2011

A History and Definition of Green Roof Technology with Recommendations for Future Research

John D. Magill
Southern Illinois University Carbondale, jdmagill@gmail.com

Karen Midden
Southern Illinois University Carbondale, kmidden@siu.edu

John Groninger
Southern Illinois University Carbondale, groninge@siu.edu

Matthew Therrell
Southern Illinois University Carbondale, therrell@siu.edu

A HISTORY AND DEFINITION OF GREEN ROOF TECHNOLOGY WITH RECOMMENDATIONS FOR FUTURE RESEARCH

by

John Magill

B.A., Southern Illinois University, 2007

A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
Master of Science Degree

Department of Plant, Soil, and Agricultural Systems
in the Graduate School
Southern Illinois University Carbondale
May, 2011

RESEARCH PAPER APPROVAL

A HISTORY AND DEFINITION OF GREEN ROOF TECHNOLOGY WITH RECOMMENDATIONS FOR FUTURE RESEARCH

By

John Magill

A Research Paper Submitted in Partial

Fulfillment of the Requirements for

the Master of Science

Approved by:

Karen Midden, Chair

Dr. John Groninger

Dr. Matthew Therell

Graduate School
Southern Illinois University Carbondale
April 2011

AN ABSTRACT OF THE RESEARCH PAPER OF

John Magill, for the Masters of Science degree in Plant, Soil, and Agriculture Systems, presented on April 8, 2011, at Southern Illinois University Carbondale.

TITLE: A History and Definition of Green Roof Technology with Recommendations for Future Research

MAJOR PROFESSOR: Professor Karen Midden

Green roof technology has a history that predates the modern era. Many functions of green roofs utilized during human history are analogous to contemporary functions. The justification of the use of green roof technology based on a review of literature shows the multiple and documented benefits that these systems can impart to the urban environment. A case study of the installation of the Southern Illinois University Carbondale green roof, showed the actual process of constructing the system. The maintenance and observation of this system gives firsthand experience. Interviews with green roof professionals allow greater understanding of current research needs. Finally, from these resources, recommendations for future research can be identified. This could ensure cogent direction in future research.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Currently the green roof industry is expanding into the North American marketplace. Green roof technology in the modern context has three decades of development in Europe. Green roof systems in North America are based on the German standards. These standards have provided an excellent starting point for the development of green roof systems installed in the much larger North American geography. The history of green roofs goes back thousands of years, and through multiple cultures. Understanding the motivations behind green roof usage in history broadens our understanding of their current uses. Once a green roof is defined, the functions and benefits of the technology through a review of literature can provide a justification for their usage. These benefits include; stormwater mitigation, passive cooling of buildings and even cities, increased biodiversity, ecological benefits, sociological benefits, and cost benefits. A case study of the installation of the Southern Illinois University Carbondale green roof provides a first hand experience concerning installation, and first year maintenance. Interviews with green roof professionals identify the concerns and opinions of individuals actively involved in the industry. Lastly, the elements of; history, justification of benefits, a case study, and interviews culminate in recommendations for future research. These recommendations could be useful to future researchers in the field, by providing them with cogent direction.

CHAPTER 2

HISTORY OF GREEN ROOF TECHNOLOGY

Green roofs and roof gardens date back to thousands of years. Despite the recorded existence of roof gardens, little physical evidence has survived (Osmundsen, 1999, p. 112-3), but history reveals the purposes of vegetated roofs were diverse. These purposes include the insulating qualities, and an escape from the stress of the urban environment.

Early evidence of roof gardens includes the mausoleums of Augustus and Hadrian. It is known that the Romans planted trees on top of many institutional buildings. The ancient historian Pliny wrote about trees being imported for these roof gardens. During the Renaissance, steeply terraced gardens and green roofs were common in the city of Genoa. In Russia, hanging gardens were favored in the seventeenth century Kremlin, and in the twentieth century, green roofs and hanging gardens were established on homes in many countries (Peck et al. 1999, p. 11-12).

In cold climates green roofs increase internal heat retention, and in hot climates they help to keep the heat out (Peck et al, 1999, p. 11-12). Cold climate examples of green roofs include the longhouses of the Vikings, who layered the walls and roofs of their homes with turf to protect against the elements. Canada has several Viking and French examples of sod roofs, found in Newfoundland and Nova Scotia.

The oldest roof garden appears to be the ziggurats of ancient Mesopotamia, built from the fourth millennium until 600 B.C.E. Located in the courtyards of temples in major cities, the ziggurats were great stepped pyramid towers of stone, built in stages. At the landings of these stepped towers, plantings of trees and shrubs on flat terraces softened the climb and offered relief from the heat of Babylon. The most famous of the ziggurats, Etemenanki in Babylon was built in the square of the city's great temple, Esagil. The best preserved of the ancient ziggurats is that of Nanna, in the ancient city of Ur, built by Ur-Nammu, and his son, Shulgi, who reigned from 2113-2047 B.C.E. King Nebuchadrezzar II, to console his wife, Amytis, constructed the Hanging Gardens of Babylon. Amytis longed for the greenery of her homeland, Media. The first accounts of the gardens are those of the priest Berossus, entitled Babyloniaka, and were written in 290 B.C.E., more than 200 years after the destruction of the gardens. Historian Josephus, in Contra Apionen, attributes this description of the gardens to Berossus: "Within this palace he [Nebuchadnezzar II] erected lofty stone terraces, in which he closely reproduced mountain scenery, completing the resemblance by planting them with all manner of trees and constructing the so-called Hanging Gardens because his wife, having been brought up in Media, had a passion for mountain surroundings" (Osmundson, 1999, p. 112-3). In 371 to 287 B.C.E., the Roman botanist Theophrastus recorded the presence of Sempervivum on walls and roof tiles. Charlemagne ordered one plant to be grown on every roof, they were believed to give a protective effect against house fires and lightning strikes.

During the Middle Ages and the Renaissance, roof gardens were owned by the rich, and by Benedictine monks. From the 1600s to 1800s, Norwegians used soil on roofs as insulation, utilizing grasses and other species to hold the soil in place. Early American settlers of the Great Plains also used this technique in the late 1800s due to timber scarcity (Hammer, 1968). Germany is known as the birthplace for modern-day green roof systems. In the 1880s, Germany experienced rapid industrialization and urbanization. Highly flammable tar was used to roof inexpensive housing, a roofer named H. Koch desired to reduce the fire hazard by adding a sand and gravel substrate. Over time, seed colonization occurred and formed meadows. Fifty of these roofs remained intact and waterproof in the year 1980. The Great Depression and World War II caused a sharp decline in roof greening. Conversely, Britain utilized the camouflaging capabilities of green roofs by using them to cover military airfield hangars in turf during the 1930s. Despite the Depression, in 1931 the Rockefeller Center in New York City was built as the first prominent US modern green roof.

Archeaology has revealed the green roofs of the Middle Ages. In this period plant materials were derived from local sod, a substrate/water retention membrane from inverted sod layers, and birch bark as a waterproofing layer, supported by roof boards and wooden beams (Hurstwic.org). Layered birch bark was used as an impermeable layer to drain water preventing roof collapse while keeping the occupants dry. Countries with sod roof traditions include Sweden, Finland, Iceland, Denmark, Norway, Greenland, Vinland and the Faeroe Islands. An example of Icelandic longhouses includes the reconstructed Hofstathir House. The presence of volcanic glass on the floor dates the home to 2500 B.C.E. (Simpson, 1999).

In 1856, Robert Chambers of England visited Iceland and the Faeroe Islands, he wrote of timber scarcity in the Faeroes, concerning a log washed up on the beach, he called it a “windfall of no common value” (Chambers 1856, p.4). Building materials were in short supply and the environment was harsh. The climate was described as a “wild, uncouth, and arctic region” where man is “roughened” (Chambers, 1856, p.6). Houses seen in the Faeroes are “bright patches of green” that appear “anomalous”; these green patches are the “sod-covered roofs of houses” (Chambers, 1856, p. 9). Concerning their construction, there is a substructure of coarse masonry, overlain by wood; they were described as “small and stifling” (Chambers, 1856, p. 11-12). Later in Iceland, in the suburb occupied by the fisherman, houses described as “sod-covered hovels” were “prevalent” (Chambers, 1856, p. 36).

The buildings found in Vinland, produced by the Vikings are of two main forms. They were large multi-roomed structures, known as halls, and interpreted as houses with a workshop. Constructed of turf sods laid against a timber framework, and paneled with wood on their inner faces, they had a central hearth. The roofs were also made of turf sods, resting on an underlay of branches supported by timbers. These houses could have housed 70 to 90 people (Hall, R. 2007, p. 161-3). Archaeological excavations in 1962 to 1965 revealed a cemetery of about 150 individuals, who had been buried around a tiny turf-built church, which measured only 2x 3.5 m (6.5 x11.5 ft.) internally. Dating of skeletons indicated dates in the period 1000-1100/1200 (Hall, R. 2007, p. 156).

Sod Roofs on the American Frontier

The Homestead Act of 1862 passed by congress stated that, a 160-acre plot would be given by deed to any family after five years on the condition they dig a well and build a house. The houses these settlers built and the settlers themselves were called ‘Soddies’.

Sod homes opened the plains in the 1870s and 1880s (Hammer, 1968). If timber was available the people would make a conventional log house. As settlement crept westward and timber became scarcer, the homesteader came to depend more and more on soil and grass for homes. The typical prairie home was made of sod or dug out of the side of a hill, and were viewed as temporary homes until something permanent could be built (Dick, The Sod House, p. 111). The dugout was a room dug in the side of a hill or ravine. The front wall was made of square cut turf, or logs if they were available. A floor sloping back onto the hill was made of poles or logs covered over with brush, a layer of prairie grass thick enough to hold dirt, and finally a layer of dirt over the grass, after a rain, water often drove the occupants from their home, the environment inside was “unhealthful” (Dick, Sod House, p. 111). More than nine tenths of the citizens of the county of Butler, Nebraska in 1876 lived in a sod house, the total cost of which was $2.78 (Dick, 1954, 112). When the roof was saturated its weight was an issue. The heavy rafters sank into the soggy walls; occasionally the structure collapsed and buried people alive. To prevent this kind of accident, heavy posts were placed in the house to support the roof. Frequently sod homes were covered with long coarse prairie grass. This type of roof also dripped water after a heavy rain. A sod house did insulate effectively and lasted for six or seven years (Dick, 1954, p. 114-115).

