Life Cycle Cost Comparative Analysis of Extensive Green Roofs in Switzerland and Holland

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Abstract

This thesis research compares the monetary costs and benefits of extensive green roofs in Switzerland and Holland. A green roof consists of extra layers over traditional roof waterproofing to support growing vegetation. The Life Cycle Cost (LCC) is calculated by discounting green roof cash flows over a 50 year time period to determine a Net Present Value (NPV). Green roofs are exemplified to provide substantial economic benefits and are one approach to sustainable real estate. In Switzerland and Holland, extensive green roofs are economically sustainable when considering the added energy savings, municipal incentives and storm water fee reductions. This thesis research finds that an extensive green roof NPV in Switzerland costs are 27% - 37% less than a conventional flat roof. Similarly in Holland, the NPV of green roofs are determined to be 16% - 26% less than a conventional flat roof. Additionally, this research explores modern software technologies to assess roof costs and facilitate planned preventative maintenance schedules and concludes with a proposed tool for benchmarking the overall sustainable benefits of green roofs.

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List of Abbreviations

BIM	Building Information Model
BRSs	Building Rating Systems
CHF	Canton of Helvetica Frank
CSR	Corporate Social Responsibility
DGNB	German Sustainable Building Council
ET	Evapotranspiration
FLL	German Landscape Development Research Society
GEFMA	German Facility Management Association
GI	Green Infrastructure
LAI	Leaf area index
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
LEED	Leadership in Energy and Environmental Design
LID	Low impact development
MUS	Multiple-Use Water Services
NPV	Net Present Value
PPL	Planned Preventative Maintenance
RAS	Rotterdam Adaption Strategy
RCI	Rotterdam Climate Initiate
SGNI	Swiss Sustainable Building Council
USD	United States Dollar
USGBC	United States Green Building Council
WLC	Whole life cost

1 Introduction

The life cycle cost (LCC) economic analysis in this research provides insight on today's cost associated with extensive green roofs in Switzerland and Holland. Green roofs are an example of restorative environmental design economically evaluated in this Mater of Science thesis research. As a result of this research, average life cycle costs of green roofs in Switzerland and Holland are determined. Additionally, an approach to benchmarking the overall sustainability of green roofs is proposed. This research also explores emerging technologies that can be integrated into maintenance strategies in order to optimize the overall effectiveness of green roofs. Due to investor risk uncertainty, green roofs have barriers to widespread implementation on an international level. "With green roofs this uncertainty revolves around the limited knowledge of their properties, costs and monetized benefits, and hence uncertainties with respect to the returns on investments, given the upfront costs of installation" (Mees, 2014, p. 54). The sustainable benefits of green roofs are widely accepted in Europe. Today, many European municipalities mandate or provide incentives for the incorporation of green roofs in building construction and renovation projects. (Weiler & Scholz-Barth, 2009; Hui S. , 2013) However, much remains to be learned about green roofs in the diverse climate regions of North America for widespread implementation in the United States of America (U.S.A.). (Monterusso, Rowe, & Rugh, 2005; Weiler & Scholz-Barth, 2009; Dvoraka & Volder , 2010)

The Ford Motor Co. Rouge River manufacturing center in Michigan, U.S.A., hosts a green roof used for phytoremediation research, a naturally occurring process in which plants remediate land contaminated with toxins. The Ford company has "cultivated 20 native plants and is monitoring how well each breaks down polycyclic aromatic hydrocarbons, a prevalent on-site toxin" (McDonough , Braungart, Anastas, & Zimmerman, 2003, p. 440). Anke van Hal (2009) exemplifies the Ford Rouge Center green roof in Dearbron, Michigan for how a company building can provide social, environmental and economic benefits in her Inaugural speech titled The Merger of Interests at the Nyenrode Business University in Holland.

> This remarkable roof enhances the wellness of the people that look out on it (People), buffers rainwater and creates a biotope for many plants and animals (Planet) but on top of that save Ford millions of dollars (Profit). This is because the life span of the roof was doubled, maintenance costs lowered substantially, the green roof give protection from UV-rays and energy costs were reduced due to better isolation [insulation]. The main financial advantage however came from the absorbing and filtering working of the roof,

> so that the usually obligatory filtering system could be left out (van Hal, The Merger of Interests, 2009, p. 20).

This 10 acre green roof atop porous concrete filters and manages excessive storm water through the use of water retention ponds while costing $35 million less than a conventional roof system specified to meet local standards. (McDonough , Braungart, Anastas, & Zimmerman, 2003, p. 440) This example shows how a green roof saves significant company costs, exhibits environmentally restorative benefits, improve employee well being and visually exemplifies sustainable corporate values.

A new design paradigm is necessary for restoring the negative affects that modern urban built environments have had on natural systems (van Hal, The Merger of Interests 2.0, 2014) However, a monetary cost and benefit analysis is highly important for the prevailing and current perspectives of property management and investment priorities. The view of sustainability based only on economic terms is being outdated and a new paradigm for investors to create a sustainable business case is proposed by Anke Van Hal called in her book *The Merger of Interests 2.0*. Van Hal is a Dutch professor at the Center for Entrepreneurship & Stewardship at the Nyenrode Business University as well as a Sustainable Housing Transformation professor in the Architecture department of the Delft University of Technology (van Hal, The Merger of Interests 2.0, 2014). The Merger of Interests perspectives looks for approaches to business where economic, social and environmental benefits can be realized. Her work focuses on sustainable business approaches to creating a high quality built environment by first considering the needs of stakeholders involved and delivering those needs through innovative solutions that are environmentally responsible. Addressing social needs in a way that benefits the environment and only then considering costs is the approach outline.

> Consider first the interests of the people involved, then attempt to promote those interests in a way which is also good for the planet (the environment, the people of the generations following us), and only then consider the costs. (van Hal, The Merger of Interests 2.0, 2014, p. 49)

Van Hal acknowledges this approach to business requires creativity and interdisciplinary collaboration to attain funding that makes the projects possible. This innovative strategy does not require the invention of something completely new but must only be new to people who deal with it, which can be “a product, a service, a process or a social development” (van Hal, The Merger of Interests 2.0, 2014, p. 47) She argues that a sustainable approach to evaluating effective business strategies must include social, environmental and economic benefits (see Figure 1, below) prioritized in that order (van Hal, The Merger of Interests 2.0, 2014).

To properly integrate green roofs into current building and renovation projects, a modern day business strategy approach to justify green roof installations is reviewed. Corporate social responsibility (CSR) focuses on social and ethical issues for successful stakeholder management. (Roaf, Horsley, & Gupta, 2004; Ainger & Fenner, 2014) One corporate strategy for a business to exemplify CSR is by constructing new facilities with a low environmental impact with the guide of third party building rating systems (BRSs) which are typically based on a Life Cycle Assessment (LCA) criteria. (Ainger & Fenner, 2014) However, there is currently a disconnection in the achievability of BRSs in the U.S.A. and comprehensive sustainability issues.

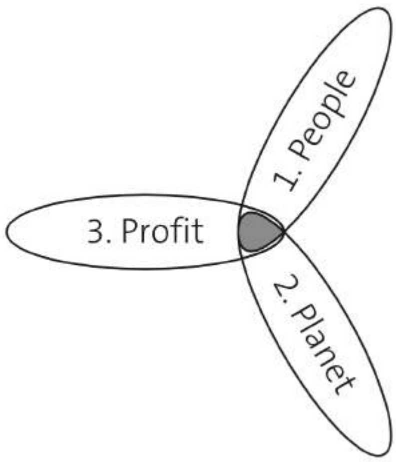


Figure 1: Sequence of Steps in The Merger of Interests Perspective (van Hal, The Merger of Interests 2.0, 2014, p. 49)

Conventional sustainability in the built environment considers the three pillars of sustainability: social, economic and environmental issues. (Wilkinson, Remoy, & Langston, 2014) Green building rating systems such as the Leadership in Energy and Environmental Design (LEED) created by the United States Green Building Council (USGBC), are mainly driven by environmental issues (Wallbaum & Feige, 2014, p. 303) and don't consider the project's financial return which is critical economic success. (Ainger & Fenner, 2014, p. 281) The effort for LEED projects to contribute to additional, holistic sustainability factors are not transparently identified unlike the German Sustainable Building Council (DGNB) sustainability rating system, which considers additional criteria beyond the conventional sustainability model, including technology, processes and other functional aspects. (Church, 2015)

1.1 Research Question

How are green roofs defined as successful in Switzerland and Holland and how can these successes be compared in terms of economic costs and benefits?

A life cycle cost (LCC) comparison is one economic analysis investors typically consider before installing green roof systems. There are many different benefits for green roofs and the purpose of this research is to quantify and compare the costs of green roofs in the two contrasting geographic locations of Holland and Switzerland.

1.2 Objectives

This research calculates the total cost in today's terms for the addition of a green roof through a discounted Net Present Value (NPV) calculation. This particular economic evaluation is important to better understand overall economic sustainability of green roofs in Holland and Switzerland. These two locations were chosen for a comparative analysis due to contrasting geographical descriptions, weather patterns and municipal incentives for green roof construction.

> As green roof popularity continues to grow, it is important for accurate life-cycle benefit-cost analysis (BCA) of green roof systems to be performed to inform both policy makers who may allocate public funds for projects with public benefits, and private building owners who may see a future financial inceptive to invest in new and relatively unproven technology. (Keeler & Carter, 2008, p. 352).

A green roof life cycle cost-benefit analysis quantifies the costs and benefits of green roofs to evaluate the positive and negative cash flows of a prospective construction or renovation. The lowest NPV is the favored option because a lower cost indicates the investment option with the least monetary expense. (Clark, Adriaens, & Talbot, 2008; Keeler & Carter, 2008) This research presents a LCC comparison of green roofs in Holland and Switzerland in order to develop a benefit-cost analysis (BCA), which weighs economic, social and environmental benefits of green roofs for a proposed green roof sustainable benefit benchmarking tool.

1.3 Terms and Definitions

Green roof	Roof of a building that is entirely or to an extent covered with vegetation planted over a waterproofing membrane. (Maksimović, Kurian, & Ardakanian, 2015, p. 64) An engineered roofing system designed to protect the building

	interior while allowing vegetation to grow on the roof surface. (Lindow & Michene, 2007, p.65)
Extensive Green Roof:	Mimic local landscape and require little maintenance or propagation. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, p. 12) Consist of a thin layer growing medium 2.5-15.2cm (1-6 inches), are often inaccessible and composed of inorganic materials. (Cantor, 2008)
Biodiverse green roof:	The plants that form the top surface will not be planted at the time of construction but will seed naturally. This may lead to an inconsistent appearance but have a high level of biodiversity (Cotgrave, 2013, p. 83) Designed to replicate the specific habitat needs of single, or small number of, species, or to create a range of habitat needs that can maximize the array of species that inhabit and use the roof. (Shah, 2012, p. 245)
Intensive Green Roof:	Often accessible and provide an amenity similar to a park facility. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, p. 12) Consists of a growing medium more than 15.2cm (6 inches) and is composed of a lightweight topsoil mixture of organic and inorganic elements. (Cantor, 2008)
Semi intensive green roof:	Typically includes grass, shrubs and coppices and other plant species that require little watering or fertilizer. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002) Consists of a growing medium with 25% above 15.2cm (6 inches). (Cantor, 2008)
Whole Life Cost:	The sum of life-cycle cost, income, non-construction cost (e.g. land, finance user support, taxes) and externalities (costs between provider and consumer e.g. business staffing, productivity). (Swiss Chapter of International Facilities Management Association, 2011, p. 8, per ISO 15686-5 (2008))

Life Cycle Cost: A technique used to establish the most advantageous long-term course of action with regard to (monetary) cost. (Swiss Chapter of International Facilities Management Association, 2011)

Life Cycle Assessment: Based on a 'cradle-to-grave' approach to assessing the environmental impacts of a product, project or service throughout its life cycle. (Ainger & Fenner, 2014, p. 269)

Building Information Modeling (BIM): A Building Information Model is a digital representation of physical and functional characteristics of a facility. As such it servers as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. (Build LACCD, 2010)

Restorative Environmental Design: An approach that aims at both a low-environmental impact strategy that minimizes and mitigates adverse impacts on the natural environment, and a positive environmental impact of biophilic design approach that fosters beneficial contact between people and nature in modern buildings and landscapes. (Kellert, 2008, p. 5)

Sustainable Development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (World Commission on Envrionment and Development, 1987)

Low-impact development: An approach managing rainwater runoff that emphasizes on-site natural features to protect water quality, by replicating the natural land cover hydrologic regime of watersheds, and addressing runoff close to its source. Examples include better site design principles (e.g. minimizing land disturbance, preserving vegetation, minimizing impervious cover), and design practices (e.g. rain gardens, vegetated swales and buffers, permeable pavement, rainwater harvesting, soil amendments). These are engineered practices that may

	require specialized design assistance (United States Green Building Council, 2013, p. 189)
Green infrastructure	A soil- and vegetation based approach to wet weather management that is cost-effective, sustainable, and environmentally friendly. Green infrastructure management approaches and technologies infiltrate, evapotranspire, capture and reuse storm water to maintain or restore natural hydrologies. (United States Green Building Council, 2013, p. 189)
Multiple-use water services	The project under the European Institute of Innovation and Technology's Climate Knowledge and Innovation Community to enhance the synergy of urban blue (water) and green (vegetated) systems and provide effective, multifunctional Blue Green solutions to support urban adaption to future climate changes (Maksimović, Kurian &Ardakanian,2015,p. 23)
Biophilia:	The theory stating that humans have an innate connection with nature and other living systems (Wilson, 1984)
Building rating systems:	Holistic, multi-dimensional, criteria based assessment tools, often third-party verified, and tied to a green building certification scheme. (Ainger & Fenner, 2014, p. 279)
Strategy:	Strategy is the direction and scope of an organization over the long term, which achieves advantage in a changing environment through its configurations of resources and competences with the aim of fulfilling stakeholder expectations" (Johnson, Scholes, & Whittington, 2006, p. 9)
Corporate social responsibility:	The commitment of businesses to contribute to sustainable economic development, working with employees, their families, the local community and society at large to improve their quality of life (Ward, Howard, & Fox, 2002)
Green building:	A set of design, construction, and building operation practices that minimize a building's total environmental impact. (Kruger & Seville, 2013, p. 3)

