.

80 – 50 (base temperature) = 30 cooling degrees.

For a winter day, the high is 50 and the low 30. The average is 40.

50 (base temperature) – 40 = 10 heating degrees.

(Nugent, 2005) and (Swanson, 2005).

Table 2.14 shows the ASLA green roof's electrical consumption based on heating and cooling degree days per month.

Table 2.14 Electrical Consumption per Heating/Cooling Day per Month (Beaulieu, 2007).

	KWH	Heating	Cooling	KWH/Unit
Jun-05	13320	4	331	39.76119
Jul-05	12720		491	25.90631
Aug-05	13200		474	27.8481
Sep-05	13080	315	5	40.875
Oct-05	8280	179		46.25698
Nov-05	9360	439	1	21.27273
Dec-05	14280	881		16.20885
Jan-06	10440	672		15.53571
Feb-06	13680	733		18.66303
Mar-06	13200	529	6	24.6729
Apr-06	10680	174	16	56.21053
May-06	10920	81	90	63.85965
Jun-06	13680		291	47.01031
Jul-06	13560		487	27.84394
Aug-06	13680		489	27.97546
Sep-06	11040	22	115	80.58394
Oct-06	8640	250	20	32
Nov-06	12000	419		28.63962
Dec-06	10920	639		17.0892
Jan-07	9480	746		12.70777
Feb-07	12960	950		13.64211

Other monitoring programs for plant growth are in the works. Richard Hindle, a botanist with a degree from Cornell and currently working on a landscape architecture degree at Rhode Island School of Design, was hired by Michael Van Valkenburgh Associates to monitor the green roof. He is monitoring plant growth and will also monitor temperature for an Urban Heat Index study using the neighboring high reflective roof next door (Beaulieu, 2007) and (www.asla.org/land/2006/0911/greenroof.html).

Beaulieu mentioned there hasn't been much of a temperature difference between the high reflective roof next door and the green roof, and ASLA is looking for a conventional tar roof to use for comparative study (Beaulieu, 2007).

The north wave, which is taller than the south wave to allow room for the HVAC to be hidden underneath, was found to have more vigorous growth. Native species were used on the south wave as experimental, which may have to do with the slow establishment time or failure of species, which was anticipated by Ed Snodgrass of Emory Knoll Farms (www.asla.org/land/2006/0911/greenroof.html, 2007).

Hindle recommended planting in September to have greater coverage. The south wave was also subjected to harsh weather conditions including high summer temperatures and heavy rains. Birds also contributed to the failed plantings by pulling out plugs in search of insects. The grating over the extensive green roof sedums did turn out to be a success, with unexpected benefits. The aluminum selected because it absorbs less heat actually worked to shade the plants and cool the temperatures. The article "ASLA Green Roof Gets Second Round of Planting" points out that this discovery may open new applications by providing stormwater benefits while encouraging safe accessibility while mitigating heat (www.asla.org, 3.27.07).

The photographs on the following pages were taken on a visit to the ASLA green roof in late March 2007. The vegetation was just beginning to come out of dormancy.

Figure 2.18 South Wave with Sprinkler.

Figure 2.19 South Wave Cacti.

Figure 2.20 North Wave.

Figure 2.21 Side of North Wave.

Figure 2.22 Steel Railing and Side of South Wave.

Figure 2.23 Staircase Entry.

Figure 2.24 Staircase Entry.

Figure 2.25 North Terrace with Stormwater Gauge.

Figure 2.26 Trumpet Creeper Vine.

Figure 2.27 HVAC Under North Wave.

Figure 2.28 Elevator Shaft (Right).

Figure 2.29 Sedums.

Figure 2.30 Grate, Sedums, and Edge of Wave.

Figure 2.31 Exposed Vinyl Soil Stabilization System.

Study III: Des Moines Public Library Green Roof

Table 2.15 Des Moines Green Roof Overview

(Lecuyer, 2006) and (Kain, 2007).

Precedent Study	Des Moines Central Library
Context	Polygonal shaped building in grid-patterned downtown Des Moines
Design Development	Functional extensive green roof Inexpensive (comparatively) Added at the request of a neighboring office overlooking the building 50,000 square feet
Maintenance	Two year maintenance plan with Enviroscapes – weeding, additional plantings
Benefits	Holds 4” stormwater per hour Inexpensive ($8.50/sf) Blends building into the park
Lessons	Can have inexpensive and effective green roof. Shows that the price of green roofs is becoming more affordable. Promotes green roofs in central Iowa and the Midwest.

Context

The Des Moines Public Library is located in the city of Des Moines, Iowa’s state capital and one of the nation’s centers for insurance business, (Lecuyer, 2006). The building is designed to blend into the surrounding park setting and it becomes "a library within a park" and "a park within the library,” (www.seedesmoines.com/userdocs/mediacenter/LibraryFAQ.pdf, 2007).

The park, with the library located at the east end is part of the city’s regeneration strategy where the library acts a connector between the central business district and the park (Lecuyer, 2006).

The building forms outdoor spaces within the city's Jeffersonian grid layout and as a result enhances pedestrian circulation. The interesting façade is leaf expanded copper in glass creating different affects during light and dark hours, (Lecuyer, 2006). The library's address is 1000 Grand Avenue and is located between Locust and Grand, and 10th and 12th streets. The park and library are a part of the Gateway West park development (www.seedesmoines.com/userdocs/mediacenter/LibraryFAQ.pdf, 2007).

As the former central library outgrew the original building, the city opened a request for proposals and the library was commissioned in 2001 to architect David Chipperfield of London. Chipperfield worked closely with the public and presented four schemes from which the public chose, (Lecuyer, 2006). The 5,000 square meter or 50,000 square foot nearly flat green roof is covered in sedums (Lecuyer 2006) and (www.greenroofs.net, 2007).

The extensive 1.5% slope library roof was planted on May 24th, 2005. Roofscapes, Inc. provided the green roof system called the Roofmeadow® Savannah roof assembly. Green Roof Plants/Emory Knoll Farms supplied plants and Enviroscape was the installer. The green roof may be viewed from taller surrounding buildings. It is not open to library patrons or the public, (Kain, 2007). Roofscapes was chosen for the low bid and the reputation of the green roof system and it's use on other projects nationwide. Due to the construction schedule the green roof was installed in mid-January, which made blowing the media a challenge. Kain explained that the green roof was actually planted in the spring using broadcast cuttings, a simple method where bags of cuttings are thrown evenly on the growing media and a rake is dragged over them to establish contact with the media. This method was done on the library's green roof with two workers in two days and according to Kain is cost effective.

Design Development

The green roof was added to the program at the request of a nearby office building that overlooked the library. The green roof was bid as an alternate but the roof structure was, "designed to be a flat roof with higher parapet walls to accommodate insulation and pavers if the green roof was not implemented in the project. Once the green roof was accepted the parapet was lowered, which lowered the glass façade," (Kain, 2007). The green roof was funded half by private donations and half public dollars.

Maintenance

The green roof has been maintained by Enviroscapes for 24 months and includes up to six maintenance visits by Enviroscapes during the two year period. The maintenance schedule provided by Enviroscapes includes mainly weeding and fertilizing. After the two year period, which ends in August 2007, the City of Des Moines Parks and Recreation Department will take over the maintenance.

Lessons

The Des Moines Public Library green roof is an example of a relatively inexpensive green roof that can be implemented for many simple projects that wish to have the benefits of green roofs while providing aesthetic relief in a city grid.

The broadcast sedum cuttings reduce the cost of the green roof, making it more affordable. This green roof demonstrates how a simple technology can be beautiful and effective at a reasonable cost. The original budget for the green roof was $400,000 and ended up costing $425,000. The cost per square foot came out to be about $8.50, which included the entire green roof system with plants (insulation, drainage media, root barrier fabric, growing media, and cuttings). $8.50 is a very competitive cost with traditional roofing materials which cost around $6 to $8 per square foot according to Snodgrass (2007). Snodgrass stated that $10 – $12 per square foot is affordable for green roofs.

The green roof is not being monitored but is promoted through education about the green roof at the library. The following photographs show construction progress and the finished library.

Figure 2.32 Des Moines Green Roof Construction
(Kain, 2007).

Figure 2.33 Construction

(Kain, 2007).

Figure 2.34 Nearing Completion

(Kain, 2007).

Figure 2.35 Completed Green Roof and Library

(Kain, 2007).

Summary

This chapter presented green roof basics, history, current standards for green roofs including the FLL and ASTM standards, LEED, and the precedent studies. The precedent studies presented show a significant number of benefits, but in order to forward the green roof industry and improve sustainable LEED credits long term data should be collected. The following is a brief review of the precedent studies, highlighting important lessons.

Ford Dearborn: Shows how a green roof can reduce, or in the case of Ford, eliminate the need for a water treatment facility. There are predictions for a significant decrease in energy use. It also demonstrates a connection with university research (Michigan State University). The sheer size of the green roof was a feat in regards to structural issues but it also provides habitat for wildlife (birds) and insects.

GAP Headquarters: The GAP green roof demonstrates the system integration of the site and building, and the surrounding landscape. It was one of the first green roofs in a Mediterranean climate and provides habitat. The green roof involves the building's inhabitants in connecting to nature.

Life Expressions Wellness Center: The green roof demonstrates the unique solution and technical details for a holistic chiropractic center in a suburban/rural setting.

Chicago City Hall: The publicity of this green roof promoted awareness of green roofs throughout the nation and internationally. The process of CDF working with the city's building permit program allowed CDF to help the city rework the program to encourage green roofs. While energy savings may be more limited because of the 12 story building, the green roof was found to significantly cool the air above the roof.

ASLA: The ASLA has been proactive in conducting monitoring of the green roof including stormwater, energy, and plant growth. The stormwater monitoring results are already showing the ability of the green roof to retain stormwater in its first season. There was also a significant difference in energy usage. The ASLA green roof demonstrates that function and inhabitable space can be integrated.

The cyclical development of my thesis research, though unintentional, mirrored the path of continuous improvement by LEED. Instead of conducting archival research first, then establishing professional dialogue, and conducting precedent studies and professional interviews, the whole process ended up overlapping and re-circulating. The methodology is detailed in Chapter 3.