The Modern Green Roof

In the early 1960s terraced green roof technologies were researched and developed in many countries, namely Switzerland and Germany. Reinhard Bornkamm, a German researcher published his work on green roofs in 1961. In 1969, the GENO Haus was built in Germany, and remained functional until 1990 (metropolismagazine). In the 1970s a significant amount of technical research on the different components of green roofing technology was carried out including studies on root repelling agents, waterproof membranes, drainage, light-weight growing media and plants. One such work was Roof Areas Inhabited, Viable, and Covered by Vegetation, by Gerda Gollwitzer and Werner Wirsing. The development of green roof markets in Germany expanded quickly in the 1980s, with average annual growth of fifteen to twenty percent. By 1989, 1 million square meters of green roofs were installed in Germany. By 1996, this number had ballooned to 10 million square meters. This remarkable growth was encouraged by state legislation and municipal government grants of thirty five to forty Deutsch Marks per square meter of roof. Other European states and cities have adopted similar types of support and policy, with several mid to large-size cities incorporating roof and vertical greening into their bylaws and planning regulations. As a result of government policy and program support in Europe, a new green roof industry has been created for plants and material suppliers, roofing professionals, installers and maintenance crews. In Germany, France, Austria, Norway, Switzerland and other European states, green roofs have become a commonly accepted feature in the construction industry and urban landscape

(Peck et al. 1999, p. 11-12). Europe has thirty years of green roof research and product development to support its successful green roof industry. The largest portion of Europe's early green roof research took place in Germany, Switzerland, and Scandinavia, and was not written in English (Dvorak, 2010, Koehler, 2007, Mentens et al., 2006)

From this broad experience, developments of guidelines were constructed based on academic research, product/component development, and field observation (Dvorak, 2010, p. 198). These guidelines, called the FLL, are often used for green roofs throughout Europe. FLL is short for the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau or in English; the German Landscape Research, Development and Construction Society. Formally, they are known as the Guidelines for the Planning, Execution and Upkeep of Green Roof Sites, and are utilized for green roof design, specification, maintenance, and testing (Dvorak, 2010, p. 198). The FLL members began to develop the guidelines in 1975, they were published in German in 1982 and in English in 2002. The FLL guidelines are prepared around German green roof research and are the most respected guidelines on the subject.

Currently, green roofs are becoming more common in the United States, although other countries are farther along in the adoption of green roof systems. In Germany for example, it is estimated that 14% of all flat roofs are green (Getter, 2006, p. 1277). Before human development began causing wide scale disturbance, soil and vegetation managed stormwater and solar energy effectively (Getter, 2006, p. 1276). Since that is no longer the case, green roofs have become one aspect of effective stormwater and solar energy management. The introduction into the U.S. urban environment only occurred recently, gaining popularity in the last few decades (Dunnet & Kingsbury, 2004).

The North American green roof industry is only beginning to develop its own green roof guidelines, but nothing comparable to the FLL guidelines currently exists for the North American sector (Dvorak, 2010, p. 198). The association of Standards and Testing Materials (ASTM) has released several guidelines that describe design characteristics for North American green roofs including the requirements of structural loads, permeability (drainage and green roof growing substrate), and a guide for plant selection and maintenance. These guidelines are entitled: ASTM E 2397, 2005, ASTM E 2399, 2005, ASTM E 2400, 2006, and ASTM WK 14283 (Dvorak, 2010, p. 198).

Currently in North America, research is taking place at several universities, including; Michigan State University, Southern Illinois University Edwardsville, Penn State University, Columbia College, Kansas State University and others. The research finds made by these universities will add to the literature that will create the North American standards for green roofs.

CHAPTER 3

JUSTIFICATION OF GREEN ROOF TECHNOLOGY

Green roofs are emerging in North America as an aspect of sustainable urban ecology. An understanding is needed of the components and benefits of these systems. A green roof is a combination of abiotic and biotic components, engineered to function as a green space in a harsh environment. There are several types of green roofs divided into the categories of intensive, extensive, modular, and brown or eco roofs.

A green roof defined is; a flat or sloped rooftop that supports vegetation (Dvorak, 2010, p. 198), on a roof or deck designed to provide urban greening for buildings, people or the environment (Dvorak, 2010, p. 197) while acting as a stormwater management system (Anderson, et al., 2010, p. 319). A green roof consists of a vegetation layer, a substrate layer (where water is retained and in which the vegetation is anchored) and a drainage layer (to evacuate excess water) (Mentens, 2006). A green roof covers a building with vegetation and soil-like substrate, a filtration layer, drainage layer, root barrier, membrane protection layer, waterproof membrane, and finally insulation (Dunnet & Kinngsbury, 2004, Snodgrass, 2006, p. 33). There is much variation in the usage and composition of these layers.

While green roofs have higher initial costs than traditional roofing, green roofs have a diverse array of potential benefits which counterbalance the high cost (Dunnet & Kingsbury, 2004), such as; reducing building loads by preventing excess heat from entering buildings, mitigating the urban heat island effect when many green roofs are installed by providing a medium that uses excess heat to evaporate water, reducing storm-water runoff by retaining precipitation, sequestering carbon dioxide and pollutants in biomass, improving aesthetic values or providing recreational benefits, creating wildlife habitat, and providing noise reduction in buildings (Dunnett & Kingsbury, 2004). Green roofs are argued to have a longer service life than conventional roofs due to; reduced membrane heat exposure, reductions in water ponding, and stringent waterproofing standards (Dunnett & Kingsbury, 2004).

Green roofs which are designed or maintained incorrectly sometimes fail. Roof failures include the overloading of the roof structure leading to collapse, root penetration of the roof membrane, the degradation of irrigation lines, drain line blockage and loss of soil caused by water drainage, the leaching of soil organic matter (Osmundsen, 1999, p. 11), mass plant death, and weed infestation contrary to design intent.

The desire to increase sustainability in the urban environment from an ecological point of view has stimulated green roof research. Green roofs are limited by economic and ecological issues. Specifically, water availability is the most limiting factor, and is likely to be more limited in the future (Benvenuti, 2010, p. 349).

Green Roof Definition and Components of Systems

Green roofs may be defined broadly as intensive or extensive systems; of great concern to their design are the elements of weight, biotic components, substrate, succession, drought tolerance, and the roof as an environment. The benefits of green roof technology include; roof ecology, stormwater mitigation, passive cooling and allayment of the urban heat island effect, sociological concerns, and long term cost.

Intensive versus Extensive Green Roof Systems

Substrate depth and the amount of maintenance required are both used to define the two general types of green roofs. In Europe, the depth of the substrate layer defines green roof systems into two general categories: intensive and extensive (Mentens, 2006).

The same green roofs are classified recently in the literature by maintenance costs: 1) high-input systems are heavier and similar to at-grade landscapes, and 2) extensive being low-input, light-weight, ecological and inaccessible systems. There is no difference between an intensive roof, a high-input roof, or a high-maintenance roof. Extensive roofs are more important from the point of view of a sustainable urban ecosystem, being lightweight they can be installed on more rooftops (Benvenuti, 2010, p. 350). More often now, elements of both systems can be found combined on one rooftop (Ampim, 2010). These systems are often called semi-intensive.

In extensive green roofs the substrate layer is at a maximum 150mm deep. The tough species from the genus *Sedum* is the dominant vegetation type. This genus is commonly low-growing, drought tolerant, with low nutritive requirement and low biomass. In certain instances extensive green roofs can be installed on roofs approaching as much as 45 degrees. Intensive green roofs however have a substrate layer greater than 150mm and are frequently treated as a garden or recreational space. Intensive roof systems can be as thick as the structure can support. Vegetation types are more diverse, and include vegetables, grasses, perennial herbs, shrubs, and trees. The pitch of intensive green roofs is generally less than 10 degrees (Krupka, 1992; Kolb and Schwarz, 1999). The development of low (extensive) and high (intensive) maintenance green roof systems has progressed significantly (Ampim, et al. 2010). So green roofs are divided into two types by substrate thickness, intensive (>150 mm depth, heavy, high-maintenance, accessible spaces/gardens) and extensive (<150 mm thickness, low-maintenance, light-weight, inaccessible, ecological).

Some green roofs have been designed as modular units, which interlock and where each contains a green roof in miniature. With a modular system, the drainage, substrate, and plants are contained within a lightweight module or tray. When interlocked, they offer drainage and coverage. Insulation is optional but often recommended. Many designs are possible and available, to be determined by the function of the roof. Each green roof should be designed specifically for the project at hand. Modular systems offer the same benefits as a traditional European green roof. Advocates of the module system cite the simplicity of design, quick installation, off-site planting that allows propagation off-season, and different substrate depth. By varying substrate depth, each module can vary to reflect weight load restrictions, so deeper modules can contain woody plants over load bearing structures (Velazquez et al., 2003, p. 1-3).

A green roof that is designed with patches of bare or mounded substrate in addition to planted areas is often called a brown roof or an eco roof. The design intent of a brown roof is to provide habitat and increase biodiversity (Gedge, 2003). Brown roofs do this by creating varying habitat, and allowing the natural colonization of plants to occur.