Greenwash(ing)	Misinformation disseminated by an organization so as to present an environmentally responsible public image. (Spiegel & Meadows, 2012, p. 363)

1.4 The history of green roofs

While it is most generally agreed that the first green roofs were the famous Babylon hanging gardens around 600 B.C. (United States General Services Administration, 2011; Werthmann, 2007), the green roof movement of today originated from Germany (Werthmann, 2007; Shah, 2012) and Japan (Kikuchi & Koshimizo, 2013) sometime in the early 1900's. Whereas the Japanese intentionally designed green roof systems to function as accessible roof gardens (Kikuchi & Koshimizo, 2013), the first German green roofs 'accidentally' sprouted from sand mixed with gravel used as fire protection atop wooden and tar roofs. Subsequently, this sparked the interest of German ecological researchers on the topic of green roofs, which ultimately led to the founding of the FLL in 1975. After World War II, accessible green roofs in Japan became widespread which lead local researchers to examine the effects and functions green roofs in more detail. (Kikuchi & Koshimizo, 2013) Much of the green roof research in Germany was propelled by the rise of environmentalism in the 1960's and the successful 'Back to Nature' campaign of the Green Party, which took power in the government in 1983. (Werthmann, 2007) Over the next 30 years in Germany, the result of savvy engineering resulted in a light, durable, reliable and cheap green roof system composed of the Sedum plant species. The Sedum green roof developments resulted from a focus on performance based criteria and is far removed from the original intentions associated with ecological restoration. Today, Sedum is the most widespread species found on green roofs in Germany (Werthmann, 2007) and around the world. (Snodgrass & McIntyre, 2010) The next phase of the international green roof development today is likely to be oriented on optimizing environmental benefits and social well being associated with accessibility and visual interaction of green roofs. (Werthmann, 2007, pp. 23-44)

1.5 Modern day 'green' vernacular

Currently there is much discussion revolving around the word 'green' in the context of business, technology, building operations and construction. Green is essentially synonymous with environmentally friendly just as blue is indicative of clean and unpolluted air or water. Brown on the other hand is synonymous with dirty and contaminated areas such as brownfields. (Spiegel & Meadows, 2012, p. 2) Although closely related, the verb green building is different from the noun for a green building. "Simply stated, a green building is one that is located and constructed in a sustainable manner and is designed to allow its occupants to live, work, and play in a sustainable manner" (Spiegel & Meadows, 2012, p. 2). On the other hand, the action of "green building is a set of design, construction and maintenance techniques and practices that minimize a building's total environmental impact" (Kruger & Seville, 2013, p. 3). While there are many definitions for what exactly a green business is, Eric Koester (2011) proposes that "a green business requires a balanced commitment to profitability, sustainability and humanity" (p.8). A green business is largely focused on profits just as a normal business is. However, there is a lack of clear green standards, which may have negative effects on the industry because any company can spread misinformation and market themselves as environmentally responsible, also known as greenwashing. (Spiegel & Meadows, 2012; Koester, 2011, p. 9) Likewise, a lack of industry wide standards for green roofs combined with the perceived risk associated with leakage has limited widespread implementation. (Weiler & Scholz-Barth, 2009, p. 271)

> Efforts continue by the American Society for Testing and Materials (ASTM) Green Roof Task Group (E.06.71) to develop acceptable industry-wide standards for green roof systems that will allow for increased opportunity for the insured to utilize them and a decreased risk to the insurers. (Weiler & Scholz-Barth, 2009, p. 271)

As previously stated, the German FLL (2002) has outlined guidelines for extensive, semi-intensive and intensive green roofs, which is referenced throughout the research presented here. A green roof is considered a 'green' technology but it's most accurately labeled as 'natural green' because it consists of natural materials. Likewise, straw bale and clay walls are other materials considered to be natural green building technologies. (Cotgrave, 2013, p. 85) Current drivers for the current green movement include clean technology developments (Koester, 2011) such as Building Information Modeling (BIM), which is used over the lifecycle of green buildings to reduce costs, energy consumption and waste. The United Kingdom government has deemed BIM crucial to its 2025 sustainability goals and will mandate BIM implementation on all federal construction projects no later than 2016. This mandate aims to bring modern green building competence and awareness to the general public. (HM Government, 2013; Manning & Brew, 2015)

1.6 Scope

Building rating systems, such as the Leadership in Energy and Environmental Design (LEED) and German Sustainable Building Council (DGNB) can potentially incorporate green roofs into building designs. Both building rating systems and green roofs are independently identified as business techniques used to strategically develop green operations. (Koester, 2011) The LEED green building rating system is the most widely used in the federal and privates sectors of the U.S.A, a country that also has a poor record of sustainable development. For example, precious farmland in the U.S.A. is being developed with housing, industry and support services at a rate of almost 6,000 acres daily. (Weiler & Scholz-Barth, 2009) Also, the U.S.A consists of only 4% of the world's population yet it produces 25% of global emissions. (Roaf, Horsley, & Gupta, 2004, p. 41). The implications of these statistics, particularly when considering climate change are beyond the scope of this report. However, due to the size of the U.S.A., its impact on global carbon emissions provides an important puzzle piece to future sustainability. One large impact that any country can make to sustainability efforts is through sustainable building operation, construction and development. (Wilkinson, Remoy, & Langston, 2014; Cotgrave, 2013) LEED is in a particularly good position to influence the future construction and designs of United States federal and public buildings (Holowka, 2014) giving LEED the unique potential to make the largest impact in the green building movement in North America and possibly the world.

The LEED green building rating system was first developed by the United States Green Building Council (USGBC) in 1998 and since then has been updated several times. (United States Green Building Council, 2014, p. 5) The LEED certification process considers social and environmental issues to guide the design and construction phases of new buildings. However, the LEED rating system is commonly accused of not including financial evaluations and economic sustainability within the criteria framework, resulting in environmentally friendly buildings that cost too much for most investors to build. (Ainger & Fenner, 2014) Green roofs encompass the ability to restore the natural environment as well as any other building component but are still not widespread due to high initial costs and investor uncertainty.

> In the United States of America especially, fiscal conservatism, public image, fear of litigation, and, often, a reticence to embrace relatively unproven technologies frequently have greater weight in the decision-making process than all of the combined economic, social, and environmental benefits that green roof systems can provide (Weiler & Scholz-Barth, 2009, pp. 45-46)

To better evaluate this economic uncertainty, the research presented here evaluates the life cycle costs (LCC) of green roofs in Europe. Unlike green roofs, green building rating system such as LEED are embraced by property owners in the U.S.A. because property values, rents and overall value retention of LEED certified buildings are higher than similar buildings. (Koester, 2011, p. 219) This study evaluates relevant green roof credits in the LEED v4 system and proposes changes for green roof evaluation and valuation within that system. LEED v4 promotes green buildings through a green design approach that “reduces the environmental harms of buildings and restores the balance of natural systems” (United States Green Building Council, 2014, p. 4) but does not transparently evaluate construction and operation costs afforded by the building owner and operator.

Alternatively, the SGNI, based on the German Sustainable Building Council (DGNB) aims to promote true sustainable real estate by considering the entire real estate life cycle in regards to social, economic and environmental criteria. (Swiss Sustainable Building Council (SGNI), 2014) The Swiss Chapter of the International Facility Management Association (IFMA Switzerland) and German Facility Management Association (GEFMA) created the SGNI economic LCC evaluation criteria. This LCC analysis tool is used to guide real estate investment decisions, optimize building designs and is used for benchmarking purposes. (Swiss Chapter of International Facilities Management Association, 2011, p. 4) LCC is one component to the respective building component’s whole-life cost (see Appendix: 11 Definition of Whole-Life cost per ISO 15686-5 (2008) (Swiss Chapter of International Facilities Management Association, 2011, p.8), p. 119). This thesis research analyzes the costs and benefits of green roofs using a Net Present Value calculation spreadsheet created in Microsoft Excel. The average NPV will provide property owners with expected costs per square meter to install and maintain green roofs over a 50-year life cycle in Switzerland and Holland. Finally, the cost and benefits of extensive green roofs are used to compare the DGNB sustainable building rating system and the LEED green building rating system for future LEED rating improvements.

2 Green Roofs

Green roofs are an added layer of soil and growing vegetation on roofs known to provide economic, social and environmental benefits. Throughout the literature review, the terms green roof, vegetated roof, living green roof and eco roof are used interchangeably. (Monterusso, Rowe, & Rugh, 2005; Oberndorfer, et al., 2007; Cantor, 2008; Weiler & Scholz-Barth, 2009; United States General Services Administration, 2011;) Green roof design guidelines are well established in European countries and it's important to examine this history so that future designers in the U.S.A have a well informed understanding on the composition and quality of green roofs. (Werthmann, 2007) The following European green roof definitions are found in *Guidelines for the Planning, Execution and Upkeep of Green-Roof Sites* (2002) created by a German organization named The Landscaping and Landscape Development Research Society e.V. (FLL). The FLL offers the most comprehensive guidelines to green roof installations. (Snodgrass & McIntyre, 2010; Weiler & Scholz-Barth, 2009; Werthmann, 2007)

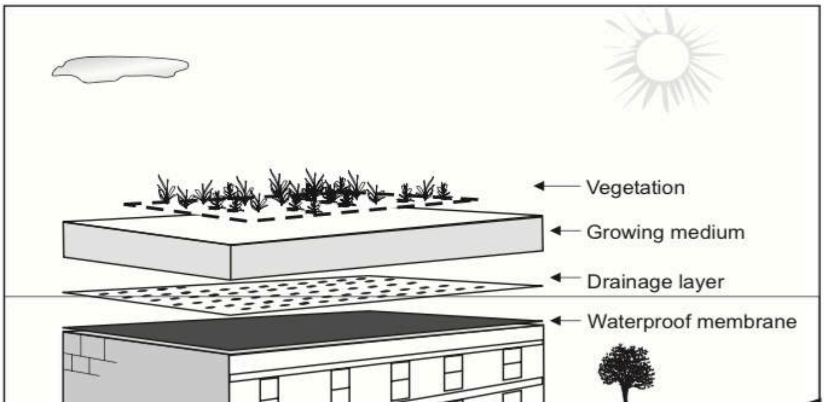
The FLL defines three main types of green roofs: intensive greening, simple intensive greening and extensive greening. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002) These green roof categories are more commonly known in English as intensive green roofs, semi-intensive green roofs and extensive green roofs (see Appendix 3: Green Roof Categories (Cantor, 2008, p. 16), p.111). There is an important distinction concerning the different types of extensive green roofs: Sedum extensive green roofs and biodiverse extensive green roofs. Sedum extensive green roofs are composed of Sedums and an engineered substrate while biodiverse extensive green roofs have a native plants and soil substrate compositions, accompanied with superior biodiversity optimization qualities. (Cotgrave, 2013, p. 83; Shah, 2012, p. 245)

2.1 Green roof layers

A green roof increases a development's vegetation landscape and minimizes a development's impervious surfaces. In the most basic terms, a green roof is a planted roof defined by the objectives and limitations of each particular project. This concept extends from a simple flat roof waterproofing covered with soil and seeds to a parking structure below bushes and trees with irrigation and highly engineered drainage systems. In fact, the most successful green roofs are hardly distinguishable as such because they seamlessly blend in with the landscape. (Werthmann, 2007) All green roofs today are composed with a series of layers that function to sustain plant life and protect the facility waterproofing (see Figure 2 below). (Rosenzweig, Gaffin, & Parshall, 2003)

A typical roof is composed of a concrete slab below a layer of insulation. Additionally, above this is a form of waterproofing which can be a sheeting or spray on material. Green roofs typically have a rubber sheet of waterproofing similar to pond lining above the building's insulation. Above the waterproofing is a root barrier layer used to protect damage from the plant roots. Above the root barrier is a drainage layer that filters, stores and directs infiltrated water. A water retention layer (see Figure 3, below) is optional and is used to retain the moisture and store water for extended dry periods. (Cotgrave, 2013; United States General Services Administration, 2011; Rosenzweig, Gaffin, & Parshall, 2003) Two drainage courses identified in the literature review include natural, course aggregates (e.g. sand, pebbles, shale, etc) and prefabricated synthetcic, dimpled plastic layers. While the granual drainage course materials are heavier than the plastic, they have a tendency to increase the water retention time, delay the peak runoff and help plants grow roots. Alternatively, the lighweight plastic drainage materials can store water for a longer time. (United States General Services Administration, 2011)

Figure 2: Diagram of a green roof system (Rosenzweig, Gaffin, & Parshall, 2003, p. 2)



2.2 Extensive green roofs

An extensive green roof is the simplest green roof design consisting of a shallow substrate and lightweight distribution. Extensive green roofs require little maintenance and are most successful with drought tolerant, wind resistant plants that survive at high temperatures. Extensive green roofs are known to provide the highest economic return on investment. (Snodgrass & McIntyre, 2010, p. 22; United States General Services Administration, 2011) The FLL considers everything below 10cm to be an extensive green roof and this is the only type of green roof that hosts **only** herbaceous, or non-woody plants. An extensive green roof may be composed of sedum, moss, grass and herbaceous plants. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, p. 35) The shallow root structure of herbaceous plants, mosses, sedums and grasses provide a minimum amount of risk in protecting the waterproofing layer. More than 80% of the green roofs in Germany are extensive and will be the most likely to have widespread implementation in the U.S.A. (Philippi, 2006)

Extensive green roof substrates are sometimes engineered to satisfy minimum weight distribution criteria. (Werthmann, 2007) "Lightweight soil is used to reduce the load on the structure and shallow root system plants are used to form the top layer. These plants need to be durable and easily regenerated to ease the maintenance requirements of the roof " (Cotgrave, 2013, p. 83) Minimizing the total dead load on a roof and maintenance requirements are common considerations for investors in choosing a green roof composed of primarily succulent plant species such as Sedum.