Information gathered for the precedent studies and professional interviews provided a basis for sustainable green roof criteria for LEED. The studies provided the basis for a critical look at current LEED green roof credits which are presented in Chapter 4 and suggestions for improvement, presented in Chapter 5.

CHAPTER 3 - Methodology

Introduction

The methodology for developing criteria to expand and add specific green roof credits to LEED (Leadership in Energy and Environmental Design) is based on archival research and three intensive precedent studies following *A Case Study Method for Landscape Architecture* (Francis, 2001). Three other studies aided in the criteria development as well. LEED is a green building rating system developed by the USGBC (United States Green Building Council) to define green building, (www.usgbc.com, 2006).

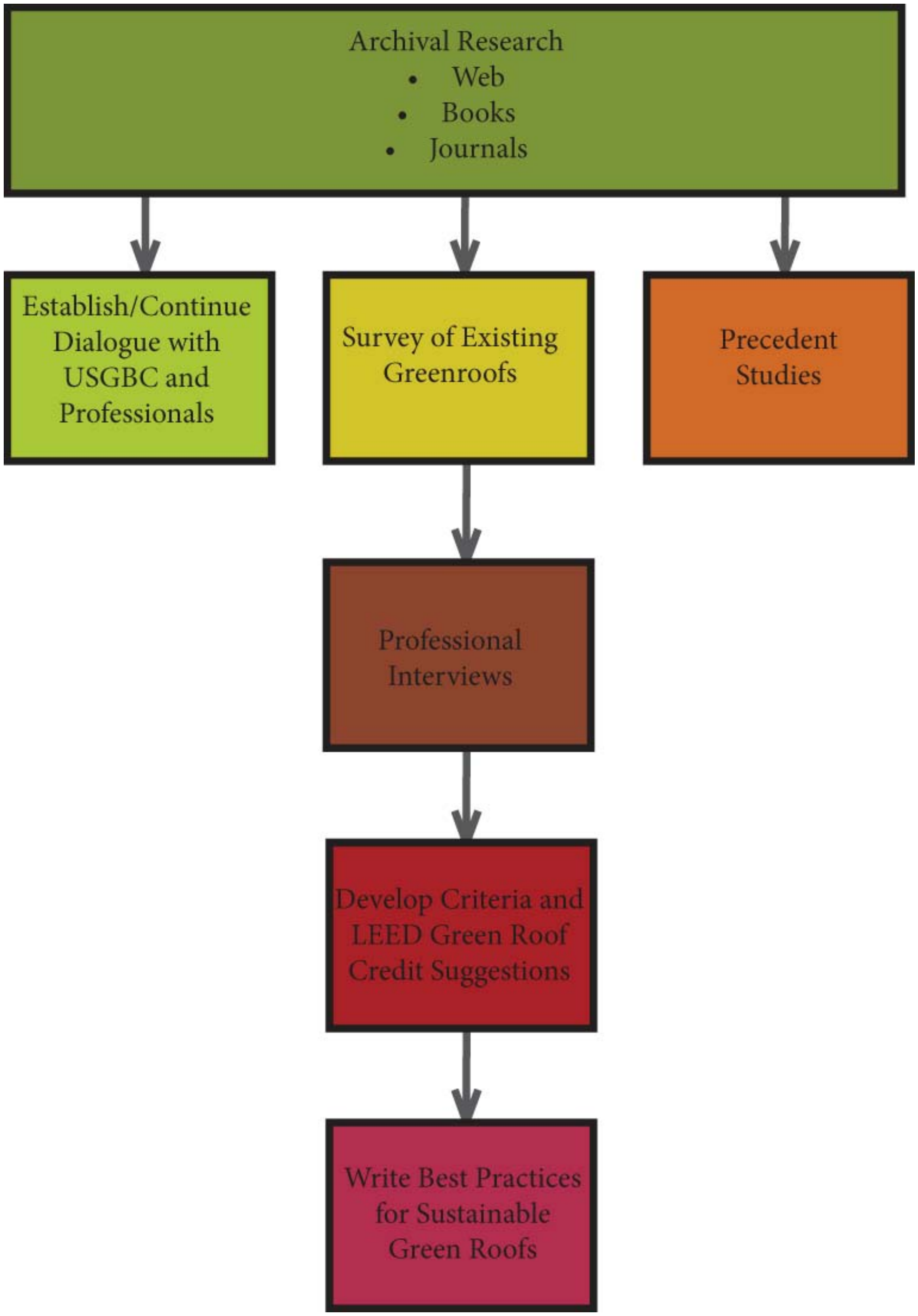
The three intensive precedent studies chosen for the study are the following: Chicago City Hall, ASLA Greenroof, and the Des Moines Public Library. These green roofs were chosen for their unique design objectives and intent in an effort to provide a variety of performance criteria to draw from for the development of specific green roof criteria. Dialogue and interviews with professionals support the development of the intensive precedent studies to establish the functional and ecological green roof criteria intended to further development by the USGBC of sustainable green roof credits. The GAP Headquarters in San Bruno, CA, Life Expressions Wellness Center in Sugarloaf, PA, and the Ford Dearborn green roof in Dearborn, MI are supportive studies.

My belief in the need for a series of green roof LEED credits was developed through archival research and precedent studies, supplemented with professional interviews. I believe much of the literature available will support the necessity for a green roof LEED standard or more specific green roof credits. The true test of my belief is the real world, if credits were incorporated by the USGBC into a “bookshelf” pool of credits.

Methods

The following diagram illustrates my methodology. It does not represent the more cyclical method that resulted as the research was conducted. Much of the research was done simultaneously with the precedent studies and interviews. As a result, interviews and professional dialog, on more than one occasion caused me to review my approach to the research, thus moving in a cyclical pattern of learning a piece of new information which altered my original idea of the results. Therefore, the criteria for green roof credits were developed on a continuous basis, beginning with archival research and refined though professional dialog, precedent studies, and professional interviews.

Figure 3.1 Methodology Diagram



Precedent Selection

The precedent studies were developed through archival research and supplemented by professional interviews. The studies were conducted based on Mark Francis's *A Case Study Method* for Landscape Architecture (Francis, 2001). Six precedent studies were chosen, but three were studied more intensively through interviews and visits. An important point is that there is no single all purpose green roof upon which criteria for a standard may be based. Precedents studies for this research were specifically chosen based on publicity for green roofs and landscape architecture (Chicago and ASLA) as well as affordability and simplicity of methods (Des Moines). In addition, gathering applicable criteria regarding building and site integration, collaboration, ecology, energy, stormwater, the heat island effect, thermal properties, structural, materials, and monitoring from each precedent was fundamental for specific green roof LEED credits.

<u>Ford</u>

The Ford Dearborn green roof was primarily chosen for its' status of the world's largest green roof, at 10.4 acres of extensive sedum. While this green roof is a break through for the industry, there are some aspects of the green roof that should be studied more carefully regarding the sustainability.

<u>GAP</u>

The GAP Headquarters green roof in San Bruno, California was selected due to the level at which the green roof was integrated with the building and the site. This is discussed in more detail in Chapter 2: Background.

Wellness Center

The Life Expressions Wellness Center in Sugarloaf, Pennsylvania is one of the steepest pitched green roofs in North America. This green roof was chosen for this quality as well as the innovation in design through the form of the roof, placement of plantings that differ from the top of the roof to the bottom, and how major design obstacles were overcome. The result can be an aesthetically pleasing green roof, and a functional extensive green roof that has overcome structural engineering obstacles.

Chicago

The Chicago City Hall green roof was chosen largely because it is one of the most publicized green roofs in the United States. The city's goals for green roof technology promotion in the city of Chicago have impacted other cities in addition to its own policies. The combination of aesthetic appeal and functional qualities also made this a good precedent study. The various media depths and subsequent diversity in plant species impact the ability of the green roof to retain stormwater, reduce ambient air temperatures, and demonstrate a wide variety of materials including the green roof buildup and foam insulation to raise planters.

ASLA

The American Society of Landscape Architecture green roof defines an area not typically viewed as inhabitable space, a rooftop, and provides environmental benefits while promoting the involvement of landscape architects in the design and implementation of green roofs. The Society has begun and plans to continue monitoring of temperature, stormwater, and plant growth since the completion of the green roof.

Monitoring is a very important part of green roofs and should, whenever possible, be integrated into a design.

Des Moines

Based on recommendations by Ed Snodgrass of Green Roof Plants/Emory Knoll Farms, I chose to use the Des Moines Public Library as a third intensive green roof precedent. The five other precedents, while significant and valuable green roofs, did not include a representation of a true low cost extensive green roof. For the other five, budget was not as much of a concern as compared to a truly economical green roof, (Snodgrass, 2007). Many companies cannot afford to have an iconic, elaborate green roof on their building. The Des Moines Library was chosen based on the assumption that it is a more economical example because it is entirely extensive and used more affordable planting methods such as broadcast cuttings. The precedent study is discussed in full in Chapter 2: Background.

Precedent Development

Archival

The first three precedent studies: GAP, Ford, and the Wellness Center were studied through archival research. The last three were initiated through archival research but then further developed with interviews and visits.

Interviews

The professional interviews provided valuable insight to supplement archival research and precedent studies. The experience and knowledge of individuals connected and working with green roofs is invaluable in the development of criteria for LEED green roof credits. Interview questions were formulated from A Case Study Method for

Landscape Architecture by Mark Francis and adapted to each green roof precedent study. Interview questions may be found in Appendix C. Preliminary interviews with Ed Snodgrass and Deon Glaser provided insight for choosing precedent studies and developing criteria (Snodgrass, 2007) and for redirecting the focus of the thesis from developing a separate LEED standard for green roofs to focusing on the existing LEED credits and their sustainability (Glaser, 2007) as well as suggesting criteria or guidelines for the further development of LEED credits addressing green roofs.

David Yocca of Conservation Design Forum provided valuable information regarding the Chicago City Hall green roof and the ASLA green roof. Kieth Swann conducted my tour of the ASLA green roof and Gerald Beaulieu discussed his stormwater and energy research. Kevin Kain of the Weitz Company provided valuable information regarding the Des Moines green roof.