Weight

The most serious of all green roof failures is collapse due to insufficient support of the structure and inadequate planning of the green roof system. Weight is a crucial issue in the construction of a green roof, which can be built on an existing structure as a retrofit, therefore, before planning a green roof system, the weight limit or load must be determined. Structural engineers categorize loads from two general perspectives: dead and live loads. Local building codes specify a roof's required live load, which includes snow, water, wind, and safety factors required for the building's performance. Live load includes transitory weight such as human traffic, and temporary installations. Dead load includes the roof weight itself, along with any permanent elements that make up the roof structure, including roofing layers, heating or cooling elements, and the projected wind or snow loads. Green roofs are designed to withstand both live and dead loads, extensive green roof systems are evaluated while saturated – adding from 15 to 25 pounds per square foot (Snodgrass, 2006, p. 37). The live weight load is the deciding factor of whether the roof will be intensive, extensive, or include elements of both systems.

Green Roof Substrate

Green roof substrate anchors the plant, provides nutrients, and stores water. The ideal green roof substrate must be stable, permanent and lightweight, and it must aerate, drain, and hold nutrients. The greater part of the substrate is mineral based and varies from 80-100%, while organic matter and fertilizer that supply nutrients comprise 0-20% (Ampim, 2010, 246). Most local soil cannot be used, because it is too heavy and unstable. Clays transport too easily in stormwater, so green roof substrates cannot contain it.

Green roof plant success is dependent on the similarity between the ecoregion and the green roof plant native habitat. Green roof substrate conditions are different from that of normal soil. The probability of success in a specific ecoregion is altered by the ability of the green roof substrate to imitate water and nutrient cycling with adequate rooting depth (Dvorak, 2010, p. 199).

Development of low (extensive) and high (intensive) maintenance green roof systems has progressed significantly, yet studies on the growing substrate as a living constituent have not yet been done (Ampim, et al. 2010). Due to climatic variations and desired plant types, there is no universal growing substrate. Typical substrate components include minerals in natural or modified forms such as; sand, lava rock, or kiln-expanded shale, clay and slate, recycled waste materials like crushed bricks or tiles, crushed or aerated concrete and subsoil; stabilized organic matter such as composts; and plastic materials and slow release fertilizers (Ampim, et al. 2010). Green roof substrates are either commercial or non-commercial. Commercial substrates are patented and secretive. There are numerous blends available. Such blends include VegTech ‘roof soil’, Sopraflor, and Litetop Soil (Ampim, 2010, p.245). Non-commercial blends are prepared by researchers and use recommended materials and guidelines.

Growing substrates are the key component of a green roof in which plant materials grow. Like natural soils, substrate provides support and nutrients for plants. Unlike natural soils, which develop in-situ over time, green roof substrates are manufactured soils that may contain a variety of natural, synthetic, and modified ingredients. The substrate is an engineered material, which is a compromise between water retention and drainage. If water retention is too great, weight limitations are overcome and the structure may collapse. If water retention is too low, conditions extend beyond those that support plant life.

Kiln-expanded substrate is an example produced by using a kiln to produce expanded shale, clay, or slate (ESCS) in the range of 1,150 C (Osmundsen, 1999, p. 176). The kiln expansion causes the formation of vesicles. Vesicles allow for high surface area for bonding of water while internally increasing air filled pore space. This property of great internal area causes a reduction in weight.

The challenge is to balance optimal physical properties such as rapid drainage and low bulk density with optimal plant growth properties such as high cation exchange capacity (CEC) and plant available nutrients (Ampim, 2010, p. 244). The CEC is the total of exchangeable cations that a soil can adsorb (Brady, 2007, index). Without adequate CEC, a green roof substrate could not support plant life, available nutrients would leave the roof in runoff as charged water.

Green roof substrate materials have differing advantages and disadvantages. Materials commonly used in Europe and North America include sand, clay, lava (scoria), pumice, and gravel. Artificial or modified mineral components of green roof growing substrates include a mixture of some of the following; perlite, vermiculite, ESCS, and rockwool (Ampim, et al, 2010, p. 245). Each contributes a quality to green roof substrate.

Recycled, waste materials and plastic foam materials used in green roof substrate mixes include crushed clay bricks, tiles or brick, crushed or aerated concrete, subsoil (construction waste), Styrofoam, and Urea-formaldehyde resin foam (Ampim, 2010, p. 245-6). Four recycled extensive green roof substrate materials, which have been evaluated in the United Kingdom, include crushed red brick, clay and sewage sludge, paper ash, and carbonated limestone. Conifer-bark organic matter greatly reduces pH when used with these aggregates (Molineux, et al, 2009, p. 1507).

Biotic Green Roof Components

Plants successful on a green roof must adapt to a harsh growing environment. Due to the thin substrate of an extensive roof system, poor water availability, wide temperature fluctuations, high wind and solar radiation, extensive green roofs are a highly stressed and disturbed environment (Jenks, et al. 2007, p. xiii). Intensive green roof plant palettes are similar to at-grade gardens. Sedum species dominate the biotic assemblage of extensive green roofs because they are highly drought tolerant. The evergreen nature of *Sedum* species allows green roofs to retain a vegetation cover year-round, and they are easy to propagate (Nagase, 2010, p. 318).

An understanding is needed on the current status of green roof plants in North America, their associations to substrate characteristics and some of the ecological implications of maintaining these systems (Dvorak, 2010, p. 199). It must be noted that green roofs are still so new to North America that no tried-and-true plant lists exist for North American use, as might be possible in other landscaping contexts (Snodgrass, 2006, p.13) The extensive green roof environment limits the plant species routinely used. Ecological theory would suggest that highly diverse vegetation might be more resilient (Nagase et al. 2010). Plants that are more functional than aesthetic may be more successful (Snodgrass, 2006).

Green Roof Succession

Most green roofs are dominated by the genus *Sedum*. Distinct and complex plant communities show greater drought tolerance than monoculture relative to improved survivability and higher visual rating, competition for the same resources is the result of monoculture (Nagase, 2010, p. 318). While sedums have historically been the dominant plant, there is an interest to expand the palette to develop green roof plant diversity.

Succession is an “orderly, unidirectional process of community change in which communities replace each other sequentially until a stable (self-reproducing) community is reached" (Johnson, et al. 2007, p. 1), but no vegetation community is completely stable if viewed over a long period of time (Greig-Smith, 1964, p. 213).

As an engineered environment, the green roof will follow patterns of other ecosystems and undergo succession. Green roofs are maintained to prevent certain plants such as trees from growing that would cause roof failure. Thus a green roof that is maintained will have specific plants intentionally removed through weeding. Weeding alters plant succession.

Abandoned spaces in urban areas have been likened to islands in a sea of concrete, and so behave like oceanic islands. The islands are often in a perpetual state of secondary succession due to human efforts to remove weeds from vacant areas. Lots that are larger and closer to one another have greater species richness than small isolated lots. Species richness is stable in areas, which have been vacant for more than 40 months in Chicago, Illinois, USA (Archibold, 2007). Urban green roofs are also like islands in a sea of concrete. It is not currently known how widely implemented green roofs will communicate biotic materials such as plants or animals. Surveying volunteer vascular plants growing on the roofs of the University of Saskatchewan showed that three broad groups of plants were identified; trees and shrubs, primary colonizers of disturbed land, and marshland species. Plant communities were similar on all roofs, although these were affected by the duration of time since maintenance was conducted. The plants were successful despite the harsh environment. Marsh plant diversity was directly related to problems in roof drainage (Archibold, 2007). In this instance the presence of a marsh plant was used as a bioindicator of roof conditions.

There is considerable interest in green roof vegetation, but there has not been much research into volunteer species on conventional rooftops. The dynamics of weed invasion and plant dispersal mechanisms have been much investigated. There are many dispersal agencies for plants, including eolian (windborne), animal, water and vegetative, but few of these can carry propagules onto a rooftop. Dispersal by birds and humans is possible, but wind is most likely the dominant method. Vascular species adapted for wind dispersal have morphological adaptations that facilitate eolian transport while these same adaptations control the quantity of time the seed can physically stay aloft (Archibold, 2007).

Green roof plants are typically vascular. Mosses have several properties to warrant their widespread use on green roofs. Mosses are primary colonizers of bare ground, and they improve water storage and soil properties. Mosses act as placeholders, holding moisture for plants that take longer to establish. Under the surface of a moss covered roof the rate of cooling was nearly six times faster than under a medium only roof, which demonstrates potential for mosses to be components of green roofs (Anderson et al., 2010, p.319). Bryophyte species considered include *Antitrichia californica*, *Dicranoweisia cirrata*, and *Racomitrium canescens*. Sedums, like mosses also create a microclimate to conserve moisture in the first five years following installation, acting as placeholders for species that take longer to establish. After this period, sedums move to the periphery (Snodgrass, 2010, p. 211).

A roof is a high stress plant environment. Plant ecologists have shown that competition is unimportant relative to abiotic factors in structuring plant communities in high-stress environments (Pugnaire, 2007, p. 369-70). While plant populations change in high-stress environments such as the Arctic, there may be no change in biomass since they are limited by abiotic factors (Pugnaire, 2007, p. 371). Arctic plant species minimize competition for nutrients, by partitioning their usage through the timing of root growth, which differs among species and growth forms. Different root depths partition a plants usage of space (Pugnaire, 2007, 375). Where mosses are a significant component of the high environmental stress community, decreasing moss biomass increased vascular plant biomass, resulting in little change in total plant biomass (Pugnaire, 2007, 377).

Biota blown by wind into an environment is called an aeolian derelict. Plant communities on many green roofs in one area could communicate plant propagules as Aeolian derelicts, bird droppings, or by seeds stuck to the shoes of maintenance crews.