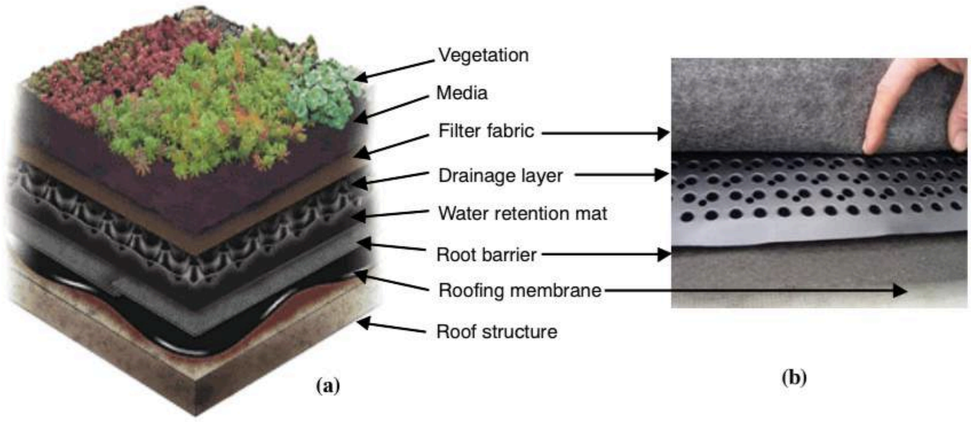


Figure 3: (a) Profile of a typical green roof (graphic courtesy of American Hydrotech, Inc.), and (b) filter fabric, drainage layer, and root barrier. (Hathaway, Hunt, & Jennings, 2008, p. 38) Photo credit American Hydrotech, Inc.

There is currently high interest in the Midwestern United States of America of using native plant species on extensive green roofs to replicate natural prairies. (Durhman , Rowe , & Rugh, 2006) A study in Salt Lake City, Utah, U.S.A., on a 2.5 acre green roof with 1-meter deep substrate identified 21 native grasses and wildflowers that could be used for future studies. However, this green roof was irrigated twice on a weekly basis. (Johnson , Kjelgren, & Dewey, 2004) Studies comparing the ability Sedums and native herbaceous plants to survive on extensive green have found that all native Sedums tested are ideal for drought tolerant conditions on green roofs in North America climate conditions. (Durhman , Rowe , & Rugh, 2006; Monterusso, Rowe, & Rugh, 2005) After a 3 year study on extensive green roofs in Michigan, U.S.A., only 4 out of the 18 native plants could be recommended for use on irrigated extensive green roofs whereas all 9 Sedum species tested were suitable for similar conditions. (Monterusso, Rowe, & Rugh, 2005)

2.2.1 Extensive Sedum green roofs

The most widely adaptable extensive green roof is formed with the Sedum species. The maintenance requirements for Sedum green roofs are typically lowest compared to other green roof options. Sedum leaves store water that can be used as irrigation during periods of drought and will consistently look the same. For extensive green roofs planted with Sedums, the top substrate layer does not necessarily resemble the local soil. “Most of its particles are quite a bit larger than the sand, silt, and clay that comprise soil” (Snodgrass & McIntyre, 2010, p. 52). The substrate layer on an extensive green roof must enable drainage and is composed of more rocks than typical soil found in a local garden or field. The substrate layer of a Sedum extensive green roof should not be composed of primarily organic content. Organic matter has great water retention capabilities but it will quickly decompress which may have negative drainage implications. (Friedrich, 2005)

According to Edmund Snodgrass and Linda McIntyre (2011) green roofs composed of sedum don’t necessarily lack in biodiversity qualities. “Sedum spathulifolium is a host for butterfly species such as the red admiral (*Vaness atalanta*) painted lady (*Vanessa cardui*), and small Apollo (*Parnassius phoebus*)” (Snodgrass & McIntyre, 2010, p. 65). However, the widespread implementation of Sedum green roofs is not always approved.

> Stephan Brenneisen, a Swiss green roof specialist and ecologist, claims that many of the thin substrates on sedum roofs lose their effectiveness over time. Some of the substrates tend to become acidic and do not sufficiently provide minerals and nutrients for the long-term health of the sedum plants. Owners rarely fertilize their sedum roofs on a regular basis and the plants suffer after a couple of years. Brenneisen also found that many sedum roofs have minimal positive effects on storm water retention, energy use, or the urban climate - core arguments that have been used to justify the implementation of green roofs. Moreover, ecologists attribute rather limited biodiversity values to sedum roofs an prefer roofs that offer a secondary habitat to endangered plant and animal species. (Werthmann, 2007, p. 35)

The lightweight sedum roof is a high performance design driven by low-costs resulting in low environmental and ecological qualities. (Werthmann, 2007, p. 32) According to some experts, the biodiversity benefits of green roofs are compromised with Sedum. “It is apparent that the standard extensive Sedum-mat based green roof may have limited biodiversity value compared to other vegetation types because of their limited flowering period and structural diversity” (Dunnett, Nagase, Booth , & Grime, 2008, p. 386) The specific plant species on a green roof is an important consideration for overall environmental and ecological benefits. Contrary to Sedum green roofs, green roofs composed of native plants and substrates are optimal for ecological benefits. While Sedum roofs are typically composed of a shallow substrate of inorganic materials, an extensive green roof with high biodiversity is due to the use of local soil substrates and varying substrate depths. (Brenneisen, 2009)

Studies done in North Carolina (Hathaway, Hunt, & Jennings, 2008) on two sample Sedum green roofs concluded that nitrogen and phosphorus concentrations runoff were significantly higher than a conventional roof and the rainwater itself. These studies surveyed extensive green roofs composed of Sedum species and consisting of plastic drainage mats (see Figure 3 above) and demonstrated the importance of media selection particularly where nutrient removal is a concern. Other studies done in Toronto found a significant amount of phosphorous in green roof storm water runoff. The concentrations of phosphorus measured in the water runoff fell significantly in the second year of monitoring, which suggests that phosphorus is being leached from the growing media. Phosphorus measured in the green roof runoff was considerably higher compared to the same measurements of a conventional roof. Therefore, green roof growing media with high amounts of phosphorous should not be used. (Seters, Rocha, Smith, & MacMillan, 2009)

2.2.2 Biodiverse extensive green roofs

Extensive green roofs designed for a high environmental performance consist of relatively few layers (see Figure 4 below) compared to designs with plastic components. It has been scientifically prove that the overall biodiversity is increased with a varied roof topography or substrate thickness. (Brenneisen, 2009; Gedge, 2003) It is generally understood that the overall affects on biodiversity of a green roof can be attributed to substrate type, depth and composition; plant species (native or non-native) and proximity to existing urban landscape also known as habitat connectivity. (Hui & Chan, 2011) The uniqueness of a biodiverse extensive green roof is that it is naturally seeded and not planted. “This may lead to an inconsistent appearance but have high level of biodiversity” (Cotgrave, 2013). In other words, the roof will be brown until the natural seeding cycle occurs and plants become established.

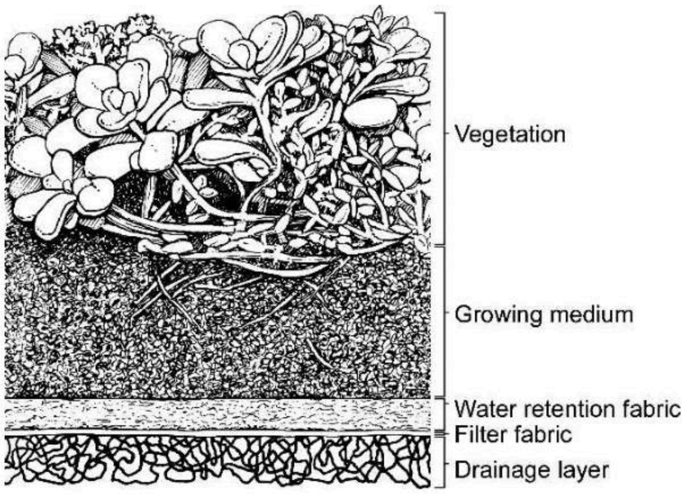


Figure 4: Cross-section of a representative extensive green roof system including typically used layers (Getter & Rowe, 2006, p. 1278)

Roof space provides a significant opportunity for ecological balance. Research in Switzerland (Brenneisen, 2009) concludes that endangered beetles find a secondary habitat on the dry microclimates of biodiverse extensive green roofs in Basel. These findings are consistent with a botanical study on 100 year-old green roofs in Wollishofen, Switzerland (see Figure 5 below) which hosts spider rich meadows, 175 plant species including rare orchids and other endangered species of plants. (Brenneisen, 2009)

Figure 5: High quality biodiverse extensive green roof - Moos water filtration plant

The Moos water filtration plant in Wollishofen was constructed in 1914 as the first reinforced concrete building of Zurich. These 9 acres of green roofs sit atop a sand filtration system that purifies local drinking water. The intention was to prevent the water from overheating in the summer and freezing over in winter. The Moos green roofs now provide a conservatory for many plants that are rare and endangered in Switzerland. (Werthmann, 2007, p. 35) The Moos water filtration plant exemplifies that biodiverse extensive green roofs provide habitats for local flora and fauna to survive amongst urban development.

2.3 Semi-intensive green roofs

A semi-intensive green roof has qualities of both extensive and intensive green roofs and is defined as having a minimum of 12cm of substrate depth. A semi-intensive green roof may host all the plants found on an extensive green roof as well as woody plants, shrubs and coppices. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002; United States General Services Administration, 2011) The noticeable difference is the root structure of woody plants, which need deeper soil to grow. While it is known that forest tree roots systems grow asymmetric they are still not well understood. (Nielsen, M., & Nicoll, 2000, p. 3) Coppice and woody plants come with waterproofing concerns due to the fact that the roots are stronger and may puncture the waterproofing. A semi-intensive green roof can be up to 100cm deep depending on the types of coppices. The FLL recommends that only non-grafted coppices be planted on green roofs. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, pp. 35-52). Coppicing is a widely used strategy in woodland conservation efforts. However, the environmental benefits of coppice management may benefit some species while disfavoring others. (Goldsmith, 1992, p. 307)

2.4 Intensive green roofs

An intensive green roof is defined as having a minimum of 15 centimeters and could potentially host the widest variety of plant species ranging from a recreational lawn to large bushes and trees. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, p. 35) Intensive green roofs can range from accessible lawn areas on a college campus (see Figure 6 below) to park-like landscapes above parking garages and due to the variety of potential plants can also host the most biodiversity. (United States General Services Administration, 2011) Intensive green roofs must be designed specifically for the function of a green roof with a robust drainage system and structural engineering. (Snodgrass & McIntyre, 2010, p. 253; United States General Services Administration, 2011)

The additional space utilization provided by an intensive green roof allows individuals to enjoy a vegetated space in an environment (e.g. an urban city) that may be limited in naturally green spaces. End user accessibility benefits that come with an intensive green roof is different from other green roofs benefits because it maximizes the social enjoyment possibilities. For example, on a hot summer day an office worker may be able to eat lunch outside on the grass, enjoy fresh air and have an improved view.

Figure 6: Intensive green roof at the Technical University of Delft Library, Holland

However, along with the versatility and usability of an intensive green roof comes a higher cost and potential irrigation requirements. (Snodgrass & McIntyre, 2010; United States General Services Administration, 2011) First, there are greater material and engineering costs to consider for additional substrate, structural support and an effective drainage design. Costs for the operations are higher due to the fact that maintenance costs are higher from accessibility issues. Also, there is always a risk of puncturing the waterproofing membrane with maintenance and gardening tools. The greater variety of plant species found on intensive and semi-intensive green roofs must be engineered accordingly. The FLL specifies "where grasses with strong rhizome growth are used, such as bamboo and varieties of Chinese reeds, the structure will need more protection that just a root-penetration barrier. Special arrangements will also have to be made for upkeep" (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, p. 22) Additional maintenance and work hours by facility service providers are one additional cost to be considered for intensive green roofs. Intensive green roofs will not be evaluated in this study due to lack of samples and pricing transparency from intensive green roof material providers.

2.5 Roof Gardens

Global agriculture land resources are shrinking due to rapid development and urbanization. "Today, 15% of the world's food is produced within cities and it is estimated that it has to be at least doubled within the next 20-30 years" (Maksimović, Kurian, & Ardakanian, 2015, p. 18) One solution to this problem is urban agriculture, including roof gardens, aquaponics, hydroponics, container gardening, vertical farming, and other technologies. (United States General Services Administration, 2011; Maksimović, Kurian, & Ardakanian, 2015) Roof gardens are often considered in the context of green roof applications because roof gardens can be an effective way to harvest local and organic produce in urban locations, reducing the associated transportation carbon emissions. Roof gardens are a special case of green roofs with extra environmental and social benefits including the potential to reuse local compost, the creation of new local work and community educational resources. (United States General Services Administration, 2011; Roaf, Horsley, & Gupta, 2004, p. 202; Maksimović, Kurian, & Ardakanian, 2015)

Roof gardens are labor intensive and require constant attention. Typical roof gardens have a substrate depth over 6 inches but some vegetables may need a minimum of 18 inches in order to grow. However, plants such as spinach, kale, lettuce and some herbs have been grown on a roof garden in Toronto, Canada with less than 3 inches of soil. (United States General Services Administration, 2011) The physical labor and additional municipal water required for roof gardens would imply high costs and is not economically evaluated in this study.

2.6 Green Roof Benefits

Green roofs have many economic, environmental and social benefits. (Shah, 2012, p. 245; Kuba, 2012, p. 253; Maksimović, Kurian, & Ardakanian, 2015) A majority of green roof economic benefits are difficult to quantify and therefore a monetary cost benefit analysis considers the increased service life of the roof waterproofing, municipal subsidies, reducing wastewater charges and energy savings. (Schönerman, 2007) Similarly, this research focuses on the economic benefits that can be directly measured and how this affects the LCC of different green roof in Switzerland and Holland. All economically relevant benefits of green roof are discussed below with a distinction between the quantifiable economic benefits used in the NPV calculations. The quantifiable green roof cost saving benefits are further explored in greater detail in the results section of this report, particularly in how they relate to the specific locations of green roofs samples used in the calculations.

Similar to the report done by the United States General Services Administration (2011) the green roof cash flow considerations from urban agriculture, acoustic insulation, job generation and increased productivity are not considered for in NPV calculation. However, these benefits are directly related social and environmental benefits and must remain an important consideration for investors due to their affect on comfort and corporate image, both of which contribute to overall corporate sustainability. Every green roof benefit identified in this research is categorized (see Figure 7 below) according to social, environmental and economic benefits.