Site Visits

For the Chicago and ASLA green roofs I conducted an in-person interview with David Yocca at the Elmhurst, Illinois office of Conservation Design Forum and Gerald Beaulieu, CFO and Managing Director of Business Operations at the ASLA office in Washington, DC.

Chicago City Hall does not allow the public or building inhabitants on the green roof. The only way to view the green roof is from one of the 33 surrounding taller buildings, which due to time constraints of the visit, was not possible. The ASLA green roof was accessible and I went on a scheduled tour with Keith Swann (Special Assistant to the EVP). Mr. Swann also presented a power point about the green roof. An attempt was made to visit the Des Moines Public Library and interview Kevin Kain of the Weitz

Company, but weather conditions prevented travel. I conducted a phone interview with Mr. Kain the following day.

Criteria Development

The development of the sustainable green roof criteria became a cyclical process with continuous refinement as I learned new information through archival research, precedent studies, interviews, and visits. A continuous development of sustainable green roof criteria is ideal, (though I did not originally foresee the connection between the cyclical development of the criteria and the need to continuously update LEED and green building standards in general) and parallels with the USGBC's progress in the update of the LEED standards to "continuous improvement". Members of the USGBC have recognized that green builders are constantly learning more about sustainable design through their work and through research, and that standards should keep up to date with new information.

After a list of criteria was developed and a majority of the precedent studies and interviews were conducted, I prioritized the criteria according to each criterion's impact on LEED and the sustainability of green roofs. I did this through comparing current LEED credits that address green roofs, lessons learned from the precedent studies, and information gathered from the interviews conducted. The next chapter presents the findings of this research.

CHAPTER 4 - Findings

The current and potential impact LEED has on green roofs is significant. The methods LEED implies or promotes within the credit requirements can impact the designer's approach to green roofs. While it is the responsibility of the designer to make sure they are up to date on green roof technology and practices, LEED can be misleading and can drive up market costs if the methods suggested are not carefully reviewed and updated on a regular basis. This chapter presents the findings of the archival research, precedent studies and professional interviews in regards to green roof sustainability and LEED credits.

Expected versus Actual Outcomes

The major goal of this study was to develop a criteria set for green roof LEED credits with the intent of submitting it to the USGBC. The information is meant for review by a USGBC committee. Upon review, it is intended for a committee to conduct further research in order to produce and establish specific green roof credits that may be integrated with the Continuous Improvement LEED Version 3.0 or in subsequent updates. The following discussion is in response to the questions posed at the end of Chapter 1 and describes how the study evolved to focus on green roof LEED credits instead of proposing a green roof LEED standard as originally envisioned.

Determining which green roofs are sustainable is a difficult task. The line can be drawn according to the level of greenroof technology available and the level of ecological knowledge and resources available. As the sustainable "green" movement progresses the demand for sophisticated structural and ecological technology will increase. This cause and effect relationship will increase the standards associated with LEED certifications. What is sustainable now, will seem elementary ten or even five years from now. Green roofs of the future may behave more like organisms than inorganic roofs with plants on top.

Professionals can effectively pass judgment in regards to success of green roofs that serve no ecological function because ecological, functional, and aesthetic components are intertwined in a dynamic relationship. If a dynamic relationship and sustainability are emphasized through LEED standards, a building with a green roof will not be certified unless it meets specific structural and ecological performance standards.

The outcome of the question, “Are there any “good” greenroofs upon which to base precedent studies?” is multi-faceted. There is no single greenroof upon which all criteria for a standard may be based. The precedent studies were chosen based on publicity for both green roofs and landscape architecture (Chicago City Hall and ASLA Headquarters) as well as affordability and simplicity of methods (Des Moines Public Library) and provide valuable lessons. The more green roofs are studied, monitored, and analyzed, the more sustainable LEED green roof credits can become.

After initial archival and precedent study research, I believed that suggesting a separate LEED standard would be the solution for the sustainability issue. I thought about suggesting four new green roof standards: LEED-GR-NC, LEED-GR-Retrofit, LEED-GR-Rural, and LEED-GR-Urban. I then initiated dialog with Deon Glaser, LEED Program Coordinator with the USGBC. She pointed out the following:

> “To be honest with you, it is highly unlikely that LEED would adopt a rating system such as LEED for Green Roofs for the following reasons:
>
> 1. As LEED changes into a bookshelf model and away from individual rating systems, there will be no new rating systems developed for specific project types. LEED is moving toward Continuous Improvement which involves aligning the existing credits across building types and developing new and important credits to the bookshelf (one large pool of credits that projects can choose from). The idea is that instead of a project team having to fit its scope into a rating system with the closest fit, it will be able to use a customized system based on its own personal project type. This process is still very much in the development phase currently.
>
> 2. LEED is a rating system for a whole building, not just one element of a building such as a green roof. If a building got LEED certified for just doing a green roof it would[n’t] be looking at the building holistically. Theoretically a building could get a certification for just the roof and the rest of the building could be wasting energy, water, and using materials with dangerous chemicals in them. That is not what USGBC wants to happen.
>
> 3. For a project to become LEED certified it must satisfy all of the prerequisites in every credit category. If there was a LEED for Green Roofs it would be difficult or nearly impossible for many projects to satisfy these prerequisites. Additionally, projects must achieve a minimum of 26 credits to even be considered certifiable. My guess would be that there is not enough one could do with green roofs to award 26 points. Each point granted requires much work and documentation and must have a significant environmental benefit. Green roofs are not able to provide enough points on their own to reach this threshold which explains one reason they are part of the entire rating system instead of their own.” (Glaser, 2007).

After receiving feedback from Glaser, completing other professional interviews and analyzing what I learned, I decided to shift the focus to sustainable green roof criteria, or a list of Green Roof Best Practices, that could be used as guidelines for designers interested in a green roof project and wanting to attain LEED certification. It is my intent to submit the results of this research to a USGBC member and other professionals within the green roof industry.

The Continuous Improvement of LEED

USGBC (United States Green Building Council) is currently developing a new LEED, Version 3.0, or "Continuous Improvement". This new format would allow for the continuous update of credits as well as aligning credits for specific building types, such as those with green roofs. LEED is also working on improving in the areas of "bioregional sensitivity" and Life Cycle Analysis (LCA). The new structure of LEED would not necessarily be a new system, but a new way of organizing and updating the existing products within the LEED Rating System Product Portfolio.

Effects of LEED on Green Roofs

LEED does address green roofs in the current standards. While green roofs are a means to an end, and depend on the program of the building, it is still important to consider the actual sustainability of a green roof. Green roof sustainability in the current version of the LEED standards seems to be an afterthought and a majority of the parameters related to green roof sustainability are not stated.

Current Green Roof Credits

Several LEED credits under the New Construction LEED product do address green roofs and are listed below with a brief description of how they apply to green roofs. Each credit is under a specific category type and numbered according to the credit's focus. This list of credits was complied through studying the LEED-New Construction Version 2.2 packet available on the USGBC's website (www.usgbc.com, 2007) and through email dialogue with Deon Glaser (2007).

- *Sustainable Sites 5.1: Site Development: Protect or Restore Habitat* addresses using vegetation on green roofs for restoring habitat using native or adapted plants.
- *Sustainable Sites 5.2: Site Development:* counts green roofs as open space.
- *Sustainable Sites 6.1: Stormwater Design: Quantity Control* lists green roofs as a strategy to minimize stormwater runoff.
- *Sustainable Sites 6.2: Stormwater Design: Quality Control* encourages the use of green roofs to promote infiltration.
- *Sustainable Sites 7.1: Heat Island Effect*: *Non-Roof* states that a green roof can be used as a potential strategy for the replacement of constructed surfaces (roof, roads, sidewalks).
- *Sustainable Sites 7.2: Heat Island Effect: Roof* promotes the use of a vegetated roof for at least 50% of the roof area. Cooler air above the roof can allow the HVAC system to be scaled back to save energy. Innovation in Design points may be earned if 100% of the roof surface is vegetated.

(Innovation in Design is an extra section in addition to the main sections of credits that allots extra points for designs that go above and beyond credit requirements.)

- *Water Efficiency 1.1: Water Efficient Landscaping: Reduce by 50%* aims to reduce a building's water usage by 50%. The goal behind the credit is to reduce the amount of water discharged on the site or wasted through industrial processes. Green roof plant choices can reduce the need for irrigation. Choosing plants that require less or no irrigation can help attain this credit. Temporary irrigation must be removed after one year.
- *Water Efficiency 1.2: Water Efficient Landscaping: No Potable Water Use or No Irrigation* gives an additional point if WE 1.1 is met and exceeded so no potable water is used for irrigation on the site.
- *Energy and Atmosphere 1: Optimize Energy Performance* allows green roofs, under Option 1: Whole Building Energy Simulation, to contribute to this credit because of the expected insulating properties of the green roof, which reduce energy demand.
- *Materials and Resources Credit 3.1: Materials Reuse: 5%*. This credit is awarded if recycled products on the green roof contribute to the total percentage needed for the project to achieve the credit.
- *Materials and Resources Credit 3.2: Materials Reuse: 10%*. The same as MR 3.1 but the total must be 10% reused materials as opposed to 5%.

- *Materials and Resources Credit 4.1: Recycled Content: 10%.* Products used on the green roof containing recycled content may contribute to this credit.
- *Materials and Resources Credit 4.2*: *Recycled Content: 20%.* The same as MR 4.2 but the total must be 20% recycled content as opposed to 10%.
- *Materials and Resources Credit 5.1*: *Regional Materials: 10% Extracted, Processed & Manufactured Regionally:* Materials used on the green roof can contribute to the credit if they were extracted and manufactured within the region supporting the use of local resources and reducing transportation costs.
- *Materials and Resources Credit 5.2*: *Regional Materials: 20% Extracted, Processed & Manufactured Regionally:* The same as MR 5.2 but the total must be 20% as opposed to 10%.
- *Materials and Resources Credit 6*: *Rapidly Renewable Materials:* Materials used on a green roof that are rapidly renewable.
- *Materials and Resources Credit 7*: *Certified Wood* gives a point if wood used on a green roof is certified.