Drought Tolerance

Drought tolerance is the primary concern for green roof plants. This is why the first species to be used were succulents belonging to the genus *Sedum*, as they are remarkably resistant to arid conditions. *Sedums* are not always suitable due to slow colonization rates and in certain climates; freezing injury (Benvenuti, et al. 2010, p. 350). Plants avoid harmful desiccation by using a variety of adaptive mechanisms such as increasing water uptake from the soil by increasing their root system size, reducing water loss by closing stomata, reducing cuticular permeability, reducing leaf surface areas, or using CAM (crassulacean acid metabolism) photosynthesis (Jenks, et al. 2007. p. xiii). CAM species can store carbon dioxide in their tissues in order to close stomata during heat stress periods. North America features many climatic conditions, which range from sub-tropical regions in Southern Florida where vegetation rarely freezes, to desert areas with extremely low precipitation, to mountainous areas with extreme radiative, temperature and eolian forces. Environmental conditions experienced by plants on North American green roofs vary widely. To understand and identify natural ecosystems, scientists have subdivided the continent into several hundred ecoregions (Dvorak, 2010, p 199).

The Roof as an Environment

An intensive green roof has a similar environment to an at-grade landscape. An extensive green roof has shallow soils, is windy, sunny, and mostly dry (Dvorak, 2009), while an alpine environment is described as windy, cold, with a short growing period, and mostly dry (Wharton, 2002, p. 9). Alpine and green roof environments have some overlapping conditions. Concerning a mountain environment, the ground loses heat rapidly at night causing dramatic variations in temperature. Since there is less contact between the air and the ground, winds reach high speeds on mountaintops. This contributes to high rates of evaporation and to low temperatures. Many alpine plants, however, are small and grow close to the ground. They have extensive root systems to anchor them against the wind. The leaves often form rosettes so that they do not shade each other from the sun. Alpine vegetation is often blue-green or yellow-green (rather than green) in color, which reflects excessive solar radiation (Wharton, 2002, p. 71). Successful green roof plants often share the adaptations described in Alpine plants. *Sedum* species successful on green roofs are most often small and grow close to the ground, are resistant to desiccation, are anchored against wind, and feature leaves comprised of rosettes. Many sedums, including the common green roof plants *Sedum acre* and *S. sexangulare*, possess yellow-green pigmentation. While an alpine environment is not identical to a green roof environment, plants demonstrate similar adaptations to succeed on an extensive green roof.

Green roofs have no equivalent in nature, they are engineered, fabricated systems (Snodgrass, 2006). The conditions of an environment dictate which organisms may survive within them. All organisms have ranged conditions in which they can survive, typically including; temperature, pH, oxygen concentration, etc. Green roof plants do not occupy extremophilic environmental conditions, but they do tolerate dry, sunny, and windy conditions beyond most plants, thus they are xerotolerant. Growth is slowed during dry periods, but metabolism does not cease in xerotolerant organisms. When dried, a small organism that loses water through its surface will dehydrate quicker than a large organism, due to greater surface area relative to volume. The organism cannot prevent desiccation by becoming water-impermeable. No biological structures are impermeable to water but permeable to oxygen. Drought tolerant organisms avoid competition by using habitats that are not available to others (Wharton, Life at the Limits, p. 25).

Ecological Benefits

A benefit of green roof systems includes habitat creation in lieu of the ecological dead space of a conventional rooftop. In England, so-called brown roofs or eco roofs are specifically designed to provide habitat in highly populated areas for bird species such as black redstarts (*Phoenicurus ochruros*) and invertebrates (Snodgrass, 2006). The development of biotic communities on urban surfaces with skeletal substrates resembles those of natural cliffs, outcrops, scree slopes and gravely river edges (Dunnett, 2006). Roofs can provide very important habitats for specialist rare or endangered species (Dunnett, 2006, p. 2). Any green roof or weed-infested ballast roof, can attract birds and insects. Designing a green roof for habitat is complex (Snodgrass, 2010, p. 206-7). European research has shown that habitat can be replicated but never recreated. Research by Dusty Gedge into green roof ecology has shown that accoutrements like logs, stones, and wads of balled-up hay can provide shade, wind breaks, shelter, and nesting habitat for invertebrate species that populate skeletal substrates (Gedge, 2003).

Stormwater Mitigation

By retaining stormwater on the roof surface, a green roof can lower the thermal loading on buildings**.** Modern approaches to storm water management strive to control the quantity and quality of urban runoff, to work in harmony with natural environmental processes to contribute to sustainable urban environments. It is best to control storm flow as close to the source as possible. When green roofs are combined with other sustainable methods of storm water mitigation, these systems can work together to be more effective than any one system by itself (Stovin, 2009)**.** Increased disturbance frequency, rapid pollutant transport, and an increase in urban flooding can be collectively referred to as the “urban stream syndrome” (Carter, 2006). Green roof implementation could help to solve this problem. Given the huge amount of unused roof area (about 40-50% of the impermeable surfaces in urban areas) (Dunnett and Kingsbury, 2004, Stovin, 2010), stormwater runoff from impervious surfaces and other urban land cover is detrimental to receiving water bodies (Carter, 2006).

In developing countries, urbanization is expected to reach 83% by 2030. This is an unsustainable use of natural systems and creates problems within and outside cities, including increased erosion (Carter, 2006). Climate change may further increase the highly fluctuating amount of runoff water (Mentens, 2004). Green roof technology has been demonstrated to reduce stormwater discharge during storm events from rooftops. The reduction consists in; (i) delaying peak runoff through absorption of water by the green roof, (ii) reducing the total runoff by retaining part of the rainfall, (iii) and distributing the runoff slowly through release of the excess water that is in the substrate pores (Mentens, 2004, Stovin, 2010, Bliss, 2009) thereby retarding peak discharge into rivers by several hours (Carter, 2006). Stormwater is retained by the roof membrane and taken up by plants and then gradually released through evapotranspiration back into the atmosphere. Water loads, which saturate the roof membrane beyond its holding capacity, escape the roof laterally via the drainage membrane and then out via drain.

In a Sheffield, UK study, a test plot during spring 2006 had average volume retention of stormwater of 57%. The key determinant was found to be the antecedent dry weather period (ADWP) (Stovin, 2010). ADWP is the time between the end of a precipitation event and the beginning of another. The assumption for water quality modeling is that pollutants constantly accumulate on surfaces in the watershed between rainfalls. During precipitation events, pollutants wash off over the duration. The greater the ADWP, the greater the quantities of pollutants will be found within an urban watershed (McCuen, 2005).

Green roofs can retain significant amounts of rainfall, this is dependent on the size of the rain event and the design can fail if not designed correctly. Widespread green roof implementation can significantly reduce peak runoff rates for small storm events (Carter 2006). Maximum run-off retention has been demonstrated as high as 88% and 44% for medium and large rain events (Simmons, 2008) But, there is no change in hydrology across the watershed for storm events greater than the 2-year, 24-h event (Carter, 2006). Green roofs could help the urban ecosystem to mimic less disturbed watersheds.

During the last two decades, a large amount of research has been published in German on the reduction of rainwater runoff for different types of roof greening. The annual rainfall-runoff relationship for green roofs is strongly determined by the depth of the substrate layer. The retention of rainwater on green roofs is lower in winter than in summer (Mentens, 2005). There is a high seasonal fluctuation of stormwater runoff on different roof systems, runoff during winter on gravel ballast or green roofs is significantly higher. Gravel roofs (86% winter runoff versus 70% summer runoff), and green roofs (80% winter runoff versus 52% summer runoff) when compared show substantial difference in winter versus summer runoff rates (Mentens, 2004).

Wide-scale green roof installation will create a more positive role in the hydrological cycle. The creation of more green areas is an answer to recent calls for more urban green space (Mentens, 2004).

Passive Cooling and the UHI Effect

Solar radiation hits the black tar of the conventional roof and is transferred into heat on a large scale, urban centers create a microclimate of hotter weather called the urban heat island effect (UHI). Green roofs reduce the UHI effect by providing a substrate for evapotranspiration and altering the surface albedo. A reduction to the UHI indirectly reduces building cooling demands (Blackhurst, 2010). Intuitively, one roof will not affect UHI on a citywide scale, only with massive installation would this benefit be realized. A green roof can cost double that of a traditional roof due to engineering and installation costs, yet it will pay for itself over time in savings for a replacement roof and on lower cooling costs over the life of the green roof. The energy savings of a green versus that of a conventional roof are from the insulating properties of a vegetated structure, evapotranspiration (ET) from the vegetation, and the substrate acting as a thermal mass (Snodgrass, 2006df). In simulations, green roofs protect buildings from solar radiation through the combined effects of shielding, insulation and ET cooling to passively cool (Hongming, 2010, p. 2950). As a passive cooling technique, green roofs are still rare in climatic studies (Theodosiou, 2003, p. 909).

Green roofs save energy for buildings from both ecological and social viewpoints; the central issue is improving the thermal regime of buildings. Individual buildings with improved comfort would decrease the need for air conditioning and heating. Widespread installation of green roofs could mitigate the harsh aspects of the UHI effect (Hongming, 2010, p. 2950).

Green roofs protect roof membranes against solar radiation, they lower the roof temperature and minimize temperature fluctuations. Solar radiation causes many materials to degrade. Temperature fluctuations cause expansion and contraction of the roof membrane and reduce its durability. The exposed membrane of a reference roof had a median of forty two to forty seven degrees Celsius, a green roof reduced temperature fluctuations in the roof membrane to five to seven degrees Celsius. On a typical summer day the membrane temperature on the reference roof reached seventy degrees Celsius, but the membrane temperature on a green roof only twenty five degrees Celsius. On a winter day without snow, the membrane temperature on a reference roof fluctuated from fifteen to ten degrees Celsius, while that of a green roof remained stable between one to five degrees Celsius (Teemusk, 2009, p. 91). The increase in roof longevity through protection from ultraviolet light is estimated at forty years, compared to seven to thirteen years for a typical roof (RRPDC, 2010).