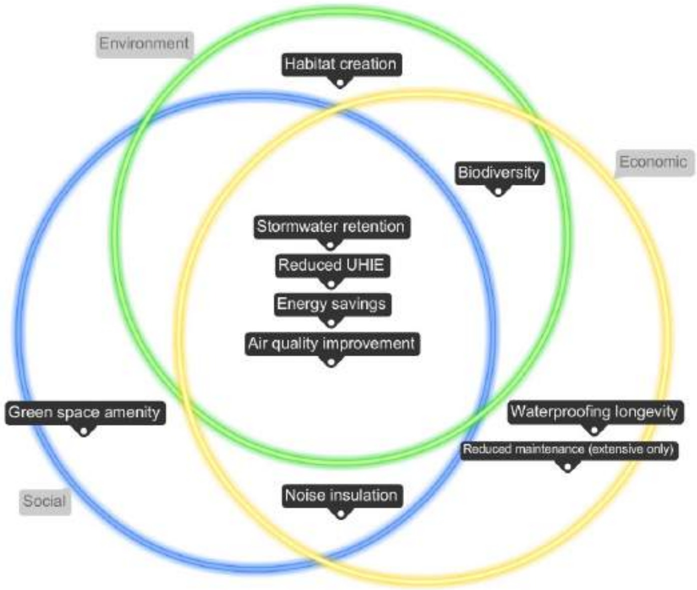


Figure 7: Social, Environmental and Economic Benefits of Green Roofs

2.6.1 Waterproofing Longevity

The substrate layer and plant medium effectively protects the waterproofing from the sun's ultraviolet radiation and extreme thermal fluctuations (United States General Services Administration, 2011; Kuba, 2012). A study by the United States General Services Administration (GSA) determined the average lifetime of a green roof is 40 years (United States General Services Administration, 2011, p. 64). Alternatively, one LCC study of green roofs in Germany estimates the lifetime to be 90 years. (Porsche & Köhler, 2003) The GSA study determined the lifetime longevity of a green roof has the greatest affect on savings while installation and maintenance have the greatest effect on cost. (United States General Services Administration, 2011, p. 113). The average life expectancy of a conventional flat black roof is 25 years. (CRB Schweizerische Zentralstelle für Baurationalisierung, 2012, p. 43)

2.6.2 Energy Savings

Total energy savings from a green roof is a function of the roof surface area, regardless of the building height and is highest on the top floor of a multistory building. (Sailor & Bass, 2014; Theodosiou , 2009) There are many contributing factors to the overall energy savings specific to any green roof including vegetation density, substrate depth, climate, location, utility rates, building age and whether or not the green roof is irrigated. (Sailor & Bass, 2014) Until recently, there has been little research into the detailed impact on energy savings provided by a green roof. As a result of modern technology and building modeling energy simulation software combined with international implementation of green roofs, scientists have had the tools necessary to study this technology more in depth. (Theodosiou , 2009; Sailor & Bass, 2014)

From roughly 2004-2007 researchers at Portland State University and the University of Strathclyde in Glasgow, Scotland independently implemented green roofs into whole building energy simulation software packages including the US Department of Energy's EnergyPlus building simulation tool and The Environmental Services Performance research (ESP-r) building simulation tool respectively. These are highly sophisticated software that require substantial skilled technical knowledge in energy modeling. In 2008 the two departments partnered with the Canada based non-profit organization Green Roofs for Healthy Cities to create a simplified tool that was usable by people with no energy modeling experience.

> The goal was to create a tool that enabled architects, developers, and others to obtain quick estimates of how green roof design decisions might impact building energy se. The result of this effort - the Green Roof Energy Calculator (GREC) has been available on-line since 2011 and is currently in its 2nd version. (Sailor & Bass, 2014, p. 43)

The GREC can analyze potential green roof designs in 100 North American cities and has been validated with multiple field studies. The GREC considers important building properties (residential or office), utility rates (from 2009) and climate zone weather patterns. GREC simulations allow designers to explore key parameters for a green roof's contribution to energy savings, including substrate depth, leaf area index and whether or not the green roof is irrigated. (Sailor & Bass, 2014)

Leaf area index (LAI) and soil depth are particularly important for estimating the energy performance of different green roof designs. LAI represents vegetation density and is a plant specific factor determined by the ratio of vegetation covering a sample area of substrate. LAI values can vary between 1 to 10 for grasses and trees respectively. The LAI of a Sedum extensive green roof would vary from 2 to 4. Soil depth is another important consideration for predicting the energy savings of a green roof. Thicker substrates retain more moisture and better resist heat flow through the roof (Sailor & Bass, 2014) indicating that an intensive green roof with a thicker substrate would have a greater impact on energy savings. Thicker substrates also have the ability to store more water and resist heat flow. (Shah, 2012; Sailor & Bass, 2014) The thermal performance and respective energy savings of a green roof in cold winter climates is relatively small. (Theodosiou , 2009; Shah, 2012) Also, the additional energy savings from thicker substrates does comes with higher initial costs (Greater London Authority, 2008) such as additional engineering and structural support for increased substrate depths.

However, extensive green roofs still can have a positive affect on energy savings, particularly in warm climates. Also, older buildings with poor insulation properties can benefit the most compared to new buildings in terms of energy savings. (Castleton, Stoven, Beck, & Davison, 2010, p. 1582) One case study on a Sedum extensive green roof covering a 50-year old building in Madrid concluded that energy consumption was reduced by only 1%. This study used location based software with historical weather data to model an energy analysis and concluded the savings would be increased with a greater roof to building envelope ratio. (Saiz, Kennedy, Bass, & Pressnail, 2006, p. 4316)

2.6.3 Storm water retention

Green roofs effectively soak up rainwater that would otherwise run off of a conventional roof. An important storm water control objective is to maintain groundwater recharge and evapotranspiration at predevelopment conditions (Water Environment Federation, American Society of Civil Engineers/Environmental & Water Resources Institute, 2012, p. 43) meaning the rain is infiltrated into the earth, some of which gets evaporated and transpired by plants. Although evapotranspiration rates are very difficult to quantify, due to the number of factors involved, it could lead to more effective storm water control. (Water Environment Federation, American Society of Civil Engineers/Environmental & Water Resources Institute, 2012, p. 112)

> Evapotranspiration (ET) is the combination of two processes: evaporation and transpiration. Evaporation is a physical process that involves conversion of liquid water into liquid vapor and then into the atmosphere… Transpiration is a physical process that involves flow of liquid water from the soil (root zone) through the trunk, branches and surface of leaves through the stomates…. The ET depends on four factors: (1) climate, (2) vegetation, (3) water availability in the soil and (4) behavior of stomates" (Goyal, 2014, p. xxi).

The optimal way to promote evapotranspiration is by maintaining undeveloped areas of site vegetation. In cities where this is not an option, "landscaped roofs are one method of evapotranspiring precipitation that would otherwise be converted to runoff" (Water

Environment Federation, American Society of Civil Engineers/Environmental & Water Resources Institute, 2012, p. 112) This one example low-impact development (LID) which is an "approach to managing rainwater runoff that emphasizes on-site natural features to protect water quality, by replicating the natural land cover hydrologic regime of watersheds, and addressing runoff close to its source" (United States Green Building Council, 2014, p. 189). The effects of green roofs on the reduction of rainwater runoff include three properties.

> The reduction consists in: (i) delaying the initial time of runoff due to the absorption of water in the green roof system; (ii) reducing the total runoff by retaining part of the rainfall; (iii) distributing the runoff over a long time period through a relative slow release of the excess water that is temporary stored in the pores of the substrate. (Mentens, Raes, & Hermy, 2006, p. 217)

Intensive green roofs are particularly beneficial in geographic regions that value green roofs for water retention; this strategy can effectively alleviate pubic water systems from excessive storm water runoff, thus reducing government replacement costs. Green roofs are one form of sustainable-drainage systems (SuDS) that effectively absorb, filter and decrease the flow of storm water run off. Compared to a conventional roof, green roofs significantly reduce the total storm water run off volume as well as the flow rates. (Shah, 2012, p. 245)

> Green roofs can reduce the amount of storm water runoff volume to sewer systems by 50 to 90%, resulting in decreased stress on sewer systems at peak flow periods. By comparison, a typical roof will retain 10% of storm water runoff. (Kuba, 2012, p. 258)

A clear distinction is made by FLL between extensive and intensive green roofs when considering water retention qualities. The FLL estimates the annual average water retention for intensive green roofs from 15% to over 50% of annual rainfall. The average water retention for extensive green roofs ranges from 40%-60% of annual rainfall. This analysis is determined from locations with annual rainfall between 650 millimeters-800 millimeters, which have been repeatedly monitored. If the average rainfall is less than this then the retention percentage will be higher and if the average yearly rainfall is more the retention percentage will be lower. Also, the annual coefficient of discharge decreases as the substrate depth increases. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, p. 37) Due to a thicker substrate layer, intensive green roofs are most effective in reducing storm water runoff. (Mentens, Raes, & Hermy, 2006, p. 223; United States General Services Administration, 2011)

Contrarily, studies have concluded that there is a limit to a deeper substrate when considering water retention benefits. “3 to 4 inches (7.5 to 10cm) will usually manage about 80 percent of rainfall from heavy summer storms; going deeper can provide some added benefits, but beyond this point the benefits are often disproportionate to the added costs” (Snodgrass & McIntyre, 2010, pp. 59-60) Deeper substrates could be counterproductive due to the fact that once the substrate becomes saturated it needs to drain before the next storm or will not retain more water. (Gagnes, 2007)

Studies simulating a Japanese typhoon and torrential rainfall patterns were conducted green roof systems with and without a drainage layer to see the effects of various substrate depths on the water retention runoff delay time. The research did not assess the relationship of substrate structure and total retention capacity. The results determined that a green roof without a drainage layer reduced peak runoff more (71.7%) than compared to a green roof with a drainage layer (57.1%). 5 drainage layers of different thicknesses were tested (25mm, 30mm, 40mm, 45mm, 55mm) and the results did not show a direct correlation between substrate thickness and the delay in runoff time or peak runoff volume. (Kikuchi & Koshimizo, 2013)

More importantly, a green roof’s water retention effectiveness is optimized with other multiple-use water services (MUS) (Maksimović, Kurian, & Ardakanian, 2015) also considered to be low-impact development (LID) systems. (Hui S. , 2013, p. 42) MUS and LID systems include infiltration beds, bio-swales, water squares, bio-retention systems, rain gardens, cisterns and more. Multiple-Use Water Services (MUS) effectively synergize urban water infrastructure and vegetated areas to capture and reuse rainwater where it falls. Although rainwater cannot be harvested for consumption it can certainly be stored and reused for grey water purposes such as washing clothes or irrigation. (Maksimović, Kurian, & Ardakanian, 2015)

Holland is leading the way with MUS service innovations and the city of Amsterdam has already started to develop and implement MUS services for a separate sewer which has proven to be cleaner and cheaper than conventional methods. (Maksimović, Kurian, & Ardakanian, 2015) Christoph Maria Ravesloot, a professor of applied sciences at Rotterdam University and INholland University, is focused on key issues that influence green vegetated roof policies and designs concerning technical specifications in general. One of his research questions focuses on technical solutions that will retain the most water for the longest time, or for a selected period of time. In most cases an extra space, under the substrate, has to be constructed to make considerable storage of storm-water of 50 mm within 24 hours possible. By doing so, there is also the potential to release the stored water by any chosen speed during the hours after the heavy rainfall. (Ravesloot, 2014) Green roofs designs for optimal water retention will need to interact with water storage technologies to synergize the respective benefits of natural vegetation combined with water purification and water reuse. (Maksimović, Kurian, & Ardakanian, 2015) Although some companies have begun producing grey water reuse products this is an area of high innovation potential. (Maksimović, Kurian, & Ardakanian, 2015)

2.6.4 Biodiversity and habitat creation

Biodiversity includes species diversity and habitat diversity, which are also the relevant factors when considering the environmental benefits of green roofs. Species diversity refers to one classification level in taxonomy while habitat diversity is used to categorize the different types of places where life exists. (Roaf, Horsley, & Gupta, 2004, p. 154156) A biodiversity crisis has been evolving over the past 30 years in a response to rapid species extinction. These environmental issues have gained increasing attention as particular microclimates have slowly diminished along with the species living there. Habitat diversity and biodiversity are extremely vulnerable to environmental changes such as development and construction. The European Union enforces laws requiring "the recording, conservation and protection of endangered species and habitats, and every country in the European Union has its own related legislation to implement this" (Roaf, Horsley, & Gupta, 2004, p. 158)

In the context of green roofs and biodiversity "natural flora should always be used as this will attract the native fauna into the building surround and supports the local ecosystem" (Cotgrave, 2013, p. 82). Biodiversity relates to monetary aspects of a green roof because a green roof with higher biodiversity will result in lower maintenance costs. (Cantor, 2008) While extensive green roofs composed primarily of sedums don't provide optimal biodiversity benefits, they do result in lower maintenance requirements. (Cotgrave, 2013, p. 84)

The contribution to biodiversity from green roofs is dependent on the plant species, substrate thickness and the respective habitats created. (Brenneisen, 2009) "The best biodiverse roofs support a range of habitats for wildlife through a range of substrates, depths and micro-habitats" (Shah, 2012, p. 246) Providing different rooftop microclimates, such as mounding substrate in concentric circles, increases biodiversity because the temperature and climate varies at different heights. Also, including sand piles can be used to attract bees to further promote biodiversity (Rothenbacker, 2012)

2.6.5 Air quality

Innovative solutions to improve air quality in city environments include increased urban vegetation. Just like plants on the ground, green roofs remove air pollutants such as sulfur oxides, nitrogenous compounds and other particulate matter. (Maksimović, Kurian, & Ardakanian, 2015; Kuba, 2012) Plants remove pollutants that are already in the air "through a dry deposition process and microclimate effects" (Yan, Qian, & Gong, 2008, p. 7266) These findings conclude that green roofs contribute significantly to air quality improvements in a city environment, especially in locations where land is not available for other measures of urban vegetation. (Yan, Qian, & Gong, 2008) Also, plants produce oxygen and reduce carbon dioxide through photosynthesis. (Maksimović, Kurian, & Ardakanian, 2015)

> Until recently, there has been little awareness of the integration of local environmental and air quality issues with building design. This is primarily because little information has been available on how pollutants disperse in urban areas and their subsequent ingress into buildings. (Kukadia & Hall, 2004, p. 11)

The city of Stuttgart located in Germany has mandated green roofs with the motive to increase air quality in the city. Improved air quality can be seen largely as a public benefit, which is highly valued in polluted city environments. Improved air quality has a large health implication leading to higher social wellbeing, decreased asthma related incidents and other health problems. (Mees, 2014, p. 62)

Providing additional green spaces to filter outdoor air should be a high priority for offices, schools and municipal agencies. Considering that most people are indoors 90% of the day, there is increasing concern regarding the negative impacts of external pollutants and the negative impact on human health, well being, productivity and comfort. (Kukadia & Hall, 2004, p. 3). Clearly, green roofs located outside only have limited affect on indoor air quality. However, outdoor air quality can also affect interior air quality, which directly affects building occupants. Air filtration of outdoor air can be done with mechanical systems but this is a very demanding and expensive process. This is why it is more desirable to intake high quality air from outdoors. (Kukadia & Hall, 2004, p. 16). Green roofs are one solution that can help trap particles and clean the air intake zones for building occupants breathing air.