Credit Weight and Cost

A project considering a green roof and LEED certification will look at the cost of the green roof for the amount of points given. A green roof is a complex engineered system. Currently there is not a weighting system for credits or for the time, effort, and funding it takes to achieve those credits. It seems unfair to award only one point (or two for Innovation in Design) for Sustainable Sites 7.2 for adding a vegetated roof on at least 50% of the roof area. This requirement may deter designers in a “points chase” from considering a green roof as they look for easier and less expensive credits to achieve.

Appropriate Plant Material

Native plants, as individual species may work well on a green roof. With recent, and well deserved, interest in native plants, many designers are led to believe or think that native plants should thrive on green roofs. The practical matter is that many native plants have not been tested for their performance on green roofs in the United States.

For example, a native prairie habitat would be very difficult to recreate on a green roof. The soil media depths required by many of the prairie species are very deep and the plants require a high content of organic matter, as well as create a good amount of organic matter. Organic matter decomposes quickly resulting in humic acid runoff which can impact streams (Snodgrass, 2007). Specifying prairie species in a soil medium too shallow will cause failure. Specifying specific species that are adapted to conditions similar to those on a green roof may prove to be successful selections.

In a phone interview Ed Snodgrass, owner of Emory Knoll Farms and author of "Green Roof Plants", explained how important it is to choose appropriate plant material. Snodgrass mentioned how he deals with phone calls from designers with inappropriate plant material specifications as a result of the LEED credits that require the use of natives or adaptive plants (2007).

Affordability is the Key to Sustainability

Do the LEED ratings push the green roof industry to a more expensive solution? This question, raised by Snodgrass (2007), is a thesis by itself, but a good question to pose. He also asked, "Do they [green roofs] have unintended consequences by driving the market down for green roofs and the square footage of green roofs down?" Snodgrass gave the example of a Chicago Wal-Mart that placed a green roof over half of the roof available because it was required. If green roofs were less expensive then the decision makers for the Chicago Wal-Mart may have allowed a full green roof. It is important to look at LEED requirements, such as natives (which require a deeper substrate and are more costly) and how the standards are written.

Snodgrass provided a breakdown of green roof costs:

Current: $30/sf

Affordable: $10 - $12/sf

Conventional Roof: $6 - $8/sf, (2007).

Currently green roofs are not economically competitive with conventional roofs. The Chicago Wal-Mart example has only half of the roof area available as green roof.

The 128,000 square foot green roof was split down the middle and 64,000 square feet were greened, thus meeting the LEED Sustainable Sites 7.2 requirement.

The Des Moines Public Library precedent study is a good example of methods used to bring the cost of the green roof down. The green roof cost $425,000 for 50,000 square feet which equates to about $8.50 per square foot. According to the breakdown of roof cost above by Snodgrass, the green roof is economically competitive with conventional roofs.

The more businesses are able to implement a green roof in terms of cost, the more likely they are to utilize the entire amount of square footage they have available. The current market economy of green roofs can have an impact on a client's decision (Snodgrass, 2007).

Usable and Functional Space

The American Society of Landscape Architects (ASLA) green roof is a prime example of creating a dynamic between usable and functional space through the use of aluminum grating over an extensive green roof system planted with sedums. This dynamic opens up a whole new avenue in green roof design in order to gain the functional benefits of green roofs while allowing the space to be habitable.

Monitoring

The ASLA green roof, though relatively new, has set several monitoring programs in place as described in Chapter 2: Background. Because each green roof is different from the next, it is important to gather information from as many as possible in order to thoroughly understand the technology. Integrating science, architecture, engineering and design is a complicated task, even for an extensive green roof system. As we come to understand more about green roofs we can learn to build them more sustainably.

Education

The Chicago City Hall and ASLA gained national and worldwide attention through their innovative green roof techniques. These green roofs prove that education is increasing awareness, which is a first step. Many articles in major news sources were published regarding these green roofs.

Best Practices for Green Roofs

Based on archival, precedent studies, and professional interviews, I developed a list of best practices or criteria for green roofs. These guidelines are meant to advise designers and the development of LEED credits. They are intended to stimulate the development of stronger green roof sustainability standards not only for LEED, but to promote quality green roofs that positively impact the natural and built environment. The findings of my research are presented in this chapter.

Building and Site Integration

A green roof is a first step in a series of best management practices that may be used on a site to mitigate environmental impacts such as stormwater. This integration of the green roof with the building, for example a water collection system and cisterns like that used for the Solaire in New York, is best when planned from the beginning of the project's conception. If the green roof is an afterthought, troubles that may arise range from structural loading issues to not having the specified plants at the right time because they need to be ordered a year in advance. It is important to understand all the building needs and programs, and then choose an appropriate green roof for the design objectives. A green roof's program may be based on an anticipated level of maintenance or management, which will have a profound impact on the short and long term viability of the green roof.

One credit, Sustainable Sites 7.2: Heat Island Effect is the only credit that deals directly with green roofs. Two of the three options under this credit offer the use of a green roof as a method to earn the credit.

> Option 2: Install a vegetated roof for at least 50% of the roof area.
> Option 3: Install high albedo and vegetated roof surfaces that, in combination, meet the following criteria:
> (Area of SRI Roof/0.75) + (Area of vegetated roof/0.5)>= Total Roof Area.
> (SRI = Solar Reflectance Index).

An "Innovation in Design" point may be awarded if 100% of the roof area is vegetated. Credit 7.2 requires under one option that a green roof be implemented on a minimum of 50% of the surface area on a building's roof. There are not parameters or guidelines for green roof sustainability.

David Yocca explained that green roofs are a means to an end and the program of a building guides the green roof's performance. For example, a green roof can be a tool for a balanced water budget (Yocca, 2007). Though green roofs are dependant on the building's program, they can have a profound impact on the building itself, the site, and the surrounding landscape which is why it is important to have green roof credits that promote sustainable methods.

Collaboration

Working with a number of professionals with different areas of expertise is essential when designing and implementing a green roof.

> "The most successful green roof projects result from collaboration. Though the prime design professional seals the documents, assumes a certain amount of liability, and takes a leadership role, they must also draw upon the knowledge and expertise of a number of qualified individuals. These professionals need to be aware of their limitations and hire additional experts when the project requires a level of competency that they do not possess" (GRHC Participants Manual, 2006).

A successful green roof design team will have professionals with varying skills and expertise depending on the size and complexity of the project (GRHC Participant's Manual, 2006). The precedents studied in Chapter 2 demonstrate that a number of different professionals (from engineers to green roof consultants) contributed to these projects. Appendix B provides a table listing the design and construction professionals for each precedent.

Ecology

An ecologically focused green roof is a system designed to minimize impacts on the site and surrounding landscape through carefully selected products and materials. Green roofs are an example of how human intervention can positively impact local ecology. While there are ecological benefits for green roofs it is essential to remember these are engineered systems that nature can and does "take over".

Ed Snodgrass (2007) noted how the succession of German green roofs from what originally was planted with sedums "evolved" to mostly bryophytes, or mosses. He explained how the rain in Germany is considerably more acidic than the North American climate, which caused the mosses to colonize roof tops. The green roofs still perform the original function of absorbing stormwater but are not as effective in improving water quality. The important point to remember is the green roof was allowed to "succeed" due to outside influences (though the acid rain is also due to human intervention – pollution) and still perform according to the original design intent. Snodgrass warned against allowing tree seedlings to sprout on green roofs. While tree seedling presence could technically be considered succession, the added biomass deviates from the original design intent of absorbing stormwater and could compromise the structure of the roof (Snodgrass, 2007).

Energy

Energy is the major section within the LEED green building standards and also the most difficult to document and build according to the standard requirements. In Energy and Atmosphere Credit 2, one option, that can receive up to 10 points, requires that the designed building be compared against a baseline case (or status quo building) in order to prove the project is going above traditional building standards and truly saving energy.

There is a computer software program, eQuest, that can simulate energy usage for the building, but there is not specific information in the program regarding green roof media, plantings, and other components that would affect energy savings (insulation, etc.). Currently, "modeling the energy effects of green roofs is a young science with little empirical verification…" (Ansel, 2004). Green roofs can reduce the need for energy used by the HVAC (Heating, Ventilation and Air Conditioning) units of rooftops by cooling the ambient air temperature during summer months. The impact of the temperature reduction varies by climate and thus energy savings can be more significant in some regions of the United States than in others. Green roofs also have insulating properties that reduce the ability of hot or cold air to enter through the system.

Green roofs have been shown to improve the efficiency of technologies such as solar power (Ansel, 2004). Combining green roofs and photovoltaics (PV's) may result in higher PV efficiency. The ambient air temperature is cooler which is better for the heat sensitive solar panels. "From research, conducted by Krauter and Ochs, it is known that lower ambient temperatures can have a positive influence on the efficiency of PV-panels" (Köhler, 2007). Growing extensive green roofs under the solar panels is a way to reduce temperatures and increase the efficiency of the panels.

> "Although the energy output of the PV-panels depended on several factors, in this survey of over approximately 5 years of data, it is estimated that the green roof resulted in an average 6% increase in energy yields" (Köhler, 2007).

The shade panels provide for some areas of the roof is also beneficial to the plants and protect them from too much heat from the sun. The cooling effect of evaporation of water stored in the green roof helps to cool the PV panels (Köhler, 2007).

Stormwater

Intercepting stormwater before it flows to the storm drain system is a key function of green roofs. Many cities in the United States have combined sewer systems (CSO's). With the increasing amount of development and impervious surfaces such as roads, parking lots and roof tops, there are many problems that occur such as flooding and poor water quality. The American Society of Landscape Architects green roof has installed a monitoring system for stormwater and based on the data so far, one may conclude that the green roof does retain a significant amount of water.

Green roofs can have a significant impact on water quality since the roof is a first step in intercepting stormwater. As the water moves through a green roof system (including plant material, soil media, and drainage media) the water is “cleansed” before any excess runs off the roof. A green roof can remove harmful substances from the environment that settle on a roof, or that are suspended in the air.