The depression by the green roofs was significant enough to be transmitted through to the internal space by as much as eighteen degrees Celsius cooler than black roofs. White roofs cool the interior of the building significantly less than a green roof (Hongming et al. 2010, p 2949). In modeling however, green and white reflective roofs have some overlapping rates of reflectance; this could imply white roofs cool the interior of buildings equally to a green roof under specific solar conditions (Gaffin, 2005). Green roof plant materials absorb radiant solar energy to fuel photosynthesis, with added heat radiation from higher plant structure (Hongming, 2010, pp. 2957).

Sociological Concerns

There is a general public preference for natural, green surroundings in urban areas, and negative responses to abundant hard surfaces and structures in urban views (Dunnett, 2006, p. 3). People have a ‘need’ for nature (Dunnet, 2006, p. 3), and have specific and known preferences to define urban green-space, such as green roofs. An urban habitat surrounded by greenery is more congruent with people’s desires than plain concrete, perhaps as an unconscious reminiscence of mankind’s evolutionary stages, during which man lived near nature. The psychological pleasure generated by vegetation, together with the widespread desire to enrich urban ecology, has stimulated green roof research (Benvenuti, 2010, p.350). Reasons behind urban dweller’s desire for urban nature-spaces, include desire for a feeling of naturalness and the aesthetic qualities of solitude, quiet, peacefulness and scenic beauty. These desires are outweighed by concerns over cleanliness – a catch-all term that means an absence of pollution. A more complex picture of urban people’s aesthetic responses indicates that human-made reference points such as bridges and buildings are desired in ‘natural’ urban settings (Dunnett, 2006, p. 2) The purpose of the site is extremely important in determining how acceptable the public or site users find wild or naturalistic vegetation (Dunnett, 2006, p. 3). There is a potential level of acceptance of naturalistic vegetation if there are very obvious ‘cues to care’ within the landscape, in both design and management (Nassauer, 1995). A cue to care is apparent evidence of design intent within the landscape. Evidence suggests that plentiful color increases public acceptance of nature-like vegetation implying that a uniform approach to supporting biodiversity on green roofs fails to account for the public’s aesthetic preferences. Simple 'cues to care', and increasing the flowering component of vegetation to maximize colorful effects, can increase acceptance of urban green spaces (Dunnett, 2006, p. 3).

The commonplace experience of nature-like settings in urban environments for many is restricted to specific settings: undeveloped, vacant or abandoned land, woodland patches, vegetation near water bodies, and designated urban nature sites. Urban nature spaces are often associated with abandonment and decay, and perceptions of danger (Dunnett, 2006, p. 3). The public therefore desires naturalistic urban spaces such as green roofs that relay feelings of natural cleanliness with human reference points, obvious cues to care, intentional colorful design and a feeling of safety.

There is increasing interest in crop production on rooftops. The benefits of crop production to a community include; increased access to fresh produce, the creation of green jobs, improved nutrition for local citizens, educational opportunities, and an increase in local economy (SkyVegetables.com).

Cost Benefit

Rapid urbanization and the need for energy and water infrastructure are making it difficult for aging stormwater systems to comply with the Clean Water Act. Most substances become more reactive at higher temperatures, so the UHI effect antagonizes air and water pollution. Green infrastructure is part of the solution to the UHI effect, with green roofs gaining greater consideration by developers, and building owners (Hao, 2011).

Cost benefit of green roof implementation can occur at the single structure scale, a citywide scale, or in reduction of the green roof cost itself. In a simulation, to assess benefits, citywide green roofs can reduce runoff to decrease the operation cost of stormwater infrastructure (Hao, 2011). In multistory buildings there are energy demand reductions in only the top floors. The two highest floors below a green roof have the greatest benefit, floors greater than four stories from the roof are not impacted (Blackhurst, 2010). The insulating abilities of green roofs in summer have been quantified and they reduce the heat flux in a building. Green roofs lower surface temperatures, and the substrate acts as insulation (Hao, 2011). Solar radiation that impacts a green roof and so does not impact the roof membrane cannot break it down. A thirty to forty year green roof is possible with proper waterproofing, installation, and maintenance (Snodgrass, 2006, p. 36). This is in sharp contrast to the seven to thirteen year lifespan given some traditional roof membranes (RRPDC, 2010).

The reduction of costs associated with green roofs is an additional method to increase the cost benefit. In Germany, extensive green roofs cost $18.50 per square meter, in the United States, the same roof would cost $47.30 per square meter (Phillipi, 2006). The greatest cost difference in green roof building materials is in substrate, at $16.00 per square meter in the United States versus less than $4.00 per square meter in Germany (Phillipi, 2006). The German green roof market is highly competitive, and this has driven prices down.

CHAPTER 4

CASE STUDY : INSTALLATION OF THE SIUC GREEN ROOF RETROFIT ON THE AGRICULTURE BUILDING

During re-roofing of the Agriculture Building in 2008, a section was designed to support a green roof largely dedicated to research. Due to the fact that only the roof framework was revised, there was a twenty-five pound per square foot weight limit for a proposed green roof. This roof was installed with the assistance of professional volunteers. These volunteers were Tom Cooper of Green Roof Solutions, Grace Koehler of Pizzo Native Plant Nursery, and Mike Curry of Midwest Trading. A plan was created and approved by SIUC campus architects and engineers. Materials were purchased through the SIUC green fee fund, College of Agricultural Science and Plant Service Operations support, as part of the landscape horticulture program. Over one hundred fifty students, professional volunteers, plant services laborers and faculty installed the green roof system over the week of September 25, 2010. Professor Karen Midden from Plant, Soil & Agriculture Systems, organized the project. All systems had the initial treatment of a root barrier rolled over the existing thermoplastic polyolefin (TPO) single ply roofing membrane.

This semi-intensive green roof has four sections; the sedum dominated classical European section is 437.5 square feet, the second sedum dominated section with a modern drainage membrane is 881 square feet, a research and wildflower meadow section of 1297 square feet, and a second research and wildflower meadow section of 1333.5 square feet. These sections are described as a sedum dominated European system (the drainage layer is entirely composed of aggregate without organic matter), a sedum dominated system, and two vascular plant systems each including space for research. The sedum dominated classical green roof system has two layers of media, the bottommost is light weight aggregate to function as the drainage layer. A filtration layer was laid between it and the topmost media layer. This topmost layer was enriched with organic matter that provides nutrients for plant growth.

The two native sections were planted with trialed plants from Intrinsic Perennials of Hebron, IL, and Pizzo Natives of St. Charles, IL. The roof also includes a smaller section within this one, which utilizes twelve coconut fiber modules designed to biodegrade over time. These were filled with native grasses. There is an additional native plant section on the southeast area of the building. Research areas have been utilized for vegetable research, including; lettuce, radishes, and tomatoes.

The SIUC green roof consisted of plants, Midwest trading green roof substrate (kiln-expanded aggregate containing perlite, a time-release fertilizer and organic matter at 3.5% total volume, filtration layer (FF35), drainage layer (GRS1.5), root barrier (RB20), waterproof membrane (TPO), insulation, and finally the roof deck. The fully saturated roof was designed to weigh twenty-five pounds per square foot. Roofers installed the insulation, waterproof membrane, and roof deck previously. Hand railings with weighted ballasts were installed, manufactured by Keeguard. The weighted ballasts allow the railing installation for liability purposes without needing to drill or otherwise penetrate the waterproof membrane.

Figure 1. From the bottom layer up; TPO (not shown), moisture retention fabric (not shown), root barrier, drainage layer, filter fabric, and growing substrate. This is contained within aluminum railings (picture by the author).

A moisture retention fabric was unrolled and cut to size in sheets onto the roof. This material was a non-biodegradable plastic fabric that can hold more than its weight in water. It served the purpose of preventing root penetration, and retaining water for the green roof, while dispersing weight on the waterproof membrane. The material was saturated with water to prevent it from blowing away in the wind. A root barrier was unrolled and cut to size on the roof, and separate sheets were taped down to each other and directly to the moisture retention fabric using Butyl tape.

The drainage layer, sometimes called a water retention membrane, was made of injection molded plastic. This layer was above the root barrier. The drainage layer was visually similar to egg cartons, with cups that can overlap into each other which coupled with the weight of the above layers, hold the drainage layer in place. The material could store a set quantity of water, not exceeding the twenty-five pounds per square foot limitation of the building. After these cups fill with water, the excess drains laterally over a small slope on the roof surface, and then off the roof via drain. The drains were not covered with green roof layers or media so that they may be cleaned of litter and inspected with ease. The drain itself is called a drain box. The drainage layer prevents saturation beyond an engineered weight.

Figure 2. The drain box and sedum establishment on October, 16, 2010.

Figure 3. The drain box and sedum establishment on April 12, 2011. Note the thickness of the sedum mat (both pictures by author).

A sheet of soft inorganic material called filter fabric was placed over the roofing membrane, which filters and protects the drainage layer from friction or filling with the green roof substrate while dispersing weight over a larger area of the membrane, thereby preventing it from getting pierced.

The green roof substrate was then added onto the roof. The substrate was brought up using a crane. The crane held bags of substrate in the air; over the roof. Large slits were cut on the bottom of the bags, allowing the media to fill wheelbarrow. Students would alternate to fill wheelbarrows with substrate as it fell from the suspended bags, and deliver the substrate across the roof. The substrate was spread out over the roof using rakes with the tines up to prevent the fabric layers or membrane from being damaged.

Plants were installed into the roof substrate, in the case of perennials, holes were made down to the filter fabric. The sedum mats that were approximately four feet by eight feet were then unrolled onto their respective sections. Care was given to not break the mats under their own weight during transport on the roof to their sections. The mats were unrolled and any corners, that were overlapping or folded under, were righted or cut to size.