2.6.6 Green space amenity

Green roofs are one component of biophilic design, which provides building occupants with a physical connection to nature. In particular, accessible green roofs provide a relaxing amenity space for building occupants to garden, attend events and better enjoy buildings. (Shah, 2012, p. 246) As a result, a green roof can effectively increase the buildings property value. According to a study conducted by UMass Boston, “green roofs can increase a property’s value by an average of 15%. Green roofs can also facilitate employee recruiting and decrease employee and tenant turnover” (Kuba, 2012, p. 259).

Health care facilities in particular can use accessible green roofs to provide therapy gardens and encourage patients to interact with nature, also known as horticulture therapy. Stress of hospital patients, in particular coronary patients, can increase time to recovery. Coronary patients were seen to greatly benefit through decreased stress levels through various physical interactions with nature. (Wichrowski, Whiteson, Haas, Mola, & Rey, 2005) Likewise, hospital rooms with a view of nature have been proven to “foster improvement in clinical outcomes – such as reducing pain medication intake and shortening hospital stays” to decrease recovery time” (Ulrich, Health Benefits of Gardens in Hospitals, 2002, p. 8)

Biophilia benefits also extend to high stress office environments. The amenity space of a green roof or other vegetation can potentially add value to buildings by improving views. (Shah, 2012, p. 246)

> One study has shown the overall value of $12 per gross square foot in terms of greater productivity and lower absenteeism. Additional research has found office workers are 2.9% more productive when the view out of their windows includes vegetation. (United States General Services Administration, 2011, p. 57)

This particular study has quantified the benefit of viewable nature in the office setting but it does not pertain specifically to green roofs. The cash savings determined by the United States General Services Administration study are not included in the NPV calculation presented here. Significant savings however can be realized if an office setting has a neighboring property with a viewable green roof. This is an example of how green roofs can make a wider social contribution to the general public. (United States General Services Administration, 2011)

These benefits have monetary saving implications because decreased hospital stays results in fewer costs to the patients and higher turnover for the hospital. Also, workplaces with increased employee work/life satisfaction, less turnover and the potential for increased productivity all contribute to economic benefits.

2.6.7 *Urban Heat Island Effect*

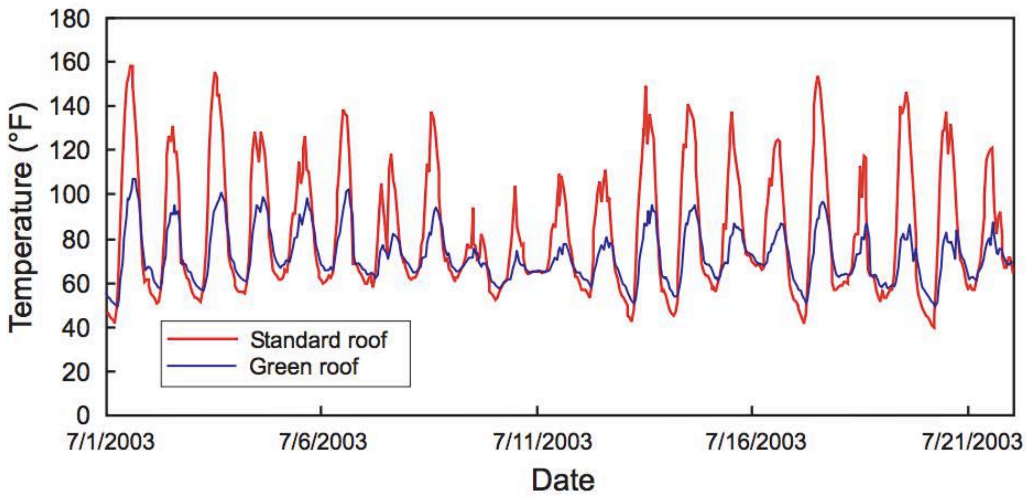
Increased surface and air temperatures, relative to neighboring rural and suburban areas, characterize the Urban Heat Island Effect (UHIE). A heat island is created when vegetated surfaces are replaced with built surfaces, which absorb heat. Vegetated surfaces moderate nearby temperatures by evaporating water from the soil, direct shading and transpiration from plants. (Solecki, Rosenzweig, Cox, Parshall, Rosenthal, & Hodges, 2003) Urban heat islands can be mitigated through the integration of green roofs into dense urban landscapes. (Roaf, Horsley, & Gupta, 2004; Rosenzweig, Gaffin, & Parshall, 2003) Green roofs contribute to a comfortable city environment during periods of extreme heat. Green roofs are highly valued in urban environments prone to high temperatures exacerbated by tremendous amounts of impermeable surfaces (e.g. pavement, concert and metal infrastructure). (Maksimović, Kurian, & Ardakanian, 2015) "These surfaces absorb shortwave solar radiation during the day and re-radiate it as long wave radiation during the night" (Solecki, Rosenzweig, Cox, Parshall, Rosenthal, & Hodges, 2003, p. 15). Vegetated surfaces such as green roofs can potentially reduce outside air temperature and the UHIE through shading, evapotranspiration and increased albedo. In large, dense urban cities (e.g. New York) this is a high social value because it mitigates high heat and ground-level ozone. (Rosenzweig, Gaffin, & Parshall, 2003)

The Pennsylvania State University Center for Green Roof Research measured the surface temperature of Sedum extensive green roofs and 3 conventional dark roofs in central Pennsylvania (see Figure 8 below) with 2 different plant types and 2 different substrate depths. (Gaffin, Parshall, O'Keeffe, Braman, Beattie, & Berghage, 2003) "On average, surface temperatures in July 2003 were 34°F (19° C) higher on the standard roofs during the day and 14°F (8° C) lower at night." (Rosenzweig, Gaffin, & Parshall, 2003, p. iv) Average temperatures for all roofs shown are the average hourly temperature measured on 5-minute intervals. (Gaffin, Parshall, O'Keeffe, Braman, Beattie, & Berghage, 2003)

Green roofs are predicted to be an integral part of helping dense, urban city environments adapt. Unlike plants, which reflect heat, the dark and impermeable surfaces found in urban environments absorb heat from the sun which raises the heat as much as 7° Celsius. (Shah, 2012, p. 246) A study conducted during a warm summer day by the Lawrence Berkeley National Laboratory and United States Environmental Protection Agency measured a 50° Fahrenheit (10° Celsius) difference between a green roof and a black tar roof. (Shah, 2012, p.

249) Besides increasing urban vegetation, another strategy to reduce the increased temperatures of the UHIE is to install highly reflective, light color roofs and paving surfaces. (Solecki, Rosenzweig, Cox, Parshall, Rosenthal, & Hodges, 2003)

Figure 8: Average surface temperature on green roofs and standard roofs at Penn State Center for Green Roof Research (Data provided by Dr. David Beattie.) (Rosenzweig, Gaffin, & Parshall, 2003, p. iv)



However, not all experts agree on the effectiveness of green roofs to reduce the UHIE. Contrarily, the reduction of the UHIE as a result of green roofs has been recorded to be minimal.

> Global warming is associated with both natural gas and the mix of technologies used for electricity generation (coal, oil, etc.), but since the addition of the green roof only significantly changes impacts of the latter, the percentage change in global warming potential is seen to be small. (Saiz, Kennedy, Bass, & Pressnail, 2006, p. 4316)

Increased green vegetation contributes to comfortable and livable city environment by reducing the UHIE through evapotranspiration. (Taha, 1997; Solecki, Rosenzweig, Cox, Parshall, Rosenthal, & Hodges, 2003) This indicates that irrigated roofs would contribute higher than non-irrigated roofs to cooling the surrounding environment. Additionally, roofs that can store more water will have a higher potential contribution to reducing the UHIE during periods of extended drought.

2.6.8 Sound insulation

A green roof provides noticeable sound insulation for the building occupants. For example, the plants and substrate layers absorb the sound of rain dropping on a green roof. “Green roofs have been employed successfully as a means of sound abatement along the new runway approaches at the Frankfurt International airport and Schiphol airport in Amsterdam" (Shah, 2012, p. 246) Experiments done by Hongseok Yang, Minsung Choi and Jian Kang (2010) recorded the potential for green roofs to diffract high frequencies on a single story structure in an urbanized environment. Green roof trays composed of 100mm deep Zinco commercial substrate with low growing vegetation were used to measure the sound pressure levels in a semi-anechoic chamber. Zinco is among the several proprietary green roof systems offered in North America. (Weiler & Scholz-Barth, 2009, p. 184) 4 parameters were considered to evaluate the effects of a green roof on diffracted sound waves, including the total area, position, vegetation type and underlying structure. The study results indicate that green roofs on single story structures are effective at mitigating noise from diffracted sound waves in an urban environment. Noise reduction over 10 decibels (dB) was observed with different surface areas of green roofs suggesting that increasing the green roof area will gradually increase the overall noise reduction. "Overall, it can be concluded that green roof systems on low profiled structures can reduce noise especially at mid and high frequency ranges for diffracted sound waves at human's standing and sitting heights" (Yang, Choi, & Jian, 2010, p. 9) This particular benefit is not highly researched or easily quantifiable but the noise insulation from green roofs can be seen as an overall community benefit that improves living and working conditions

2.7 Green roofs and Facility Management implications

A Facility Manager plays a central role in safely and effectively coordinating the synchronization facility services. In this section, the facility manager is assumed to be an owner's representative for the green roof installation project. In particular, a facility project manager is highly important to delivering a successful green roof installation. Facility project managers must be good at coordinating the many facility services involved in a green roof projects including the architect, landscape architect, building services engineer, horticulturalist, ecologist, soil scientist, roofing consultant and more. (Hui, 2013, p. 59; Weiler & Scholz-Barth, 2009) Coordinating subcontractors and minimizing scheduling conflicts is easier to achieve if the construction manager is fully aware of the scope of work, the irrigation systems required and relevant trades which install them as well as other construction logistics for a green roof project. Clear responsibility delegation and constant project oversight are essential to the green roof project's success. (Weiler & Scholz-Barth, 2009, pp. 203-239) The maintenance requirements of different green roof systems depend on a variety of factors including microclimate, elevation, substrate composition, substrate depth, irrigation, plant types and accessibility. (Hui, 2013, p. 52) Clearly, there is no once size fits all strategy for green roof maintenance and many decisions must be made on a case-by-case basis.

2.7.1 Structural prerequisites

Green roofs are an additional component to the roofing system and must be engineered for structural integrity and waterproofing. Due to the importance of waterproofing, pipes, wires and ducts must never be designed to puncture the watertight membrane. (Hui, 2013, p. 43) Considering that a deeper substrate implies a heavier weight, the relative benefits of intensive and extensive green roof systems must consider the loading capacity of the building and increased costs. In an initial design phase of a new building or renovation, the structural engineer must assess the load of the green roof system. (Weiler & Scholz-Barth, 2009; Kuba, 2012) The particular load requirements for extensive green roofs are “10-50 pounds per square for the entire system when fully saturated with water” (Kuba, 2012, pp. 257-258) while an intensive green roof weighs approximately “80 to 120 pounds per square foot or more” (Kuba, 2012, p. 258) when fully saturated with water. Another study has reported the loading requirements for green roofs terms of metric units. An extensive green roof composed of a sedum mat weighs between 60-90 kg/m^2. An extensive green roof with a typical substrate layer fully saturated with water weighs between 80-90 kg/m^2. An intensive green roof weighs 200-500 kg/m^2 when fully saturated with water. (Shah, 2012, p. 247)

Flat roofs, or low-sloped roofs are best for installing and maintaining green roofs. Sloped green roofs on the other hand need to reinforce the substrate and vegetation to resist slipping due to the force of gravity. (Weiler & Scholz-Barth, 2009, p. 4) The FLL recommends a minimum of 2% slope for extensive green roof applications and green roofs with a slope less than 2% need to be treated as special structures for drainage purposes. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002) If the roof is sloped more than 16% is will need special reinforcements to keep the plants and substrate from slipping.