A green roof acts as a first interception of stormwater, filtering and slowing the velocity before the water moves over the site. The very thin membrane of the Ford Dearborn green roof can only hold water for so long before it begins to dry out, which is why the entire 10.4 acres of sedum green roof is irrigated (though said to be minimal). Vegetated mats were used for this project and while they are beneficial in Europe, where the climate is more conducive to the use of thinner media and plantings, they are more difficult to establish in the United States without irrigation (Snodgrass, 2007). Also, vegetated mats are more expensive than plugs or broadcast cuttings, and take much longer preparation time.

Heat Island Effect

A single green roof cannot reduce the urban heat island effect by itself, but if many green roofs are used in a particular area there would be a cumulative effect. Even so, a green roof can reduce the ambient air temperatures significantly, as is the case on the Chicago City Hall green roof.

Structural

Most of the structural aspects of a green roof should be coordinated with a structural engineer, but there are several considerations besides loading requirements that landscape architects and designers should be aware of. Integrating the building systems with the green roof can contribute to the level of sustainability a building achieves. The Chicago City Hall green roof is not an extensive example of the potential for integrating the building systems with the green roof, but it does collect stormwater on the penthouse green roof and uses it to supply the lower green roof with water during dry periods. Wind uplift, or the force of wind affecting structures on the roof, is another issue to be mindful of. The ASLA green roof used steel structural support in the waves and uplift mitigation cables. No doubt this was coordinated with an engineer, but this factor definitely affects the design of the green roof.

Materials

The current LEED materials and resources credits provide an avenue for green roofs to contribute to meeting the credit requirement. Several questions arise regarding green roofs and materials. Is it sustainable to add extra weight such as steel and concrete to support a green roof? Does the net energy used and carbon emissions created by implementing the green roof balance with the benefits of the green roof? The rest of this section mentions factors important to consider regarding the application of materials on green roofs.

Green roofs in Germany use many recycled products for growing and drainage media such as crushed tiles. Crushed concrete should not be used for green roof media because the fine particles can clog the filter fabric and destroy the green roof over time.

The FLL standards discuss fire safety and making sure materials used on the green roof are up to fire code. The use of buffer areas with media and sedums can help reduce the risk of fire. The conveyance of materials can require a significant amount of time, energy, equipment, personnel and transportation which should be factored in to any green roof project. Materials that could leak possible contaminants into the green roof should be avoided to preserve water quality. Flood testing is necessary to ensure there are no leaks in the waterproofing membrane. Taking measures to prevent wind and water erosion of the growth media is important. Using mats or already established vegetation is an option. The ASLA green roof used a soil stabilization system and gravel mulch to hold the soil media in place.

Deriving Conclusions

The findings of my research provide a basis to derive conclusions for LEED green roof credits and pose suggestions regarding the continuous improvement of LEED and the integration of sustainable green roof requirements. Chapter 5 discusses the conclusions from this research.

CHAPTER 5 - Conclusions

Initially I thought a separate green roof standard would bring more focus to green roof sustainability within LEED. After speaking with Deon Glaser of USGBC, my focus shifted. "LEED is a rating system for a whole building, not just one element of a building such as a green roof," Glaser said. She goes on to say, "Theoretically a building could get a certification for just the roof and the rest of the building could be wasting energy, water, and using materials with dangerous chemicals in them. That is not what USGBC wants to happen" (Glaser, 2007).

I agree that a separate green roof standard would be counterproductive to LEED objectives. One could argue that focusing solely on the building and not looking at the green roof component more carefully is also counterproductive. That is where this research comes into play.

An interview with David Yocca of Conservation Design Forum further supports the issue because green roofs are a means to an end. Yocca explained that the building program guides green roof performance. The green roof, in turn, can have a profound impact on the building's performance and the building site, therefore it is important to clarify sustainable green roof credits.

The first portion of this chapter mirrors the findings chapter and addresses conclusions and suggestions regarding the results of each topic discussed. The second portion focuses on expected versus actual research outcomes, research limitations, significance of the research, what I would have done differently in retrospect, and future research suggestions.

The Continuous Improvement of LEED

Through the restructuring of the LEED Rating System Product Portfolio, a project with a green roof can focus on credits with green roofs while still going for LEED certification. Existing credits may be updated more easily and new credits regarding green roofs may be added. LEED is in the process of developing the version 3.0 therefore the specifics of how the new system will work will not be known until the version is released. The focus will be on incorporating knowledge and improved technologies as soon as possible, which benefits the sustainability of green roofs.

The new ASTM standards (five so far) could be integrated into green roof standards. As new standards develop, LEED's Continuous Improvement program would allow for the incorporation of new standards into LEED. As LEED moves toward "continuous improvement" it should allow for the integration of new sciences and research for green roofs and by editing LEED credits to reflect a sustainable approach to green roof design and construction.

Effects of LEED on Green Roofs

Designers should not have to choose a green roof if it is not in the building's program, but LEED should have a stronger breakdown of green roof credits that delineate sustainable practices for a green roof. Credit 7.2 should address sustainable green roof practices more specifically or there could be a new credit, 7.3, that focuses specifically on green roof best practice guidelines.

Green roof sustainability could be addressed through existing credits such as sustainable sites and water efficiency. A new stormwater credit could require green roofs to retain a certain percentage of stormwater for a particular storm event for a certain length of time. Or another stormwater credit could require improved water quality and infiltration.

New credits may be defined regarding native plant use and monitoring. Monitoring is a huge factor in learning about how green roofs work and how to improve them. Monitoring credits could be weighted as to the extent of the study and the length of time. More points would be awarded according to the number of studies (urban heat island temperatures, stormwater, plant growth, etc.) and how long the monitoring takes place. The data collected should be analyzed and published.

Current Green Roof Credits

Chapter 4: Findings presented the current green roof credits and a brief description of what they cover. The following table follows the same order but offers short suggestions regarding each credit. Under the section “Best Practices for Green Roofs”, more detailed discussion and information is offered regarding important criteria for green roofs.

Table 5.1 Current Green Roof Credit Suggestions.

Credits	Suggestions
Sustainable Sites 5.1	Placing plants, native or adaptive, on a green roof does not protect or restore habitat. A natural habitat cannot be restored on a green roof because a green roof is an engineered system. Green roofs can provide habitat, but this should be clearly defined along with the selection of appropriate plants for green roofs.
Sustainable Sites 5.2	This credit is appropriate.
Sustainable Sites 6.1	Listing green roofs as a strategy for quantity control of stormwater is a first step. Create additional sustainable sites credits for green roofs or integrate more requirements within current credits.
Sustainable Sites 6.2	Define more parameters for water quality and quantity.
Sustainable Sites 7.1 and 7.2	Valid credit that addresses the mitigation of the UHI effect with green roofs. Define more parameters.
Water Efficiency 1.1	Valid credit that addresses the water usage. May include a requirement or option for water collection on the green roof or other integrated systems.
Water Efficiency 1.2	This credit promotes not using irrigation on a green roof and is applicable. Include the collection and storage of water for use on the green roof or in the landscape (depending on regional requirements).
Energy and Atmosphere 1	Integrate and account for green roof components that contribute to energy savings into an energy computer modeling program.
Materials and Resources Credits 3.1 - 7	Green roofs can contribute to the existing credits. Include clarification and more information regarding specific green roof products.

Credit Weight and Cost

Though it is important to get the cost of green roofs to a more affordable level, green roofs, particularly intensive green roofs, are expensive. The points awarded for a green roof, if the designers are able to utilize all of the credits mentioned in the previous section, still do not seem to reflect the amount of time, energy, effort and money poured into gaining those points as compared to more simple points that may be attained by, for example, installing an electric car recharge station.

Whether this issue is a major deterrent for designers to install green roofs remains a question, but the relatively few green roofs that have been installed on LEED projects may reflect that it is a concern. Credits that directly require green roofs should award a greater number of points.

Appropriate Plant Material

Designers should be wary when using natives on green roofs. This does not imply that natives should not be used, but designers should exercise caution when attempting to "recreate" native ecosystems on a building structure. Green roofs are engineered systems and should be treated as such. Incorporating native or adaptive plants on green roofs must be done selectively. A key to a successful green roof is making sure the plants become established quickly in order to reap benefits such as stormwater retention and to justify the cost of the investment. LEED credits should be written to make designers aware of the impact of plant selection on the success of a green roof.

While green roofs are engineered systems, designers should be sensitive toward the impact on the site and local ecology. LEED should incorporate written methods of appropriate plant selection that is sensitive to the fact that a green roof is not a natural habitat. Certain reference ecosystems that may be considered are those that tolerate high stress with a minimal amount of topsoil and outcrop areas.

Because the new version is considering bioregional sensitivity, a credit requirement focusing on green roof plant selection can easily be incorporated into the new standard version. LEED may also integrate green roof plant selection in the credits that already mention plant selection, specifically Sustainable Sites 5.1.

Affordability is the Key to Sustainability

Green roof LEED credits should integrate a methodology to drive the price down. Right now most green roofs are not competitive with conventional roofs, though they are becoming less expensive to design and install. LEED can help drive the cost of green roofs down by requiring more simple methods to implement green roofs. The Chicago Wal-Mart example mentioned in Chapter 4 had the potential to cover its roof entirely with an extensive system. It is unknown specifically why Wal-Mart decided to only green part of the square footage, but given the company's economic reputation a conclusion may be drawn that cost was involved.

Requiring or emphasizing the use of simple methods such as blown media and broadcast cuttings reduces the cost and makes it more affordable for the many companies, businesses, and building owners that make up a city. The more green roofs implemented in a city, the more widespread the benefits including stormwater, heat island, and air quality to name a few.

Usable and Functional Space

The LEED standards may suggest combining usable and functional space but this should be left for the designer(s) to decide.

Monitoring

Emphasizing and rewarding multiple points for monitoring within LEED credits may increase the volume of data regarding green roofs. Collecting, recording, and analyzing data for energy savings, temperatures, plant growth, and stormwater would provide valuable information. Development of a nationwide database of green roofs is in the works through several green roof organizations and websites. Now it is important to start adding real data on green roof benefits. LEED credits will not be feasible without hard facts such as stormwater retention percentages and water quality standards to meet. This information, as it is gathered, would increase the confidence of the general public, developers and builders resulting in a larger base of people willing to accept green roofs.