The plant list for the meadow or wildflower section of the SIUC green roof included 17 plants with the growth forms of grasses, a sedge, flowering plants, and sedum. Grasses include Blue Grama (*Bouteloua gracilis*), and June Grass (*Koeleria cristata*). There is one sedge species, called Copper Shouldered Oval Sedge (*Carex bicknellii*). Flowering plants include Nodding Wild Onion (*Allium cernuum*), Wild Columbine (*Aquilegia canadensis*), Heath Aster (*Aster ericoides*), Harebell (*Campanula *rotundifolia*), Lanceleaf Tickseed (*Coreopsis lanceolata*), Purple Prairie Clover (*Dalea purpurea*), Prairie Smoke (*Geum triflorum*), Cylindrical Blazing Star (*Liatris cylindrical*), Foxglove Beardtongue (*Penstemon digitalis*), Pale Beardtongue (*Penstemon pallidus*), Prairie Cinquefoil (*Potentilla arguta*), Hairy Wild Petunia (*Ruella humilis*), and Fame Flower (*Talinum calycinum*). The sedums were the most reliable green roof plant, and this roof included; Goldmoss stonecrop (*Sedum acre*), *S. rupestre*, *S. rupestre* 'Angelina', Widowscross (*S. pulcellum*), Helix Sedum (*S. sexangulare*), Golden Carpet Sedum (*S. kamtschaticum*), *S. album* 'Coral Carpet', and *S. spurium* 'Dragon's Blood'. This plant community will respond to its environment to develop its own ecology. These plants have all been trialed in the Chicago area at USDA zone 5. Southern Illinois University Carbondale is in USDA zone 6, so this roof will trial the plant materials.

The green roof system was watered for the first month, allowing the plants time to establish roots into the media. Initially, watering a green roof caused a larger portion of the organic matter to become suspended and dissolved in the water leaving the roof as enriched runoff, and is called first flush. Any runoff observed for the first month of drainage was similar in color to chocolate. It took two and one half hours to water the green roof, and water could be heard percolating through the media.

Buckhorn Plantain (*Plantago lanceolata*), Chickweed (*Holosteum spp*.), Shepherd's Purse (*Capsella bursa-pastoris*), dandelion (*Taraxacum spp.),* and other weeds are emerging from the nursery media that the green roof plants were initially propagated in. Removing the weeds by hand is not possible without ripping off the aboveground portion and leaving the roots. The sedum mat is established and thick. Some of the plugs are pushing out of the ground, perhaps from freeze-thaw cycles. The wooden frames of the coconut-fiber tray systems are starting to break down at the surface.

Figure 4. Coconut fiber trays are degrading at the surface of the substrate (picture by author).

Sedums display darker fall colors, which they retain throughout the winter. In the Spring, some plants begun their spring growth. Many plants that appear to have not survived the winter are dry and heaved out of the ground. Weeds were numerous and well-established. Some of the coconut fiber modules have degraded. Flowering Onion (*Allium cernuum*) retained its green foliage throughout the entire winter. Plants brightened their colors once the growing season began and succulent growth and flowering was present in many places. *Coreopsis lanceolata* bloomed with an orange and yellow irregular flower.

General Observations

General observations were made from the installation and maintenance of the SIUC green roof. Firstly seeing the green roof layers being placed down and explained as components made it easy to comprehend how the system works as a whole. Green roof plants planted late in the growing season tend to lift out of the ground, dry out and freeze. Sedums become darker in the autumn, and stay so until the growing season begins. Several green roof plants are evergreen in nature. The roof was always covered with tiny jumping spiders. One could assume that the presence of a predator could indicate that of prey.

The watering of a green roof is time consuming, it is difficult to saturate the media to have caused ponding, the layers were extremely efficient at water drainage. The sound of a green roof changed when you walk on it, dependent on saturation. The sound of water as it drained through the layers could also be heard. Places that were walked on regularly during maintenance and research efforts could be noted, because the media broke down into smaller clasts.

CHAPTER 5

INTERVIEWS WITH PROFESSIONALS OF THE GREEN ROOF INDUSTRY

By interviewing professionals in the green roof industry, inadequacies of green roof research may be discovered leading to recommendations for future research that will guide future researchers into an efficient direction. As individuals involved in the green roof industry, their understanding of green roof research suggests cogent directions of future research. Interviews were conducted with Tom Cooper of Green Roof Solutions, Mike Curry of Midwest Trading, Jason Barrett of Tremco Roofing, and Grace Koehler of Pizzo Native Plant Nursery. The following 11 interview questions were asked via phone interview of each professional, his or her answers were recorded by Garageband for Mac OS X 10.6.7 and exported as a podcast to iTunes and then transcribed. The Tom Cooper interview was filmed live on the green roof. Answers were summarized down to their essence. This dialogue could inform and direct subsequent exploration into green roof technology.

Interview Technique

1) How did you become involved in the green roof industry?

2) What type of green roof systems have you worked with?

3) What type of plant materials have you worked with?

4) How has the industry changed or stayed the same while you have been involved with it?

5) What are some success/problem stories of your green roof experience?

6) What challenges do you see in the industry?

7) Do most customers seek green roofs due to city mandates or preferences?

8) What are some topics/issues of green roof research that you would like to see explored?

9) What do you expect the green roof industry to do in the next ten years?

10) What is your hope for the next fifty years of green roof technology?

11) Is there anything that you would like to add, or anything I forgot to ask you? thank you for your time.

Interview Findings

In these interviews, three of the four professionals in the green roof industry were somehow involved in the landscape trade prior to pursuing green roof technology. All of the interviewees have worked with intensive, extensive, and semi-intensive green roof systems. Three of the four have worked with modular systems.

Concerning plant materials, all of the interviewees have worked with sedum, and most with woody landscape materials such as trees or shrubs. These plant choices are driven by media depth. Crop production on green roofs is perceived as an emerging influence. Plant trials need to be carried out in every region of North America, and climate change will complicate these trials. These professionals are concerned with increasing diversity on rooftops beyond Sedum. Fertility of plants is an issue that must be balanced with the release of nutrient enriched runoff.

All interviewees noted that the industry has expanded and that there are more businesses, and people involved. Some of these businesses are not investing in thorough research and development. They maintain that proper system design is imperative to green roof success.

LEED incentives have been a strong driver of roof diversity. In a few instances, professionals indicated that in America, the market demands an orderly sense of aesthetic for green roof plantings. This creates a challenge for maintenance. Maintenance as a subject is neglected or doubted by green roof clients. Mandates or incentives, cost reduction, and the period until there is a return on the investment are primary concerns of the public when deciding to install a green roof. Developing a standard beyond the FLL is a concern of green roof professionals. The public wants guarantees on technology from a market that is still immature. Professionals of the green roof industry believe it will expand in the future and will blur the distinction between the landscape and the home. Professionals are concerned about water management issues, derived from climate change, stormwater infrastructure, and runoff.

Of note, none of the professionals expressed anything specific concerning green roof design below the substrate, including; filter fabrics, drainage layers, root barriers, and waterproof membranes. Professionals mentioned elements of plant, substrate design, cost, mandates and maintenance as their primary concerns.

Additional Comments of the Interviewees

1) How did you become involved in the green roof industry?

Tom Cooper came to sustainable business after leaving the finance industry.

Mike Curry started in civil engineering, and then transferred to Plant, and Soil Science (PLSS). He then worked for 20 years as a design and build contractor and Registered Landscape Architect (RLA), as a certified Green Roof Professional (GRP), he had worked on Chicago City Hall.

Jason Barrett earned a bachelor's degree in PLSS, and then began working with the Brickman Group. He then transitioned into working with modular green roofs.

Grace Koehler is a 1979 College of Ag (PLSS) Alumnus, initially in turfgrass management, who learned ecology when she was responsible for natural areas management through the Kane County Forest Preserve; She worked on Chicago City Hall in 2000. She now works for the Pizzo native plant nursery.

2) *What type of green roof systems have you worked with?*

Tom Cooper has worked with extensive to intensive roof systems, and healing gardens.

Mike Curry predominantly works with custom designs, on extensive, intensive, turf lawns, and semi-intensive green roofs.

Jason Barrett has worked with modular and hybrid systems, involving Hydrotech and Tremco.

Grace Koehler has worked with all different types; modular, greengrid, green roof blocks, coconut core trays, and built in place systems from intensive to extensive systems, involving Tremco and Hydrotech.

3) *What type of plant materials have you worked with?*

Tom Cooper has worked with sedums into woodies.

Mike Curry has worked with intensive to extensive roof systems.

Jason Barrett has mostly worked with sedum, into trees, and a putting green.

Grace Koehler has worked primarily with sedum, natives, perennials, and shrubs, dictated by media depth and more LEED credits for greater diversity.

4) *How has the industry changed or stayed the same while you have been involved with it?*

Tom Cooper notes that the industry has grown 25% through the recession.

Mike Curry notes the education of the public has increased, initially systems were only in Europe, universities are now involved, with an improved desire to understand design, driven by its needs. The public is aware, along with building owners, architects, civil engineers, and roofers.

Jason Barrett noted that the industry has grown, more people are interested, but some only in quick profitability and not in adequate research and development. Modular companies are increasingly common, but today's systems are unproven. In early 2009 the public gained awareness of green roof systems.

Grace Koehler believes the industry has changed quite a bit, initially there were few players and little data, but it is now more competitive and price driven. There are more plant materials, and that for a quicker investment return vegetable production is increasing. There is still inadequate long-term data for our market. Cost reduction requires financial incentives to occur, and LEED has been useful. Diversity is the primary concern. The production of native plants is challenging, requiring three years for marketability.

5) *What are some success/problem stories of your green roof experience?*

Tom Cooper indicated that mixing trades like roofing and landscape, it is not defined who controls the scope of the work.

Mike Curry responded that there's work to be done on system design. The public is now aware of green roofs. Americans want orderly aesthetic, which demands high maintenance. Established plants will compete with weeds, if that is a concern.