2.7.2 Safety and security

Many conventional roofs and green roofs host mechanical, electrical and plumbing equipment and must be accessed by operational staff on a regular basis. Commercial buildings with flat roofs which host plant equipment and are well suited for green roof integration. Accessibility on all roofs must raise safety concerns to prevent injuries from falling. Extensive green roofs do not necessarily require higher levels of maintenance than a conventional roof. Intensive green roofs require higher levels of maintenance due to higher plant species diversity. (Hui, 2013, p. 53)

Particularly in Germany, safety lines and barriers are used to protect maintenance workers from falling from roof heights and must be considered during planning processes. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002, p. 20; Weiler & Scholz-Barth, 2009, p. 301) Also, fire concerns and abatement strategies are required for green roofs which dry up (e.g. grasses, dried up mosses) which could self ignite when the roof temperatures are extremely high. Fire prevention measures on green roofs are required in some cities such as simple precast pavers to be installed at a particular distance to help stop a fire if one should occur. (Weiler & Scholz-Barth, 2009)

Green roofs with public accessibility must have important safety requirements due to its elevated location above ground. If the green roof is publicly accessible it must comply with local laws regarding "occupancy, exiting, lighting, guardrails and barrier free access" (Hui, 2013, p. 63). Facility service workers must also take safety precautions in order to not fall. For example, stairways leading to the roof must have handrails and be non-slippery. Also, dangerous electrical wires should be moved or taken away. (Hui, 2013, p. 46)

2.7.3 Extensive green roof maintenance

Extensive green roofs are composed of vegetation which has adapted to the extreme climate conditions found on a roof such as wind, heat drought and cold and therefore require little means of maintenance and resources. (Shah, 2012, p. 245) For a high quality biodiverse extensive green roof the SFG recommends 75% of the roof area to be covered with at least 20 different indigenous plant species within two years for maintenance purposes. Bare parches that are several square meters must be reseeded. One or two surveys per year should be conducted to keep the gravel strips, roof borders and other roof outlets clear of vegetation. (Schmid, 2007) After substantial project completion and initial maintenance during the contract period, the long-term green roof maintenance is the responsibility of the owner. These services are imperative for the green roof's overall success. Typically, these services are contracted out to facility service providers. These services require a trained eye, including monitoring plant health, irrigation needs, fertilizer needs, weed identification, insect infestations and other potential diseases. A key indicator for plants in distress is a lack of flowers, foliage color change or both. Damaged plants may be a result of drought, excessive water saturation, oxygen deprivation, incompatible substrate compositions, pH imbalances, nutrient depletion, excessive fertilization, root exposure, too much sun exposure and vegetation heave which occurs during free-thaw cycles. (Weiler & Scholz-Barth, 2009, p. 296)

2.7.4 Intensive green roof maintenance

Due to the fact that intensive green roof support systems are highly integrated, it is recommended that intensive green roof maintenance requirements be integrated with the building maintenance program. (Weiler & Scholz-Barth, 2009) Due to the wide variety of intensive green roof designs there is no standard prescription for maintenance schedules. Intensive green roofs have a deeper substrate and can also host wider variety of plants, trees, shrubs, grasses, perennials and annuals. As a result, this implies substantial maintenance input similar to a park setting. (Weiler & Scholz-Barth, 2009; Shah, 2012) For example, "intensive green roofs can require a substantial input of resources – the usual pruning, clipping, watering and weeding as well as irrigation and fertilization" (Shah, 2012, p. 245)

Intensive green roof maintenance is highly specific to each particular roof. In addition to the maintenance requirements for an extensive green roof previously stated, additional maintenance requirements specific to intensive green roofs include regular monitoring of substrate moisture content, organic content, nutrient level and pH levels. If the growing substrate is composed of organic content it is also important to monitor substrate volume loss. Skilled labor is required in order to avoid utility or waterproofing damage. This includes not using sharp tools if the exact subgrade conditions are not known, proper irrigation system adjustments and proper use of herbicides, fertilizers and other cleaning agents. Drainage systems and outlets should be frequently monitored for damaged pipes, to ensure the framing and flashing are leak free, free flow of water from the storm water outlet and to ensure drainage pipes are free of clogs. Changes in programming must be compatible with the design loads, location of utilities, system profile below the surface and the substrate depth. (Weiler & Scholz-Barth, 2009, pp. 305-307)

2.7.5 Conventional roof maintenance

Peter Caplehorn (2012) exemplifies the importance of preventative maintenance of a conventional roof in his book *Whole Life Costing: A New Approach* (2012). According to Caplehorn "no building can survive maintenance-free, especially the roof. The documentation should contain very specific measure, including regular inspections, certainly in the first year, to ensure all is well" (Caplehorn, 2012, p. 37). Caplehorn states the following steps are required for proper preventative maintenance and cleaning schedules of conventional roofs.

- during the first year, inspections should be at a minimum of three months to determine the rate of debris collection on the roof
- subsequently, inspections should be set to suit the roof, typically annually
- each inspection should be recorded with notes and photographs
- these should be copied to the client and the team
- each inspection should trigger clearing and any other work identified (Caplehorn, 2012, p. 37)

Both the green roof and conventional roof maintenance requirements are examples of planned preventative maintenance. All green roofs have 3 typical stages of maintenance regardless of their specifications. First, installation maintenance is required during the first year to irrigate when necessary, pull weeds and replace dead plants. Second, development maintenance is necessary to help the vegetation grow to its full potential but is less time consuming than installation maintenance. Finally, ongoing maintenance is required once or twice annually to remove weeds, inspect drains. Intensive green roof systems necessitate comparatively higher levels of maintenance, which also results in higher operational costs. Roof gardens, which are essentially a rooftop farm, require the most maintenance. (Hui, 2013, pp. 52-53)

2.7.6 Leak detection

A green roof leak may have numerous possible origins but it must be remedied quickly upon detection. "A roof leak may be caused by incorrect roof design, inappropriate selection of materials, or poor quality of the waterproofing installation" (Weiler & Scholz-Barth, 2009, p. 275). Green roof leaks are typically found at locations of noncontiguous membrane coverage (e.g. flashing penetrations at drains, roof perimeters, expansion joints, parapet connections, etc.) and is usually not a problem with the waterproofing membrane itself. (Hui S. , 2013; Weiler & Scholz-Barth, 2009) Facility managers must consider the specific waterproofing compatibility with chemicals used during installation phases (e.g. fertilizers, herbicides, deicing salts, etc.) (Weiler & Scholz-Barth, 2009) Depending on the specific plants species selected for a green roof, a specialist membrane may be required which is designed specifically for root resistance with an additional protection layer (e.g. copper). (Harrison, Trotman, & Saunders, 2009) Green roof warranties from the installer are highly recommended as well as detailed inspections before the warranty ends. Single source green roof contractors are recommended because they are the most likely to ensure their service with a warranty as well provide the crucial maintenance within the first two years. (Hui S. , 2013, pp. 53-60)

2.8 Photovoltaic (PV) panels and green roof combination

Research in the field of green roofs is looking at ways to further optimize space on roofs. Traditional designs may suggest that PV panels and green roofs are exclusive roof components however current research suggests that they may compliment each other. Through direct shading of the solar panels, a higher range of habitats can be found on the green roof. Shaded green roofs have decreased evaporation rates and reduced stress experienced by plants during a drought. Also, the cooling effect of green roofs also cools down the PV panels and increases the efficiency. There are many variables to consider for PV performance. However, an initial study in Germany found a higher PV efficiency of 6% when combined with green roofs. (Köhler, Wiaralla, & Feige, 2007, pp. 1-16)

2.9 Similar green roof LCC studies

A study by Corrie Clark, Peter Adriaens, F. Brian Talbot (2008) economically evaluated green roofs in Ann Arbor, Michigan in the United States of America and determined the NPV of an extensive green roof is 20.3 – 25.2% less than the NPV of a conventional roof. This study attempts quantitatively evaluate 3 green roof benefits of energy savings, storm water fee reductions and air pollution reduction into a discounted Net Present Value calculation over 40 years. (for a detailed discussion of Net Present Value see section 5.1.2) Green roof installation costs and savings were estimated from a case study on 75 roofs on the University of Michigan campus in Ann Arbor, Michigan in the United States of America. Storm water fee reductions were estimated using a local storm water ordinance. Energy savings were calculated by comparing recorded energy costs for 75 campus buildings in 2003, estimates from building energy simulation software and estimating the heat flux through the roof with a 1-dimension heat flux equation. Air pollution benefits were estimated from annual Nitrogen oxide (NO_x) uptake, which was then translated into health benefit cost savings. (Clark, Adriaens, & Talbot, 2008)

Contrarily, a benefit cost analysis of green roofs by Timothy Carter and Anthony Keeler (2008) has determined a NPV of green roofs to be 10-14% more costly than its traditional counterpart. The same cost savings impacts were estimated using a green roof test plot on the University of Georgia and theoretically applied using a benefit cost analysis for replacing all flat roofs with green roofs in The Tanyard Branch watershed located in Athens, Georgia. Both studies attempt to quantify the environmental benefits (storm water retention, air purification and energy savings) over the 40-year life expectancy of extensive green roofs. The estimated health benefits from green roof air purification is a social benefit, not a direct cost saving for the building owner and is not included as an economic saving in the LCC research presented here.

Other green roof LCC studies confirm the long-term economic benefits of green roofs. A study by Ulrich Porsche and Manfred Köhler (2003) compared green roof LCC in Germany, the U.S.A. and Brazil. According to this report, an extensive green roof without PVC-products are more expensive in the initial construction costs compared to extensive green roofs with PVC products. The reasoning for this is not transparent. Also, this particular report considers a green roof lifespan to be 90 years and claims that the biodiversity benefits for an extensive green roofs and an intensive green roof are the same, which is inconsistent with the rest of the literature review. Also, the study reports the lifecycle costs in $/m [dollar per meter] as opposed to other LCC studies which report costs in terms of meter squared ($\$/m^2$). (Porsche & Köhler, 2003, pp. 462-466) Therefore, these results are not directly comparable to the results in the study presented here. In an effort to develop an accurate, standardized and transparent LCC methodology for green roofs, this study presents a proposed LCC structure for green roofs in the form of a NPV calculation spread sheet which only considers direct monetary costs and savings over a 50 year time period. (see Table 3, page 60.)

3 Switzerland and Holland literature review

Both Switzerland and Holland are located in within Europe and have special cultural and political influencing factors concerning the use of land. Germany is another European country with a long history of maximizing green space in urban environments. “A study of 25 large German towns concluded that in nearly all cities 40% of the urban surface are covered and sealed [with green space] and in some cities even 50%.” (Porsche & Köhler, 2003, p. 463) Land use ethics is a priority for the European Union, having an imperative influence vegetated roofs.

> Land use is No. 9 on the European Union’s common indicators list, although the other nine indicators each include issues relating to land use… The indicator says: ‘A sustainable city is one that enhances the efficiency of land use within its territory, protects highly valued un-built land, biodiversity value and green areas from development and restores contaminated and derelict land [brownfield sites]. Most cities and urban-regional authorities implement policies aimed at increasing urban densities through targeted development. There is also a wide range of policies at all levels for protecting sits with agricultural, landscape and ecological value and able to sustain biodiversity’ (Roaf, Horsley, & Gupta, 2004).

Although Switzerland is not a part of the European Union, it is located in central Europe and exemplifies the same attitude towards the high priority of biodiversity. In Europe, the promotion of biodiversity is a top priority when considering the best development strategies. This helps explain the position Switzerland has with imposing biodiverse green roof mandates in major German speaking cities.

3.1 Switzerland Literature Review

Green roofs in Switzerland have been popular dating back to the 1970s with pilot projects beginning in the 1980s.

> At that time, the main drivers for creating them were that they delivered energy savings (less winter heating), promoted health, well being and ‘ecological construction’, and reduced storm water runoff and overheating (Brenneisen, From Pilot to Mainstream: Green roofs in Basel, Switzerland, 2010, p. 1)

Today, the green roof policies in Switzerland aim to maximize native biodiversity. The Swiss Professional Association of Building Greening (Schweizerisch Fachvereingung Gebäudebegrünung - SFG) is a network of green roof professionals committed to promoting green roof policy standards in Switzerland. The SFG awards labels for extensive green roofs based on water retention criteria, a function of substrate depth based on the regional precipitation rates and ecological value. (Brenneisen, SFG- Gründach- Label: Hat Qualität in der Dachbegrünung eine Perspektive?, 2007)

3.1.1 Zurich

Today, biodiverse extensive green roofs are mandated in many major cities in the German speaking part of Switzerland, including Zurich and Basel. These mandates apply to unoccupied, new or renovated flat roofs. (Green Zurich City, 2014) The motive behind green roof municipal policies in Switzerland is to maximize environmental benefits. Ecologist research was highly influential in political agenda to increase pubic awareness on the benefits for green roofs, which also led to quality standards that ensure durable green roofs. (Mees, 2014, p. 62) Vegetation surveys have shown that biodiverse extensive green roofs in Zurich have a range of 330 plant species, 27% of all native plant species occurring in urban areas of Switzerland and 44 of these plant species are endangered. (Tschander, 2007)

The Green Roof Competence Center is located in Wädenwil in the Canton of Zürich at the Zürich University of Applied Sciences (ZHAW) Gruental Campus. This is where Stephan Brenneisen directs green roof biodiversity research. The methodologies developed in Doctoral research by Brenneisen for evaluating the overall biodiversity on Swiss green roofs have been instrumental in guiding Swiss municipal policies. The PhD research by Brenneisen from 2003 was later reformatted in 2009 which is the version cited here. "Brenneisen's work, to date, is the most comprehensive study of green roofs and biodiversity" (Gedge, 2003) The findings of Brenneisen have been instrumental for international green roof biodiversity research. This is particularly true in London, England, where most green roofs sedum mats. The London Biodiversity Partnership have conducted green roof biodiversity research based on scientifically proven methodologies developed by Brenneisen (2009). Studies in the city of London indicate a lower biodiversity value than once perceived attributed on Sedum extensive green roofs. (Gedge, 2003)

3.1.2 Basel

Green roof pilot projects were first seen in Basel in 1970 as ecological approach to construction. The drivers then for green roofs include energy savings, well-being, good health promotion, stormwater retention and temperature moderation. Following the European Union year of Nature conservation in 1995, the first Basel green roof campaign (1996-1998) was initiated with green roof construction subsidies. The first campaign was funded by an "Energy saving fund" which was used by the Basel municipality to subsidize building energy saving measures. Prior to the first green roof campaign approximately 220,000m^2 of green roofs existed in Basel with an additional 80,000m^2 constructed as a result of the first campaign. In 1998 approximately 290,000m^2 of all flat roofs in Basel were green roofs. (Brenneisen, 2010)

By counting the endangered beetles, spiders, other invertebrate and birds on Basel green roof habitats, Brenneisen statistically proved that the overall biodiversity found on green roof is directly related to the substrate thickness. (Brenneisen, 2009; Gedge, 2003) In 2002, the Basel Canton amended the building code (Nature and Landscape Conservation Act **§** 9; Building and Planning Act **§** 72) to require green roofs on all flat roofs. (Brenneisen, 2006) The law was guided by ecological research that proved that using local soils and varying the substrate depth optimizes biodiversity of extensive green roofs. (Brenneisen, 2009) This law requires that all flat, inaccessible roofs over 500m^2 must be biodiverse extensive green roofs composed of native substrates with varying topography. By 2006 approximately 23% of all flat roofs in Basel were green roofs. (Brenneisen, 2006; Brenneisen 2010)

The second green roof campaign in Basel started in 2005 and by 2006 approximately 23% of Basels flat roofs were green roofs. (Brenneisen, 2010) "In Basel the Stadtgärtnerei (urban green department) checks the required architectural roof plan of each new or renovated building, and performs a physical inspection upon completion, taking the quality guidelines into account" (Mees, 2014, p. 60). The benchmarking timeline for the quality standards is over the first 2 years. The focus on maximizing contributions to biodiversity doesn't necessarily sacrifice water storage and retention capabilities of green roofs. Many large green roofs in Switzerland (and Germany) have no rainwater runoff. "In these developments, rainfall is captured on the vegetative roofs, returned to the ground water through infiltration and reused for irrigation, toilet flushing, etc." (Hui S. , 2013, p. 42) Heinz Sigrist is a Swiss construction contractor who specifies green roof designs. His job is to assist the general contractor to determine the proper green roof design but he does not take responsibility of the structural requirements. For example, he may specify the roof drainage layer or if the roof could use a water reservoir. His main concerns are to maintain a system so it is 75% green in 2 years. (Sigrist, 2014)

3.2 Holland Literature Review

Cities in Holland do not have the same consistent goals and measures to incentivize green roof construction. The green roofs evaluated in this research are located in Holland and Amsterdam which both have different political objectives for city-wide green roof installations. Specifically, the municipality in Amsterdam aims to promote holistic sustainable benefits from green roofs while the municipality in Rotterdam focuses on bringing an innovative approach to green roof design in order to maximize water storage benefits.