ASTM standards and other technical standards are currently being developed, but the more information gathered on specific green roofs in different regions of the United States, the better.

Monitoring may be incorporated into existing and individual green roof LEED credits or a new category of credits could be created for monitoring. An additional credit may be offered with each LEED category, such as adding *Sustainable Sites 6.3: Stormwater Design: Monitoring*.

Monitoring may coincide with the different levels of LEED certification such as Certified, Silver, Gold, and Platinum. Giving monitoring more point weight should also be considered due to the amount of time and resources that go into conducting studies.

The length of the studies and the extent of what is studied should also be taken into consideration when points are awarded.

Monitoring could be incorporated into the different green roof credits such as stormwater and plant selection (monitoring plant growth) or a separate section for monitoring could also be a solution. If a separate section for monitoring is developed, it may be combined with monitoring other building functions. LEED should promote monitoring and create or link to a network of greenroof data and information to further increase the extent of North American research.

Education

A LEED credit involving education would promote awareness and understanding of green roofs. An education credit may be combined with monitoring and/or collaboration. Examples of education requirements could include signage, usable space that teaches users about the green roof components so they can see how green roofs work up close, and the involvement of the public. Not all green roofs have the same program elements so education could be one option for a credit. Even if education is not a credit, it should be emphasized in the written LEED standards.

Best Practices for Green Roofs

Based on archival research, precedent studies, and professional interviews I developed a list of best practices or criteria for green roofs. These guidelines are meant to advise designers and the development of LEED credits. They are intended to stimulate the development of stronger green roof sustainability standards not only for LEED, but to promote quality green roofs that positively impact the natural and built environment.

Building and Site Integration

Designers should take care to make sure the green roof design coincides with the building and site design. The green roof should not be an afterthought but part of the program from the beginning. Green roof projects that pursue LEED certification should be required to show evidence of connecting the green roof, building and site as a unified whole. Because building and site integration does not fit into a specific credit category, the credit may be written as a prerequisite for a sustainable sites credit because of the ultimate effect the green roof has on the site through integration with the building.

Collaboration

Multi-disciplinary involvement from the beginning is key to a successful green roof project. LEED credits may be awarded for showing a diverse project design and implementation team. As part of a LEED submittal, a simple form to document involvement in the collaboration process for team members to fill out as the project progresses might provide an effective method for emphasizing a diverse team. Green Roofs for Healthy Cities (2006) discusses the roles of professionals involved in green roof design and installation in the “Participant’s Manual for Green Roofs Infrastructure: Design and Installation 201” which include: client, building architect, landscape architect, structural engineer, civil engineer, environmental engineer, mechanical engineer, roofing consultant, accredited green roof professional, growing medium consultant, horticulturalist/agronomist, cost estimator, owner's testing agent, general contractor, landscaping contractor, roofing contractor, leak detection specialist, irrigation specialist, quality control representative, landscaping maintenance contractor, manufacturers, and regulatory bodies (2006, p. 11-13). It is not likely that all of the roles listed by Green Roofs for Healthy cities would be involved in a project, but a certain number of qualified professionals may be required to receive credit. Green roof collaboration would be a partial fulfillment of an "Innovation and Design Process" credit (ID Credit 3: Collaboration).

Ecology

Promoting ecology through the LEED standards can be done several ways (not limited to):

1. Providing documented information on plant diversity with a species count and proof of those species surviving after a year and at five year interval checks.
2. The use of an appropriate reference ecosystem such as the plant community chosen for the Philips Eco-Enterprise Center in Minneapolis Minnesota. While the green roof is still relatively new and the success of the plants will depend on a time factor, this is a good example of how the designers studied a native plant community that grew in shallow rocky soils – similar to replicated conditions on the green roof. Ed Snodgrass (2007) suggests being careful when choosing natives and states there is a narrow spectrum for

biodiversity on green roofs because they are engineered systems. Instead of a replicated ecosystem, most green roof plants end up being several selected natives living individually on a green roof (Snodgrass, 2007).

3. Providing documented information on insect and animal biodiversity with a species count and proof of those species surviving after a year and at five year interval checks. Many species documented on green roofs depend on the height of the building but fauna usually include: birds, bats, butterflies, insects and other pollinators such as bees. The effects of structures such as butterfly and bat houses and bee hives to encourage biodiversity would be interesting to study.

4. Providing documented information of long term monitoring of green roof succession. While there is little research regarding green roof succession, it would be interesting to study if plant "communities" on a green roof evolve. It is important to note that succession does not mean adding biomass such as tree seedlings (Snodgrass, 2007).

Energy

Energy savings is a complicated subject. The green roof is just one component that affects the efficiency of a building, but it can have a major impact in terms of heating and cooling. It is not in the scope of LEED to develop a method of tracking specific energy savings for a green roof that separates that data from the rest of the building, but this is one tool that would be very useful for green roof design. A method for a LEED credit involving a green roof would actually be incorporating the energy savings model into the Energy and Atmosphere credit where a baseline case is presented and then a building with a green roof is compared to the baseline.

A credit for combining technologies could have multiple benefits. Research has shown that the combination of solar panels or photovoltaics (PV's) and green roofs can benefit each other. Green roofs cool the air above the roof and help increase the PV's efficiency. The PV's in turn shade parts of the roof at times which benefits the plants. The higher efficiency of the PV's produces more energy reducing a building's dependence on fossil fuels and non-renewable energy sources. A credit should be written to address the combination of green roof technology and solar panel technology.

Stormwater

A sustainable green roof LEED credit for stormwater should include requirements for retention, collection and storage, and water quality. Green roofs allow for a decreased need and/or size of additional stormwater facilities on site (See the Ford Dearborn green roof precedent study in Chapter 2). A credit could require the integration of a stormwater collection system that collects a determined percentage of all water falling on the roof during a particular storm event. This water may be reused inside the building for toilets, cooling and heating, or even a living machine. Another option may be to decrease the volume of water released on site by a certain percentage. This may be integrated with an existing water efficiency credit.

If cisterns or storage tanks are used, the method of pumping water and energy used should be justified. If the building ends up using more energy to pump water collected on the roof from a basement cistern, then that is counter productive to conserving energy use. In the case of the Solaire building in New York, storing 30,000 gallons of water on the roof for gravity flow was not feasible so the water was stored in the basement. Rain barrels and other collection devices should attempt to provide gravity flow. In any case, the use of a pump should be carefully considered and this should be addressed in LEED. Green roofs should minimize the use of irrigation and reuse water in times of drought.

Any reused water should be appropriate to the intended use depending on whether it is used in the building or released back onto the site, keeping in mind this impacts ecosystems and fluvial systems downstream.

Improving water quality is another significant task that green roofs may accomplish. It is important to make sure green roof systems reflect the intended use. If the green roof will be used to collect water for reuse, the treatment of the layers of soil media and drainage media should be designed for that purpose.

Chemicals such as fertilizers, herbicides and pesticides should be minimized or eliminated in application on a green roof.

> "The nutrient content of the substrate is generally kept low and this has also been regulated in the FLL guidelines (2). The nitrogen content (CaCl2) should be below 80 mg/litre, P2O5 (CAL) below 200mg/litre and K2O (CAL) below 700mg/litre, in order to decrease the risk of leaching and pollution of the storm water (2)," (Emilsson, 2004, p.7).

An additional credit for monitoring water quality and quantity should be included. Monitoring nutrient levels, heavy metals and other chemicals as well as the amount of water retained on the roof is important to be able to prove that the green roof is measurably better than a baseline or control roof. LEED should not restrict options for creative water use.

Heat Island Effect

For LEED, the green roof should present an initial estimate of temperature reduction for certification, but also provide short and long term temperature data collection and require applicants to compare the data to a baseline or control green roof. If a green roof is a retrofit, collecting readings before installation are strongly recommended.

Structural

Structural requirements are not necessary for a LEED standard but structural aspects still play a major role in energy savings and sustainable design. Promoting the integration of the building systems with the green roof system and taking wind uplift into consideration should be mentioned within LEED, but are not necessarily a credit or requirement.

Materials

This section focuses on materials for green roofs but does not necessarily recommend LEED change the requirements already aligned in the current standards. It is recommended that LEED provide more information in regards to specific green roof materials.

LEED should provide information on appropriate and inappropriate recycled materials for green roofs. Green roof materials should contribute to the percent recycled credits as well as regional materials. Care should be taken when incorporating recycled products to make sure they are not detrimental to the green roof functions, such as crushed concrete (clogs drainage). Materials can help meet safety considerations such as fire mitigation. Designers should be aware of techniques such as buffer areas with gravel and types of plant materials that are not appropriate. Any materials that may leach pollutants, such as treated, wood should be avoided.

The conveyance of materials requires time, energy, equipment, personnel, and transportation. These issues should be addressed to reduce the amount of energy used and distances traveled. While the green roof market is relatively new it may be difficult to get many materials locally, but this may be remedied in time as the green roof market expands to more areas of the country. Designers should comply with the LEED credit for regional materials as much as possible.

A credit or credit requirement should be incorporated that requires flood testing of the waterproofing membrane. This is a critical step in the installation of a green roof. Catching leaks early, before the remaining layers are put in place, can save a project. The green roof should be regularly inspected for leaks. Designers should also take care to control erosion through the use of mats, fabric covers, and rapid cover by vegetation.

Research Limitations

Green roof technology in North America is still relatively young compared to the research and development conducted in Europe. Because research is lacking in North America it is difficult to create specific standards across the varying climates and eco-regions on the continent. This is where the development of green roofs in North America is a challenge and why the techniques must be tested and appropriately adjusted to particular climates and eco-regions. If the USGBC follows through with bio-regionally weighted credits, it will be helpful for green roofs, specifically when more green roofs are piloted and research is collected. As it has been in Europe, it will take years to more fully understand the dynamic of green roofs in different climates within the United States.