Jason Barrett responded that you must design specifically for the project to succeed.

Grace Koehler responded that green roofs succeed more often in six or more inches of media. Modular systems often fail, because they are viewed as temporary and maintenance is not budgeted for. Maintenance is critical for the first two to three years, and then annual inspections suffice. Americans expect intact designs, plants should be able to acclimate in their own way, and some will become more aggressive; success is defined by expectations.

6) *What challenges do you see in the industry?*

Tom Cooper responded to mix trades within the green roof industry is challenging.

Mike Curry responded that it is challenging when inaccessible and unseen green roofs colonize with volunteer plants that are contrary to design intent, and that establishment and maintenance is challenging.

Jason Barrett responded that challenges include installation, design, and not designing projects for an instant effect. Substrate design is imperative. RLAs need to become aware of the need for using trialed plants.

Grace Koehler responded that managing expectations for guarantees is difficult. Challenges include creating an understanding of what the end product should be, that cost is always an issue, and that a lack of professionalism will not go away. The technology has improved. She is concerned that climate change will continually challenge the plant materials, making a reliable definition problematic.

7) *Do most customers seek green roofs due to city mandates or preferences?*

Tom Cooper responded that customers are motivated by both mandates and personal preference. The public is more aware of low-impact construction. Do not discount the desire of the public to feel they are improving ecology.

Mike Curry responded that; most green roofs are installed through mandates, LEED incentives, and personal interest. Interested people are often professionals involved in science.

Jason Barrett responded that preferences or mandates is regional specific but largely driven by stormwater taxes, and regions have different preferences including healing gardens in healthcare, or research by universities, that is dependent on client desire.

Grace Koehler responded that green roofs are driven by mandates, with rare people that want to do the “right thing”, and that is increasing in Chicago.

8) *What are some topics/issues of green roof research that you would like to see explored?*

Tom Cooper hopes to understand how green roofs will be affected by climate change, and that we must develop an American standard beyond the FLL.

Mike Curry responded that North America requires differing nutrient requirement, plant materials, and maintenance. Long-term health and nutrient values of medias are unknown. Fertilizers need to be designed for green roofs, and that integrating technologies, to utilize runoff for grey water applications, while avoiding enriched runoff. Research should focus on utilizing grey space.

Jason Barrett responded that wind, diverse plant palettes, native plant trials, crop production, and the long-term maintenance or restoration of green roofs designed improperly, are topics needing research exploration.

Grace Koehler responded that native plant long-term survivability, research concerning growth effects in green roof media in lieu of nursery media, vegetable production, and fertilization and nutrient requirements that avoid enriched runoff, need to be explored by researchers.

9) *What do you expect the green roof industry to do in the next ten years?*

Tom Cooper expects the industry to grow by 150%.

Mike Curry expects the industry to expand like the German model, and beyond the recession. Green roof benefits will demand that we continue installation, until it is visible to the public.

Jason Barrett expects the industry to continue. Companies whose systems have inadequate research will fade away. He expects people will be driven to reduce the time until cost benefit is realized, that property owners will want green roofs to add property value, and that the rooftop will become an area to relax. He responded that biodiversity will continue as a driver, the Chicago market will expand outwards, that mandates will approximate the European model of green roof industry.

Grace Koehler responded that competition will decrease pricing, with advances in substrate and plant choice. She expects that future mandates will be driven by stormwater to relieve infrastructure pressure, that plants might be propagated in the green roof substrate, and that endangered species might come back through green roofs. She anticipates that the landscape and the home will integrate.

10) *What is your hope for the next fifty years of green roof technology?*

Tom Cooper hopes to fulfill the reality of Malcolm Wells, to live in homes that add to our surroundings rather than destroy them.

Mike Curry hopes the industry grows into agricultural production, to mitigate environmental and water management issues.

Jason Barrett hopes that green roofs will become a landscape system, to blend the landscape and the home. He hopes we will increase and document roof longevity, and see the benefits we preach today come to fruition.

Grace Koehler hopes that green roofs proliferate the residential market, with new construction having a green roof.

11) *Is there anything that you would like to add, or anything I forgot to ask you?*

Mike Curry added that the green roof industry did not exist when he was in school, and that green roofs are a trend worth investigating.

Jason Barrett added that proper design is critical, including trialed plants and the right soil specifications, that long-term cost is most relevant, and that academia now knows about green roofs.

CHAPTER 6

RECOMMENDATIONS FOR FUTURE RESEARCH OF GREEN ROOF TECHNOLOGY

The recommendations for research are based on a review of literature and on thoughts suggested by interviews with professionals involved in the North American green roof industry. Research directions herein refer to conditions on extensive or semi-intensive rooftops; such systems are dominated by thin, skeletal substrates and are structured by abiotic conditions. Research efforts have not focused on intensive green roof systems because they are similar in conditions to an at-grade landscape. Most studies thus far have focused on a single benefit for a specific building or group of buildings (Blackhurst, 2010). Currently, the literature and the interviews point to a research need concerning; making previous research in other languages available to English speakers, reliable and diverse plant lists specific to North American regions from native and volunteer communities, green roof bioindicator development, and the substrate as a living component. The living components of the substrate include soil bacteria and fungi.

Future Research Justified from Literature Findings

A very simple problem exists for North American green roof researchers; the majority of past research on green roofs is published in languages other than English. Any effort to translate and distribute this material could prevent research efforts from being repeated needlessly by English speakers. The development of trialed plant lists for

North American use is needed specific to ecoregion. The objective of ecoregional extensive roof plant lists could be to avoid monoculture (for ecosystem robustness and LEED credits), to consider volunteer species, and to support the natural biodiversity of the location. In essence, any plant community established in a skeletal substrate could be evaluated as green roof plants. The relationship between plant establishment and frost heaving could be further explored.

Native plants are popular and are supported by compelling ecological arguments. Species targeting green roofs are rare in North America. Green roofs in the United States, even sedum dominated extensive roofs, have high species diversity if one accounts for invertebrates and migrating birds. If a non-native plant does not show invasiveness, it could contribute to biodiversity. However, plants adapted to the extreme abiotic conditions of skeletal substrates have difficulty competing with plants outside of such an environment. Low biomass, low height, rosette leaves, pigment adaptations, and slow establishment rates often characterize skeletal substrate plants. The purpose of adaptations relating to dessication reduction and low-nutrient requirement is to utilize environments and therefore resources that other species cannot. Native plant communities on a green roof are intended to be specific to their ecoregion of origin. The ecology, runoff quality, and stormwater mitigation of native plants, versus that of traditional green roof plants is not understood. Since a purely native plant green roof is more difficult to design, research into this area will be challenging.

Limestone and granite barrens, talus slopes, desert cliffs (Dvorak, 2009), Southern Illinois cliff lines and Mississippi river limestone bluffs (Mohlenbrok, p. 8) have skeletal substrates and so could be sources of new green roof plant materials for their ecoregions. Propagating and testing these green roof potentials could develop robust green roof plant communities. Many of these plant communities are threatened, which could add to the benefits of green roofs supporting them.

Simply surveying volunteer plants growing on successful rooftops, then eliminating aggressive species, and evaluating the rest, could be an effective way to identify future green roof plants. Inversely, volunteers on green roofs in a state of failure could identify problem areas, the presence of a marsh plant for example could be used as a bioindicator of poor drainage. A list of bioindicators for each ecoregion could be developed, which could include invertebrates. Research that further defines the work of Dusty Gedge, into invertebrate colonization of green roof accoutrements (Gedge, 2003) such as logs could be reproduced in any ecoregion with unique results.

An understanding is needed of green roof plants in North America, relating to substrate type, the ecological effects of maintenance (Dvorak, 2010, p. 199), and the growing substrate as a living constituent (Ampim, et al. 2010). As an example, establishing the local Mychorizzae in the sterile green roof substrate could improve vascular plant establishment.

To further develop green roof substrate from recycled materials including construction waste could be valuable. The use of recycled crushed concrete or brick with mortar vestiges could have high lime content, therefore a plant from a limestone barren may thrive in such an environment. The relationships between substrate chemistry and plant success are numerous and unexplored. The physical behaviors of green roof substrates relating to water retention and drainage might change when other materials are used or different plant communities utilized. Relationships exist between substrate depth, fertility, succession, and weed colonization. There is also very little research focusing on green roof failures. By learning from miscalculations in green roof design, the same errors could be avoided in future roofs.

It is not currently known how widely implemented green roofs will communicate biotic materials such as plants or animals. Until green roofs are common enough in North America to communicate propagules, this research will be restricted to modeling. All of the benefits of green roofs have a varying sense of scale. Passive cooling of a structure with a green roof alleviates heating and cooling demands, however to affect the Urban Heat Island effect, numerous green roofs are needed. Decreasing runoff is important to mitigate stormwater, yet no one would argue that a single green roof in a city, will decrease the need for stormwater infrastructure. Until green roofs are implemented on a massive scale in urban centers, many of their argued benefits will only be demonstrated through modeling. As the North American green roof industry increases in scale, additional research opportunities will appear. Until then, North American urban green roof research will physically need to relate to one or several green roofs.

Future Research Justified from Interview Findings

Interviews can imply patterns, but these thoughts are inferred and not proven. The professionals have a practical understanding of their fields. Most green roof professionals enter the industry through an involvement in landscape horticulture, but this is not always the case. Professionals feel that the public is now aware of green roof technology, and that cost of green roofs will always be a challenge. Decreasing the amount of time until a return on an investment in green roof installation is a constant need. As a professional, one will work with a variety of systems that are tailored to the structure upon which they are built. Such systems include extensive, semi-intensive, and intensive green roofs. Substrate design is critical and often changes with the project at hand. However some companies use the same substrate design in all of their projects. Substrate fertility is a concern in today's market, with professionals feeling that the fertilizers are not understood in relation to enriched runoff prevention. Customized green roof fertilizer research would be useful.