3.2.1 Amsterdam

Amsterdam is a city in Holland that is invested in promoting green roofs through subsidies although the water retention and storage benefits are not the main focus as it is in Rotterdam. According to Auke Brouwer, an Urban Ecologist in the Urban Planning Department of the city of Amsterdam, green roofs are subsidized in order to improve biodiversity, well being of people as well as water retention benefits. Brouwer is in charge of all the green roof subsidy work and says the city of Amsterdam has not required a specific green roof design to be installed. Some of the seven city districts have their own subsidy program and they have supplementary requirements. “A lot of private owners in Amsterdam did it because it was too hot in the summer and now bedrooms are reportedly more comfortable for sleeping” (Brouwer, 2014). This is in agreement with the 2006 case study on an 8-story building in Madrid, which concludes that “energy consumption for space cooling is a significant factor” (Bass, Saiz, Kennedy, & Pressnail, 2006) as a result of the green roof. Amsterdam city proactively checks the green roof installations in order for building owners to receive their subsidy. This check requires time and man-hours of city employees, which is an expensive issue. (Brouwer, 2014)

The city of Amsterdam and surrounding areas have a recent history of developing methods to effectively integrate the natural environment into the urban landscape. In particular, the IJburg housing development and nature restoration project on the northeastern shores of Amsterdam highlights a celebrated development project. City planners and ecologists worked together to create high quality residences while simultaneously improving water quality and aquatic life ecosystems. The IJburg project has been “the biggest wetland redevelopment undertaking in Europe” (Kinder, 2011, p. 2435) The success is largely due to the way city planners let nature develop on its own.

> IJburg planners are turning city infrastructure into the place where nature is born before emigrating [immigrating] out into the local and continental countryside. And, instead of trying to midwife these nature elements directly through fisheries, nurseries, or total ecosystem construction in one fell swoop, planners are instead looking for infrastructural building techniques that can activate latent hydrological,

> biological, and optical potentialities able to spontaneously create vibrant ecosystems of their own accord. (Kinder, 2011, p. 2448)

Today, the site undergoes rigorous environmental monitoring and reporting that will be used to repeat and further improve these successes of environmental restoration environmental accomplishments. (Kinder, 2011) Similarly in the paradigm of green roofs, biodiversity quality assessment is invaluable evidence that quantifiable ecological gains can be made.

3.2.2 Rotterdam

The delta city of Rotterdam hosts the largest port in Europe and a majority of the city lies below sea level (Molenaar, Aerts , Dircke, & Ikert , 2013, p. 31) with the lowest point at 6.67 meters below sea level. (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013, p. 15) Water enters the city from four directions: the Rhine river, the sea, ground water and rain. (Molenaar, Aerts , Dircke, & Ikert , 2013, p. 34) making it highly vulnerable to climate change. To proactively address climate change issues the municipal board of Rotterdam started the Rotterdam Climate Initiative (RCI) that aims to make the city completely climate resilient by 2025 and reduce $C0_2$ emissions by 50%. (Molenaar , et al., 2010, p. 30)

Rotterdam is innovation oriented when dealing with the effects of climate change by creating solutions to deal with water. To this day, the variable weather patterns have minimally affected the city environment. “However, faced with the uncertain consequences of the changing climate, it is essential that Rotterdam makes itself less vulnerable. Rotterdam must continue adapting to changes in the delta. Doing nothing is not an option! ” (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013, p. 17) From 2007-2012 the Rotterdam Water Plan 2 focused on implementing strategies to address water storage concerns while simultaneously beautifying the Rotterdam city environment. Green roofs and plazas that can temporarily store water during periods of heavy rainfall are preferred methods of the Water Plan 2 to capture and delay storm water runoff. (Bolsius , Karakus, Oosters, van Haersma Buma , & Geluk , 2007, p. 80) The Rotterdam Adaption Strategy (RAS) scheme (see figure 9 below) revolves around sustaining and optimizing the existing delta and water infrastructure. The dike system in Rotterdam is complex, robust and inflexible. Protection of the inner delta being flooded is at the upmost importance because flooding here would be disastrous in terms of mortalities and real estate damage. The main dike system protects the inner dike very well and there is minimal risk of this flooding; however, the Dutch use preventative measures to ensure the dike system is long lasting to protect the city far into the future. (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013, pp. 15-45)

Figure 9: Rotterdam adaption strategy scheme (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013, p. 7)

The RAS uses preventative measures to minimize the negative affects of climate change in a way that will allow the Rotterdam economy to profit from climate changes. This is being done through scenario planning of the potential affects climate change could have on the environment and their respective outcomes, including: rising sea and river levels, heat waves intensifying rainfall, and increased drought periods. (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013, p. 35) As a result of the scenario planning, five likely environmental changes are predicted: outer dike flood protection, inner dike flood protection, extreme rainfall, drought and high temperatures. Green roofs are one small-scale solution that contributes significantly to minimizing the effects of nearly all possible outcomes, particularly the flooding of the delta and inner delta. Green roofs can “limit the flow of water to the outlets and will therefore increase resilience of the water system” (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013, p. 75). Additionally, green roofs support key strategies that address raising climate temperatures which aim to include more vegetated surfaces in the city. Green roofs act as a sponge during extreme rainfall events to retain and reduce runoff rates into the burdened water dikes. In the event of a drought green roofs and green facades acts as an added value by contributing to higher biodiversity in the city. (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013) The Rotterdam Climate Proof (RCP) program started in 2008 as part of the RCI and seeks to adapt to the effects of climate change. As of 2009 the RCP program increased 25,000m^2 of water storage capacity and 20,000 m^2 of increased green roof space in Rotterdam. In 2010 the green roof subsidy program in Rotterdam was continued and aimed at an additional increase of 50,000 m^2 of green roof space (Molenaar , et al., 2010, p. 16).

4 Corporate Sustainability

Corporate sustainability can be thought of as meeting the demands of a firm's stakeholders while simultaneously not compromising the ability to satisfy future stakeholder demands. Conventional sustainability accounts for social, environmental and economic capital. In the business landscape, the theoretical model of corporate sustainability has been expanded to include 6 criteria, including "eco-efficiency, socio-efficiency, eco-effectiveness, socio-effectiveness, sufficiency and eco-effectiveness" (Dyllick & Kai, 2002, p. 130). Corporate social responsibility is defined as the commitment of businesses to contribute to sustainable economic development, working with employees, their families, the local community and society at large to improve their quality of life (Ward, Howard, & Fox, 2002) Corporate social responsibility focuses on the internal functions to enhance workplace well being. Building rating systems aim to achieve this as well as provide corporations, organizations and businesses with an opportunity to visually exemplify a commitment to sustainable development strategies. The Leadership in Energy and Environmental Design version 4 (LEED v4) green building rating system prioritizes environmental benefits and social benefits does not conduct an economic evaluation critical to sustainable investments. (Cotgrave, 2013) The German sustainable building rating system (DGNB) on the other hand does consider economic, social, environmental criteria plus many other modern day sustainable criteria.

Increasing attention focuses on the potential for the landscaping portion of property development projects and how it contributes significantly to an overall sustainability rating. (Cotgrave, 2013) Green roofs in particular, offer the chance for a highly visual and beneficial building component, which contributes positively to building rating systems such as LEED and DGNB. The effects of green BRSs on market prices have been topics of recent research and most studies have concluded a positive correlation of green building rating systems on market prices. However, these studies lack in sample sizes and have not all been through review processes. (McAllister, 2014)

4.1 A business strategy for a green roof

While there are many definitions for the term strategy, it is commonly understood as a business approach to create fit among different business units. (Porter, 1996) Today, this is true for a corporate level strategy, which is effected by external environmental forces, internal capabilities and the values and expectations of stakeholders. (Johnson, Scholes, & Whittington, 2006) Corporations typically have an interest in corporate social responsibility (CSR) to sustain positive relationships with socially conscious stakeholders and for marketing strategies. (Prout,

2006) A focus on key stakeholder relationships should lead a corporation to focus not only on profits but also on relationships. “A corporation that becomes too focused on profits is likely to lose the support and cooperation of key stakeholders, such as suppliers, activist groups, competitors, society, and the government” (Enz, 2010, p. 101) Corporate level strategy concerns the organization’s entire scope and how to add value to different business units. In other words, the corporate level strategy is most important because it guides other strategic decisions. (Johnson, Scholes, & Whittington, 2006) Businesses that place a high value on sustainable agriculture and increasing shareholder value could and should incorporate a green roof into a corporate level strategy. Examples of such businesses could be viticulture, gastronomy, hospitality, outdoor equipment retail and production, landscaping contractors, offices with many nature enthusiasts, etc. A green roof can potentially be integrated in a corporate strategy to gain acceptance from internal and external stakeholders while simultaneously synchronizing business units.

In order to strategically integrate the green roof into a business strategy it must synchronize separate sub units of the business and satisfy stakeholder expectations. The winemaking business provides on example of how a green roof can fit into the strategic agenda. Viticulture is highly dependent on the natural environment and its affect on annual grape crops. Viticulture is also a land development process that inherently disrupts the natural environment. However, the opportunity to incorporate a green roof on the vineyard property (e.g. an office building, tasting room, storage, fermentation facilities) would provide an opportunity to synchronize priorities to provide the highest quality winemaking environment while simultaneously minimize the impact on the environment. Increased biodiversity offered by a biodiverse green roof would be beneficial to vineyards, or any agricultural land in need of local pollinators such as insects and bees. (Weiler & Scholz-Barth, 2009) Also, the green could moderate temperatures of winemaking facilities, wine cellars and ultimately save cooling energy. The design of tasting rooms and public meeting spaces can be incorporated into a green roof to gain stakeholder acceptance through an aesthetically pleasing atmosphere. The green roof does not need to be visible from the ground level in order to make a difference. The green roof could be used as a stakeholder platform to cultivate connections and trust in the community. Alternatively, the green roof could provide a future site for vineyard grape vines. A similar analysis can be done for business with on-site urban farming (e.g. grocery stores, restaurants, hotels, tea gardens, etc.)

4.2 Green roof social benefit implications

Green roofs are one component of biophilic design and are economically evaluated in this study. Biophilia is the concept stating that humans have an innate connection with nature and other living systems (Wilson, 1984). Biophilic design aims to translate this understanding in design to enhance social interaction and well being in the built environment; this approach is considered to be the missing link between low impact development and long-term sustainability (Kellert, 2008). "Surveys of the inhabitants of large cities showed that 70-80% of the population feels itself under provided with green in the neighborhood" (Porsche & Köhler, 2003, p. 463).

In particular, the field of health care has increasing scientific studies focusing on biophilic design affects on health outcomes and stress. This is because several studies have found recovering hospital patients in rooms with a view of nature "can produce substantial and clinically important alleviations of pain" (Ulrich, 2008, p. 94). One significant pioneer project in Basel was the construction of additional clinics at the University of Hospital, all consisting of green roofs. The intent was to provide patients with a quality view of vegetation in order to benefit the recovery process. (Brenneisen, 2010) Additionally, office workers that can view nature from their desk are reported to have less work related frustration, more enthusiasm for their job, higher life satisfaction and overall improved well-being. (Kaplan, 1993).