Having the supportive research from the European countries provides a step in the right direction, but it is now time to get ready to stand on our own. The continuous development of ASTM standards for green roofs and the integration of green roofs on buildings will provide a solid base for all components and approaches to designing green roofs constraints and weather prevented my visit of the Des Moines Public Library.

The new version of LEED has not been released therefore it is unknown how it will be structured and difficult at this time to make suggestions specifically to the Version 3.0. It is also not in the scope of this thesis to derive data to make solid suggestions for the specific wording or development of LEED green roof credits. While many universities have undertaken research, there is simply not enough data to offer final recommendations for green roof credits. Many of the green roofs are relatively new (several years old) in the United States and many do not have monitoring programs.

Limitations of the research in general were due to time, location, and funding. I hoped to originally conduct six precedent studies, but in an effort to collect more specific information on the studies, I decided three green roofs were feasible. I was able to visit with Conservation Design Forum and the American Society of Landscape Architects in person, and speak by phone with the Weitz Company (which constructed the Des Moines Public Library). Of the three I was actually able to visit was the ASLA green roof in Washington D.C. The Chicago green roof does not allow visitors for liability and time

It was not feasible based on time constraints, nor in the scope of the research to incorporate sustainable green roof requirements and write new green roof LEED credits. The goal was to suggest preliminary sustainable green roof criteria and to make suggestions regarding the criteria application to LEED. While I would have liked to derive appropriate percentages for stormwater retention or water quality, the purpose of the conclusions was to suggest strategies for improving and expanding green roof LEED credits based on qualitative research.

Further Research

The following section includes suggestions for further research based on the findings and conclusions.

Data Collection

Continuation of the research should begin with the collection of data on as many green roofs as possible to compile enough information to base improvements of green roof sustainability requirements and LEED credits upon. This would be a green roof market-wide effort and not necessarily done by the USGBC. The collection of research data from universities such as Penn State, Michigan, and North Carolina can act as additional base information for specific LEED requirements.

Reference Standards

Developing green roof standards such as the ASTM standards will be key to integrate into LEED requirements because the standards are based on scientific research and data by technical experts in the field.

Monitoring within the LEED System

Research regarding a monitoring program within the LEED system that not only monitors a green roof, but the entire building system and site functions could offer valuable insight for the green building industry. For most projects monitoring is too expensive. Exploring the possibility of including monitoring as options within certain LEED credits could allow for extra points. A building that has a certain amount of monitoring would be able to reach a higher certification such as Silver, Gold, or Platinum.

Dynamic Credits

While the certification process is a significant accomplishment, I have questioned whether a one time LEED certification is enough. Further research regarding an initial installation certification and subsequent green building inspections to maintain certification of a project would be interesting to develop. Is it feasible and is it necessary? Sustainability isn't a single occurrence. Incorporating initial installation certification and future "checkpoints" to ensure sustainability could further validate a green building. Dynamic credits may include initial installation and future function requirements that are checked on regular increments such as one year, five years, 10 years and so on.

Green Roof Sustainability

Ed Snodgrass posed several questions regarding the sustainability of green roofs in general, "Does it more energy to create a "sustainable" green roof (with deep media to accommodate native plants and a replicated ecosystem) which may consume more energy to produce an ecologically diverse green roof with a negative coefficient?" (2007).

Should there be a separate eco-roof/best management practice (BMP) market from a roof garden market? (Snodgrass, 2007). In related discussions he asked whether it is sustainable to add extra weight such as steel and concrete to support a roof and whether the net energy used and carbon emissions created by implementing the green roof balance with the benefits of the green roof. These are questions the green roof industry is working to answer and are the subject of multiple research projects.

Alternative Methods for Promoting Green Roofs

While it is important to promote green roofs through LEED, there are other green roof agencies that may be more appropriate vehicles for the promotion and development of sustainable green roof best practices and standards. Green Roofs for Healthy Cities (GRHC) is currently working on creating a green roof accreditation program for professionals in related fields. There is already a significant amount of research done by this organization. GRHC is, at this time, the most appropriate organization to lead the development of best practices for sustainable green roofs. Other alternatives may be the Sierra Club or Audubon Society which may have interest in promoting ecological practices within cities. The American Society of Landscape Architects could contribute to the development of sustainable criteria for green roofs, as well as the American Institute of Architects and other professional organizations that may be linked to green roofs in order to preserve the multi-disciplinary aspect. The organizations that do promote green roof sustainability would provide quality control for green roofs standards and could work closely with LEED and reference standards such as ASTM to continuously improve green roof sustainability.

Beyond the Research

The conclusion of this research is only the beginning. It would be beneficial to share my research with professionals involved with green roofs, LEED, and those involved in related subjects such as stormwater mitigation. I may choose to present at conferences and prepare articles that develop the work further.

Significance of the Research

LEED has a profound impact on the green roof market. It has the potential, simply by incorporating green roofs into the credits, to drive market costs of green roofs up or down. This research comes during a time when LEED is revamping the system and looking to shift to a "Continuous Improvement" approach as well as increased interest in green roofs in North America. This and similar research has the potential to have an impact on LEED Version 3.0 or subsequent updates, specifically if the system is transformed so that it may be continuously improved.

Another focus of the new LEED version is bioregional weights. Green roofs are affected by regional climates even more so than some building components because they are often the first point of contact with the elements such as stormwater. Rooftops are exposed to harsh winds and temperature fluctuations. This information is presented to create an awareness of the importance of incorporating more stringent sustainable green roof credits within LEED that can be adapted to changes in the system regarding bioregional weights.

Simply requiring a green roof as a strategy for green building is not enough. Green roofs are a major component of a building, and if they are included in a program, they should be considered just as seriously as the remainder of the building components. Glaser (2007) indicated that if a LEED standard focused solely on green roofs and not the entire building then it would not ensure the remainder of a building is sustainable. This research presents suggestions for the improvement of LEED regarding green roof credits, which has the potential to be adopted into the new version of LEED currently being developed by the USGBC.

Green roofs can have a very significant impact on energy use and environmental quality. It is the designer's responsibility to make sure that a building is sustainable if that is a goal. It is the responsibility of a green building organization to ensure that its green building standards requires all buildings that it certifies to attain a level of sustainability.

By including and emphasizing green roofs in the LEED standards, the method of writing the standards and their requirements should incorporate ways to bring the cost down and simplify green roof construction methods. This research brings attention to green roof sustainability within LEED. Use of clearly articulated guidelines and criteria should help drive the cost of green roofs down, thus increasing the number of green roofs built and helping cities to benefit from what green roofs can accomplish in an urban environment.

In Retrospect

I could study and develop this topic indefinitely. Time is always a factor. Ideally I would have visited and interviewed each precedent study to learn as much as possible. Due to limited funding and ability to travel, I was not able to visit most of the green roofs discussed in this thesis.

Conducting interviews, whether on phone or in person, should have been started as soon as I completed my thesis proposal in May 2006. During my work I felt I needed to do extensive archival research before I began interviews. Doing the interviews simultaneously would have given me the opportunity to follow up more than once and have more of a continuing dialogue.

Instead of focusing on more general green roof credits or best practices, I would have focused on a particular credit and worked to develop it in detail. Due to the more general nature of this research it was not in the scope to develop each potential green roof credit in detail.

Concluding Thoughts

When designing green roofs, Ed Snodgrass advised to look for "elegant technology" by finding the solution to the simplest, lowest ecological footprint (Snodgrass, 2007). I believe this should be a driving force not only for green roofs, but for all design.

As designers we can have a positive or negative impact. William McDonough explains in his article "A Field of Dreams: Green Roofs, Ecological Design and the Future of Urbanism" that

> "…the human impact on the environment can be positive, vital, and good – even regenerative." (2003).

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Appendix A - LEED Checklist

Figure 5.1 LEED Checklist

LEED LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

Version 2.2 Registered Project Checklist

Project Name
City, State

Yes	?	No		Sustainable Sites	14 Points
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Development Density**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity and Carpooling	1
			Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
			Credit 5.2	**Reduced Site Disturbance**, Maximize Open Space	1
			Credit 6.1	**Stormwater Management**, Rate and Quantity	1
			Credit 6.2	**Stormwater Management**, Treatment	1
			Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
			Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
			Credit 8	**Light Pollution Reduction**	1

Yes	?	No		Water Efficiency	5 Points
			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes	?	No		Energy & Atmosphere	17 Points
Y			Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
			Credit 1	**Optimize Energy Performance**	1 to 10
			Credit 2.1	**Renewable Energy**, 2.5%	1
			Credit 2.2	**Renewable Energy**, 7.5%	1
			Credit 2.3	**Renewable Energy**, 12.5%	1
			Credit 3	**Additional Commissioning**	1
			Credit 4	**Ozone Depletion**	1
			Credit 5	**Measurement & Verification**	1
			Credit 6	**Green Power**	1

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Figure 5.2 Checklist

Yes	?	No			
			Materials & Resources		**13** Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
			Credit 1.2	**Building Reuse**, Maintain 95% of Shell	1
			Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1
			Credit 2.1	**Construction Waste Management**, Divert 50%	1
			Credit 2.2	**Construction Waste Management**, Divert 75%	1
			Credit 3.1	**Resource Reuse**, Specify 5%	1
			Credit 3.2	**Resource Reuse**, Specify 10%	1
			Credit 4.1	**Recycled Content**, Specify 5% (post-consumer + ½ post-industrial)	1
			Credit 4.2	**Recycled Content**, Specify 10% (post-consumer + ½ post-industrial)	1
			Credit 5.1	**Regional Materials**, 10% Manufactured & Sourced Locally	1
			Credit 5.2	**Regional Materials**, 20% Manufactured & Sourced Locally	1
			Credit 6	**Rapidly Renewable Materials**	1
			Credit 7	**Certified Wood**	1

Yes	?	No			
			Indoor Environmental Quality		**15** Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
			Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
			Credit 2	**Ventilation Effectiveness**	1
			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials**, Paints	1
			Credit 4.3	**Low-Emitting Materials**, Carpet	1
			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6.1	**Controllability of Systems**, Perimeter	1
			Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
			Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
			Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Yes	?	No			
			Innovation & Design Process		**5** Points
			Credit 1.1	**Innovation in Design**: Provide Specific Title	1
			Credit 1.2	**Innovation in Design**: Provide Specific Title	1
			Credit 1.3	**Innovation in Design**: Provide Specific Title	1
			Credit 1.4	**Innovation in Design**: Provide Specific Title	1
			Credit 2	**LEED™ Accredited Professional**	1

Yes	?	No		
			Project Totals (pre-certification estimates)	**69** Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

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Appendix B - Precedent Matrix

Figure 5.3 Precedent Matrix Page 1.