Plant materials will vary based on roof design, but the industry is favoring more installation of semi-intensive systems, therefore more perennials are entering the market. Plant trials are needed everywhere in North America, but will become increasingly complicated from climate change. Consumers need to understand that only trialed plants should be used on green roofs. The use of crop production on green roofs is one of increasing interest and demand. Plant diversity is a strong driver of green roof plant selection. Native plants are continuing to enter the market.

LEED credits have helped to increase diversity on the rooftop beyond Sedum. LEED no longer accepts eight sedum blends as diverse. Mandates and incentives drive the current market, with fewer instances of people involved somehow in the industry desiring green roofs on their buildings. The FLL is a useful set of guidelines for green roof design, however a North American standard must be developed, which is driven by the sheer size of the continent.

Maintenance is a challenge because many clients do not account for it. Maintaining green roof plants within an orderly design is difficult, because plant communities are dynamic. Additionally, the concern and interest in local healthy food is a strong driver of green roof installation, and therefore worthy of thorough research.

Concluding Statement

The history of green roofs shows how our ancestors used them to regulate the temperature of their environments. Structures with green roofs are cooler in the summer heat, and warmer in the winter compared to most others. While difficult to measure, green spaces make people feel better. Green spaces improve our lives.

A green roof is a primary succession environment that is analogous to a high stress environment. Future researchers can learn about green roof ecosystems from the study of high stress environments with skeletal substrates. The use of non-native plants is completely acceptable; functionality should drive green roof plant selection.

Crop production on green roofs, including vegetables, is an emerging method to bring agriculture back to the urban environment. From wasted grey space we can create useful green space. Local foods require less energy to transport to the consumer due to less distance being involved. One consideration for vegetable research on green roofs is that the benefit of stormwater mitigation is reduced. Extensive green roofs are xeric environments, and many vegetables are not xerotolerant. The roof will need to be irrigated to support crops in most climates. Therefore, the saturated membrane will not be able to retain as much rainwater. Care must be taken in future vegetable research to not repeat the mistakes of modern agriculture, including; over irrigation, the release of nutrient enriched runoff, the use of toxic compounds, and an increase in sediment transport. The benefit of all green roof technology is to utilize wasted space that we can no longer afford to ignore.

REFERENCES

Ampim, Y., Peter, A., Sloan, J., Cabrera, R., Harp, D., & Jaber, F. (n.d.). Green Roof Growing Substrates: Types, Ingredients, Composition, and Properties. *Journal of Environmental Horticulture*, *28*(4), 136-143.

Anderson, A. (2010). Potential value of mosses for stormwater management in urban environments. *Urban Ecosystems*, *13*, 319-332.

Archibold, O. (2007). Volunteer vascular plant establishment on roofs at the university of Saskatchewan. *Landscape and Urban Planning*, *79*, 20-28.

Blackhurst, M. (2010). Cost Effectiveness of Green Roofs. *Journal of Architectural Engineering*, *16*(4), 136-143.

Bliss, J. (2009). Storm Water Runoff Mitigation using a Green Roof. *Environmental Engineering Science*, *26*, 407-417.

Brady, N. C., & Weil, R. R. (2002). Index. In *The Nature and Properties of Soils: Nyle C. Brady, Ray R. Weil.* Upper Saddle River, NJ: Prentice Hall.

Bremness, L. (1992). *The complete book of herbs*. Johannesburg: Southern Book Pub.

Carter, T. (2006). Vegetated roofs for storm water management at multiple spatial scales. *Landscape and Urban Planning*, *80*, 84-94.

Chambers, R. (1856). *Tracings of Iceland & the Faröe Islands,*. London and Edinburgh: W. & R. Chambers.

Davis, A. P., & McCuen, R. H. (2005). *Stormwater management for smart growth*. New York: Springer Science.

Dick, E. (1954). *The Sod-house frontier, 1854-1890: a social history of the Northern Plains from the creation of Kansas and Nebraska to the administration of the Dakotas.* [S.l.]: [s..n.].

Dunnett, N. (2006, May 11). Roofs for Biodiversity: Reconciling Aesthetics with Ecology. *Greening Rooftops for Sustainable Communities*. Retrieved from http://www.greenroofresearch.co.uk/ecology/Dunnett,%20N.%20P.%202006%20Green%20roofs%20for%20biodiversity-%20reconciling%20aesthetics%20with%20ecology.pdf

Gaffin, S., Rosensweig, C., Parshall, L., Beattie, D., Berghage, R., O'keefe, G., & Braman, D. (2005). Energy balancing modeling applied to a comparison of white and green roof cooling efficiency. Roofmeadow.com. Retrieved from http://www.roofmeadow.com/technical/publications/GaffinetalPaperDC-0009.pdf

Getter, K., & Rowe, B. (2006). The Role of Extensive Green Roofs in Sustainable Development. *Horticulture Science*, *41*(5), 1276-1285.

RRPDC. (2010). Richmond Regional Planning District Commission / Richmond Area Metropolitan Planning Organization. Retrieved April 01, 2011, from http://www.richmondregional.org/planning/Stormwater/green_roof.htm

Greig-Smith, P. (1964). *Quantitative plant ecology*. London: Butter Worths.

Hall, R. (2007). *Exploring the World of the Vikings*. London: Thames & Hudson.

Hammer, K. (1968). *North Dakota History: 1870-1889* (1st ed., Vol. 35). ND.

Hao, N. (2011). Scaling of Economic Benefits from Green Roof Implementation in Washington, DC. *Environmental Science Technology*, *44*, 4302-4308.

Hongming, H., & Jim, C. (2010). Simulation of Thermodynamic Transmission in the

Green Roof Ecosystem. *Ecological Modelling*, *221*, 2949-2958.

Jenks, M. A., & Wood, A. J. (2007). *Plant desiccation tolerance*. Ames, IA: Blackwell Pub.

Johnson, E. A., & Miyanishi, K. (2007). *Plant disturbance ecology: the process and the response*. Amsterdam: Elsevier/AP.

LLC Copyright. (n.d.). Greenroofs.com Projects - Rockefeller Center Roof Gardens. *Greenroofs.com: The Resource Portal for Green Roofs*. Retrieved March 05, 2011, from http://www.greenroofs.com/projects/pview.php?id=666

Mentens, J. (2005). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landscape and Urban Planning*, *77*, 217-226.

Molineux, C., Fentiman, C., & Gange, A. (2009). Characterizing alternative recycled waste materials for use as green roof growing media in the U.K. *Ecological Engineering*, *35*, 1507-1513.

Nassauer, J. (1995), Messy Ecosystems, Orderly Frames. Landscape Journal. 14(2), 161-170.

Peck, S. (2009). Green roofs and the urban heat island effect. *Environmental Engineering Science*, *103*(7).

Peck, S., Callaghan, C., Kuhn, M., & Bass, B. (1999). Greenbacks from Green Roofs: Forging a New Industry in Canada. *Canada Mortgage and Housing Corporation*, 11-12.

Philippi, P. (2006, May 11). How to get cost reduction in green roof construction. In Greening Rooftops for Sustainable Communities. Retrieved April 11, 2011, from http://www.sustainable-eastside.net/Green%20Roofs%20Report%202.07.05.pdf

Pugnaire, F. I., & Valladares, F. (2007). *Functional plant ecology*. Boca Raton, FL: CRC Press.

Short, W. (2003). Hurstwic: Turf Houses in the Viking Age. *Hurstwic, a Viking Age Living History Society*. Retrieved April 05, 2011, from http://www.hurstwic.org/history/articles/daily_living/text/Turf_Houses.htm

Simmons, et al., M. (2008). Green roofs are not created equal: the hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate. *Urban Ecosystems*, *11*, 339-348.

Simpson. (1999). A reinterpretation of the great pit in Hofstathir Iceland. *Geoarcheology: An International Journal*, *14*(6), 511-530.

Sky Vegetables - innovative, urban, sustainable agriculture. (2010). Sky Vegetables - The Sky Is the Limit! Retrieved April 13, 2011, from http://www.skyvegetables.com/about.html

Snodgrass, E. C., & Snodgrass, L. L. (2006). *Green roof plants: a resource and planting guide*. Portland, Or.: Timber Press.

Stovin, V. (2010). The potential of green roofs to manage urban stormwater. *Water and Environment Journal*, *24*, 192-199. doi: DOI: 10.1111/j.1747-6593.2009.00174.x

Teemusk, et al, A. (2009). Temperature Regime of Planted Roofs compared with Conventional Roof Systems. *Ecological Engineering*, *36*, 91-95.

The potential of green roofs to manage urban stormwater. (n.d.).

Velazquez, L. J. (2003). Modular Greenroof Technology: an Overview of Two Systems. In *First Annual Green Rooftops for Sustainable Communities Conference*. Chicago, IL.

Voyde, E. (2010). Quantifying Evapotranspiration Rates for New Zealand Green Roofs. *Journal of Hydrologic Engineering*, *15*(6), 395.

Wharton, D. A. (2002). Life at the limits: organisms in extreme environments (pp. 9-11). Cambridge, UK: Cambridge University Press.

Wylie, J. (1987). *The Faroe Islands: interpretations of history*. Lexington, KY: University Press of Kentucky.

VITA

Graduate School
Southern Illinois University

John D. Magill Date of Birth: March 9, 1982

2380 E. New York St., Aurora, IL 60502

1323 W. Erie St. #3F, Chicago, IL 60642

Jdmagill@gmail.com

Southern Illinois University Carbondale
Bachelor of Arts, Geology, May 2011

Southern Illinois University Carbondale

Research Paper Title:
A History and Definition of Green Roof Technology with Recommendations for Future Research

Major Professor: Karen Midden