Greenroofs	ASLA Greenroof	Des Moines Central Library	Chicago City Hall
Year	Spring 2006	Opened Apr. 8, 2006	2001
Location	Washington DC	Des Moines, IA	Chicago, IL
Climate	Continental	Continental	Continental
Landscape Architect(s)	Michael Van Valkenburgh Associates, Inc.; CDF		Conservation Design Forum
Architect of Record		David Chipperfield of London	
Architect(s)	Project Architect: DMJM Design	HLKB: Paul Mankins, Brett Mendenhall, Jon Sloan, Brian Lindgren, and Mindy Aust.	William McDonough + Partners
Engineer(s)	Structural: Robert Silman Associates		Halvorsen & Kaye Associated, PC Katrakis & Associates; Environmental Engineer: Atlier Dreiseitl; Project Engineer: Roy F. Weston, Inc.
Consultant(s)	Consulting LA: Conservation Design Forum		
Contractor(s)	General Contractor: Forrester Construction	Weitz Company: Bob Andersen, Kevin Kain, Brandon Schulte, and Mick Askren	Roofing Contractor: Bennet & Brosseau Roofing; Roofscapes Contractor: Church Landscape
Others		Greenroof Plant Provider: Greenroof Plants/Emory Knoll Farms; Greenroof Provider: Roofscapes, Inc. Installation: Enviroscape	Plant Suppliers: Bluebird Nursery, Intrinsic Perennial Garden, Midwest Groundcovers, The Natural Garden, Teerling Nursery; System Manufacturer: Roofscapes, Inc.; Membrane Manufacturer: Sarnafil;
Client/Owner(s)	ASLA	Des Moines Central Library	City of Chicago
Square Feet/Area	3,300	50,000	20,300
Construction Costs	$950,000	$8.50/square foot	$2.5 million

Figure 5.4 Precedent Matrix Page 2.

Greenroofs	The GAP Headquarters 901 Cherry	Ford Dearborn Assembly Plant	Life Expressions Wellness Center
Year	1997	2003	Summer 2001
Location	San Bruno, CA	Dearborn, MI	Sugar Loaf, PA
Climate	Mediterranean	Continental	Humid Contenental
Landscape Architect(s)	Hargreaves & Associates		N/A
Architect of Record	William McDonough + Partners		
Architect(s)	Executive and Interior Design: Gensler & Associates	William McDonough + Partners	Van Der Ryn Architects
Engineer(s)	Ove Arup & Partners		Roofscapes, Inc.
Consultant(s)		Environmental Consultant: ARCADIS; Greenroof Consultant: XeroFlor America; Stormwater Consultant: Cahill Assoc.; Vegetation Consultant: Wildtype Native Plants	
Contractor(s)	Gen: Swinterton		
Others	Greenroof Consultant: Paul Kephart, Rana Creek Living Architecture	Construction Manager: Walbridge Aldinger; Vegetation Supplier: Hortech Inc and Walters Gardens; Roofmembrane Installer: Christen, Detroit; Waterproofing: Splast; Drainage: Colbond, Inc.	Greenroof Installer: David Brothers Landscape Services (PA); Waterproofing Provider: Sarnafil, Inc. (Canton, MA); Waterproofing Installer: Houck Services, Harrisburg, PA
Client/Owner(s)	GAP, Inc.	Ford Motor Company	Ron and Joanne Gallagher
Square Feet/Area	69,000	454,000 (10.4 acres)	6,000
Construction Costs	$60 million for entire building		

Appendix C - General Interview Questions

General Design

Questions are derived from the critical dimensions of case studies Table 2 in Francis's Landscape Architecture Case Study Methodology. Questions should be broken into parts based on the interviewees expected knowledge and involvement with the greenroof or subject (instead of asking one person all of the questions). Use "Critical Dimensions of Case Studies" as a checklist for greenroof precedent information.

1. Baseline and/or contextual information not gathered in archival research about the greenroof:
    a. How many square feet is the greenroof? Is it on multiple levels/areas?
    b. What are the dimensions of key elements?
    c. What is the amount of site coverage and greenroof media/surface?
    d. Who are the consultants/designers/team members involved in the project?
    e. What are the key design concepts?
2. How were key participants (landscape architects, architects, other professionals, client, users) involved in the greenroof project development?
    a. How well did the greenroof project team work together?
    b. Who was the team leader and what was their role in the beginning of the project?
    c. Did this role change during the course of the project?
    d. What did you learn about working with a greenroof team to complete the project?
    e. Was it difficult to coordinate between different professionals?
    f. Were there any differences in coordinating between professionals in comparison to a non-greenroof project?
    g. What were the positives and negatives of multi-disciplinary interaction?
    h. Do you have any advice for future designers and team members of other greenroof projects in regards to working in a multidisciplinary setting?
3. Process
    a. What was the decision making process like?
    b. What was the design process like?
    c. Describe the implementation process?
    d. Describe the socio-political process?
    e. Who influenced the greenroof decisions and outcomes? Why?
4. What were the program elements and goals (social, ecological, functional, aesthetic, economic, other)?
    a. Was the program modified during the course of the project?
5. How would you approach/design/install/manage the greenroof differently?

6. Are there things you would change about the design/approach/install/management of the greenroof?
7. What problems did the greenroof try to solve? Were they solved? If so, how? If not, why? Were other unexpected problems solved?
8. How is the greenroof used?
    a. Who uses it?
9. What was the initial budget; what were the final costs?
    a. What are the reasons for any differences?
10. Are there any management or maintenance problems?
    a. What are the maintenance costs?
    b. How is the project perceived by space managers?
11. How has the greenroof performed over time?
12. How were unique constraints (such as loading, retrofit) addressed in the process?
13. What, if any, were the factors that make this project unique? (loading req. environ., etc)
14. How was the community served by the greenroof?
    a. What is the greenroofs social impact and meaning?
    b. How was the greenroof perceived and valued by the community?
15. How was the environment served by the greenroof?
    a. What did the project contribute to the professional knowledge base?
16. Was there a monitoring system or study conducted?
    a. If yes, what was monitored/studied and what are the results so far?
    b. If no, do you plan to monitor in the future?
    c. What were the estimated monitoring costs per year?
17. What were the underlying challenges of the site?
    a. What are the technological constraints?
18. Describe the site-specific lessons learned in comparison to more general lessons?
19. Has there been any controversy associated with the greenroof? Has this been resolved? If so, how?
20. Site visits (if cannot visit site – interview those who have)
    a. What does the greenroof look like?
    b. How does it work?
    c. How does it feel?

Criteria Questions

<u>Functional </u>(if monitoring system)

1. What are the energy savings of heating and cooling compared to a conventional roof?
2. Has there been substantial (a quantifiable amount – something that has been measured) run-off reduction as a result of the installation of the greenroof?
    a. How much? Under what conditions? How long was the

monitoring/study?

3. What was the initial cost?
4. What are the expected long-term/life-cycle costs?

5. What is the stormwater storage/retention capacity of the greenroof?
6. What is the greenroof's effectiveness in decreasing the volume of runoff?
7. Does the greenroof reuse stormwater? How?
8. Is there data showing the quality of runoff?
    a. How does it compare to conventional roofs?
9. Were you able to decrease stormwater facilities at grade or in other locations on the site?
10. Is there irrigation? If so, what type and how often are plants irrigated?
11. Has the greenroof affected the temperatures on the roof?
12. Has the greenroof affected energy costs?
13. Does the greenroof help insulate the building?
14. What is the load bearing capacity (lbs/sf) of the roof?
15. What is the weight of the substrate?
16. Are recycled materials incorporated into the greenroof components?
17. Were any measures taken for fire safety?
18. Did the greenroof decrease the need for typical building materials? (insulation mats)
19. Were there materials installed that may leach pollutants (treated wood for bed forms) into the soil or substrate?
20. What is the moisture retention capacity of the substrate?
21. What methods of erosion control/substrate movement controls were taken?

<u>Ecological</u>

1. Are monitoring and/or research studies conducted for the greenroof?
    a. If yes, what is being monitored/researched?
        i. Are the results as expected? If no, how so?
2. What are the ecological design considerations that went into the greenroof?
    a. How do these benefit the users/owner/community/environment?
    b. Was it designed to be self sustaining (little to no maintenance/ferts)?
3. Are there signs of specific ecological processes at work on the roof?
4. Is there evidence of insect/bird/animal biodiversity? If so, what is occurring?
5. Is there evidence of soil microbe (bacteria, fungi - mychorizae, etc) biodiversity?
6. Has there been a study of long term effects on nearby creeks/streams (this is more large scale citywide – probably not able to study yet, except maybe Germany)
7. Were native plant species used? If so, how have they fared? What plants are thriving? What plants have not worked well? Do you know why?
8. What constitutes a sustainable greenroof?

Aesthetic

1. What was the design intent?
    (Questions about general design should cover this category.)

2. What were your aesthetic intentions?

<u>LEED Questions</u>

1. How are percentages determined (ex 30% better energy efficiency)?
2. In your experience, does the LEED checklist guarantee energy performance? Is it helpful in creating a building that improves energy performance?
3. Is LEED only available to wealthy owners and professionals (cost of certification)?
4. Does LEED inflate "green washing"?
   Specific to LEED project with a GR

1. Was the decision to build a greenroof made before or after the decision to go for LEED certification? Why?
2. Do you feel the credit weight for a greenroof is adequate?
3. What were the strategies you used to attain the greenroof credits for LEED?
4. What would you do differently, in retrospect?
5. How did you feel about the LEED process?
6. What, specifically to your greenroof project, do you feel are the advantages and disadvantages of the LEED process?

If project not LEED certified

1. Why did the project not pursue LEED certification?