4.3 Leadership in Energy and Environmental Design version 4 (LEED v4)

The Leadership in Energy and Environmental Design version 4 (LEED v4) Reference Guide for Building Design and Construction (2014) is created by the United States Green Building Council (USGBC) and widely used throughout the United States of America and abroad. According to the LEED v4 Reference Guide for Building Design and Construction (2014) "LEED seeks to optimize the use of natural resources, promote regenerative and restorative strategies, maximize the positive and minimize the negative environmental and human health consequences of the construction industry, and provide high-quality indoor environments for building occupants" (United States Green Building Council, 2014, p. 5). LEED v4 is a green building rating system based on credit criteria that is driven by a social and environmental cost benefit analysis. The credits system allows projects to achieve different levels of LEED certification (Platinum, Gold and Silver). Green roofs have the potential to influence 6 credits for commercial buildings and 9 potential credits in health care facilities for LEED New Construction projects. The LEED v4 certification process aims to promote buildings that are designed to deliver the following seven goals:

- reverse contribution to global climate change

- to enhance individual human health and well-being

-to protect and restore water resources

- to protect, enhance, and restore biodiversity and ecosystem services

- to promote sustainable and regenerative material resources cycles

- to build a greener economy

- to enhance social equity, environmental justice, community health, and quality of life

  (United States Green Building Council, 2014, p. 5)

Through these 7 goals the USGBC aims to guide the construction industry to enhance positive benefits on the environment and social well being while simultaneously mitigating its negative affects on the environment and human health. Out of these seven goals, four are directly associated with the environment, two are directly associated to humanity welfare and one goal (to build a greener economy) is associated with environmental, social and economic issues. However, this particular goal can be interpreted as ambiguous or unclear. An analysis of these goals indicates that environmental issues are the first priority, followed second by social issues. The economic benefits are seen only after the building is occupied. The facility operating costs are claimed to be lower during the operating phase as a result of LEED implementation. (United States Green Building Council, 2014, p. 6)

4.3.1 LEED Credits directly impacted by green roofs

The LEED v4 criteria are lacking in green roof definitions as well as the respective benefits of different designs. The credits that can be discretely impacted by green roofs are discussed (see Table 1, below) to determine the optimal green roof from the LEED v4 perspective. Green roofs have the potential to directly impact 3 of the LEED v4 credits including Sustainable Sites - Site Development (Option 1) Protect or Restore Habitat, Sustainable Site - Open Space and Sustainable Site - Heat Island Effect. Green roofs also affect 3 additional credits although their overall impact on the credit is unclear. These credits include Sustainable Site - Rainwater Management Option 1, Water Efficiency - Outdoor Water Use Reduction and Indoor Environmental Quality - Quality Views.

Table 1: LEED v4 credits directly impacted by green roofs. Adapted from (United States Building Council, 2014)

LEED v4 credit	Intent	Requirements	Value
Sustainable Sites – Site Development (Option 1) Protect or Restore Habitat	Focuses on promoting biodiversity by requiring native or adapted vegetation. (United States Green Building Council, 2014, p. 163)	Preserve and protect from all development and construction activity 40% of the greenfield area on the site (if such areas exist) - AND - (Option 1. On-site restoration) Using native or adapted vegetation, restore 30% (including the building footprint) of all portions of the site identified as previously disturbed. Projects that achieve a density of 1.5 floor-area ratio may include vegetated roof surfaces in this calculation if the plants are native or adapted, provide habitat, and promote biodiversity. Restore all disturbed or compacted soils that will be revegetated within the project's development footprint to meet the following requirements: Soils (imported and in situ) must be reused for functions comparable to their original function. Imported topsoils or soil blends designed to serve as topsoil may not include the following: soils defined regionally by the Natural Resources Conservation Service web soil survey (or local equivalent for projects outside the U.S.) as prime farmland, unique farmland, or farmland of statewide or local importance; or soils from other greenfield sites, unless soils are a byproduct of a construction process. Restored soil must meet the criteria of reference soils in categories 1-3 and meet the criteria of either category 4 or 5: 1. organic matter; 2. compaction; 3.infiltration; soil biological function; and 5. soil chemical	2 points

		characteristics. Projects teams may exclude vegetated landscape areas that are constructed to accommodate rainwater infiltration from the vegetation and soil requirements, provided all such rainwater infiltration areas are treated consistently with SS Credit Rainwater Managements.	
Sustainable Sites - Open Space	To create exterior open space that encourages interaction with the environment, social interaction, passive recreation and physical activities. (United States Green Building Council, 2014, p. 177)	Provide outdoor space greater than or equal to 30% of the total site area (including building footprint). A minimum of 25% of that outdoor space must be vegetated (turf grass does not count as vegetation) or have overhead vegetated canopy. The outdoor space must be physically accessible and be one or more of the following: a pedestrian -oriented paving or turf area with physical site elements that accommodate outdoor social activities; a recreation=oriented paving or turf area with physical site elements that encourage physical activity; a garden space dedicated to community gardens or urban food productions; a preserved or created habitat that meets the criteria of SS Credit Site Development - Protect or Restore Habitat and also includes elements of human interaction.	1 point
Sustainable Sites - Heat Island Effect	To minimize effects on microclimates and human and wildlife habitats by reducing heat islands.	Option 1 - Install a vegetated roof and meet the following criterion:	Option 1: 2 points

	(United States Green Building Council, 2014, p. 197)	$\frac{Area\ nonroof\ measures}{0.5} + \frac{Area\ of\ high\ reflectance\ roof}{0.75} + \frac{Area\ of\ vegetated\ roof}{0.75} \geq Total\ site\ paving\ area + Total\ roof\ area$ Option 2 - Place a minimum of 75% of parking spaces under cover. Any roof used to shade or cover parking must (1) have a three-year aged SRI of at least 32 (if three-year aged value information is not available, use materials with an initial SRI of at least 39 at installation), (2) be a vegetated roof, or (3) be covered by energy generation systems, such as solar thermal collectors, photovoltaics, and wind turbines.	Option 2: 1 point

The Sustainable Site credit Site Development (Option 1) Protect or Restore Habitat focuses on promoting biodiversity by requiring native or adapted vegetation. The Sustainable Site Open Space credit focuses on connecting building occupants with the outdoors by mandating 30% of the footprint (area) to be open space; 25% of this must be vegetated. (United States Green Building Council, 2014, pp. 163-177) Both of these credits have one strict requirement regarding green roofs. A biodiverse green roof satisfies the first credit while an accessible green roof satisfies the second credit, unless an overhead vegetated canopy is used.

The Sustainable Sites credit Heat Island Effect Option 1 is highly dependent on vegetated roofs while Option 2 can be completely satisfied with a vegetated roof. (United States Green Building Council, 2014, pp. 197-202) The credit criteria state that this option is satisfied by a vegetated roof but does not give any specific requirements for irrigation. This is a problem because energy conservation and reduction of the UHIE are enhanced with irrigation.

> This is most important in the case of a green roof for cooling energy conservation, since the evapotranspiration at the soil surface and in the canopy layer is highly dependent on the water availability in the soil layer during hours of heat stress. Dry conditions in summer, which usually occur in eco-roofs, limit the amount of water that

> can evaporate in order to provide the cooling effect. In contrast, regular irrigation can provide the necessary water to promote this process and consequently lead to a more intense passive cooling effect. (Theodosiou , 2009, p. 297)

The difference in counteracting the UHIE with an irrigated green roof and a non-irrigated green roof is due to the fact that evapotranspiration can only take place if water is present. Although an irrigated roof would perform higher for the sake of reducing a heat island, any vegetated roof will satisfy this credit. This means that based on the other two previously mentioned credits, an inaccessible biodiverse extensive green roof merits 2 exclusive points while an accessible green roof merits 1 exclusive point. Additionally, an accessible biodiverse green roof can be used to satisfy both of these credits for all 3 points.

Other LEED v4 credits can also be indirectly influenced by incorporation of green roofs into the building design. However, their overall impact on the credit remains unclear. The Sustainable Site credit Rainwater Management - Option 1 (2-3 points) mandates green infrastructure (GI)[1] and low impact development (LID)[2] designs to reduce rainwater runoff and improve water quality. The point criteria weighs a higher scoring on property areas which retain the most rainfall (United States Green Building Council, 2014, p. 183) which is still a debate within the green roof research community. Some experts conclude rainwater storage indicating preference for an intensive green roof due to the higher capacity to store more water in a thicker substrate. (Mentens, Raes, & Hermy, 2006) Contrarily, some studies suggest that there is a limit to substrate depth and water retention capabilities. (Gagnes, 2007) A green roof should not be expected to capture and retain all rainwater but is more affective when combined with other techniques such as "infiltration beds, rain gardens, bio-retention systems, cisterns and rain barrels" (Hui S. , 2013, p. 42)

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[1] Green infrastructure (GI): a soil- and vegetation based approach to wet weather management that is cost-effective, sustainable, and environmentally friendly. Green infrastructure management approaches and technologies infiltrate, evapotranspire, capture and reuse storm water to maintain or restore natural hydrologies (United States Green Building Council, 2013, p. 189).

[2] Low impact development (LID): an approach to managing to managing rainwater runoff that emphasizes on-site natural features to protect water quality, by replicating the natural land cover hydrologic regime of watersheds, and addressing runoff close to its source. Examples include better site design principles (e.g. minimizing land disturbance, preserving vegetation, minimizing impervious cover), and design practices (e.g. rain gardens, vegetated swales and buffers, permeable pavement, rainwater harvesting, soil amendments). These are engineered practices that may require specialized design assistance (United States Green Building Council, 2013, p.189).

The Water Efficiency credit Outdoor Water Use Reduction (1-2 points) intends to promote a reduction in outdoor water use by requiring no permanent irrigation systems or reducing the project's landscape water requirement (LWR) by a minimum of 50%. (United States Green Building Council, 2014, p. 287). This credit is affected by whether or not the green roof is irrigated and since extensive green roofs are typically not irrigated (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002) it would help satisfy this credit. However, the entire landscaping of the particular project must be assessed to determine an impact of a non-irrigated green roof. The Indoor Environmental Quality credit Quality Views intends to provide end users with a quality view. (United States Green Building Council, 2014, p. 739). To satisfy this requirement all 75% of regularly occupied spaces must provide occupants with direct views of specific criteria, one of which is viewable flora or vegetation. Any green roof design can impact this credit requirement, as long as it is viewable from a regularly occupied space.

The NPV of green roofs on healthcare facilities is beyond the scope of this report due to a limited sample size of hospitals with green roofs. Interestingly, LEED v4 healthcare credits highlight the importance of biophilic architecture in promoting occupant well being. Accessible green roofs can directly earn an additional 2 LEED points and contribute to a total of 4 points for healthcare facilities. The Healthcare specific LEED credits clearly indicate preference for an accessible green roof where hospital patients, visitors and employees can directly experience nature.

4.3.2 LEED Regional Priority

In order to address location based environmental issues, LEED encourages particular credits based on a project's geographic location by offering 4 additional Regional Priority credits for a maximum of 4 points. LEED projects aims to be more transformative if teams recognize their location's priority environmental issues and address them through design, construction, and operation choices. LEED encourages a focus on regional issues through Regional Priority credits, which are normal LEED credits that USGBC volunteers have determined to be especially important for the project in the respective geographic location. (United States Green Building Council, 2014, p. 792) The 6 Regional Priority credits available to a project are determined by USGBC volunteers and can be accessed online. According to this online database of Regional Priority credits: Zurich, Switzerland and Amsterdam, Holland have identical regional priorities. The potential credits to achieve RP credits include: Optimize energy performance, Thermal Comfort, Sensitive Land Protection, Site Development – protect or restore habitat, Rainwater Management and Light Pollution Reduction. (United States Green Building Council, 2014) A green roof has a direct impact on all of these credits except Light Pollution Reduction.

4.4 Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) sustainable rating system

Germany has taken a community wide approach to implement sustainability and storm prevention measures through the use of green roofs. (Roaf, Horsley, & Gupta, 2004, p. 201) In particular, Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) sustainability standards, created by the German Green Building Council is a sustainability rating system for buildings and urban districts which uses a holistic approach to sustainability and integrated energy design. (Faurbjerg, Pedersen, Jensen, & Sorensen, 2013) The design process starts with architectural concepts aiming to achieve holistic sustainable criteria. Architectural concepts are then compared and eliminated depending on energy simulations and project requirements. It is important to note that these sustainability criteria encompass a large range of holistic concepts including “environmental, economic, sociocultural and functional aspects, technology, processes and site” (Church, 2015). Motives behind DGNB urban development strategies are to implement multifunctional components that contribute most to overall sustainability. DGNB Urban Districts (DGNB(UD)) is a design tool that aims to achieve sustainable community development. A green roof is an example of a multi-functional building component and is highly valued in the DGNB(UD) rating system.

> The green roof that results in a high score in the DGNB(UD) criteria concerned with local handling of rainwater, urban microclimate, biodiversity, public squares and access to green areas… The focus on multifunctional solutions that will come out well in many criteria might lead to a tendency towards a set of standard solutions, like green roofs with public access. (Faurbjerg, Pedersen, Jensen, & Sorensen, 2013, p. 62)

The DGNB(UD) building design process considers a wide range of sustainability issues from the conceptual design process. The DGNB(UD) criteria are not directly comparable with the LEED New Construction criteria because it considers development for the entire community.

The DGNB Core 14 standards for individual building projects are applied internationally and can be customized to local regulations. Green roofs are specifically assessed in three different rating categories in the DGNB Core 14 standards. The green roof relevant criteria include: *DGNB Criterion ENV 2.2 Drinking Water Demand* and *Waste Water Volumewhich* contributes to 2.3% of total score (DGNB GmbH, 2014), the *DGNB Criterion ENV 2.3 Land Use* which contributes to 2.3% of total score (DGNB GmbH, 2014) and *DGNB Criterion SOC 1.6 Quality of Outdoor Spaces* which contributes to 0.9% of total score (DGNB GmbH, 2014). These credits make up the potential impact that green roofs can directly or indirectly contribute to the DGNB's overall sustainability rating. The impact of criteria directly influenced by green roofs has a total 5.5% of the total score in the DGNB rating system.

Additionally, the DGNB considers monetary aspects of building concepts and designs. The *DGNB Criterion ECO 1.1 Life Cycle Cost* has an overall 9.6% share of the total score. The Life Cycle Cost component of the DGNB rating system is more than all the previously mentioned criteria combined. Selecting the most economically sustainable building and building components is a very important step in the evaluation of truly sustainable buildings. (DGNB GmbH, 2014) The LCC component is nearly weighted nearly double as compared to water use, land use and the quality of outdoor spaces. In other words, a modern day approach to a sustainability rating system is highly influenced on the costs of a building throughout its lifecycle.

4.5 DGNB and LEED similarities

Preliminary design options in the DGNB sustainable rating system must satisfy strict environmental criteria based on a building's Life Cycle Assessment (LCA). The LCA of each design uses building models to consider many criteria including building layout, building materials, facility operations and other lifetime factors that influence energy consumption. The goal is to reduce the total energy consumption while simultaneously maximizing renewable energy use. This particular criterion uses building models to quantify energy flows and consumption, which can then be compared to baseline standards. (DGNB GmbH, 2013)

LEED also promotes the integration of current technology for energy analysis through computer software. If LEED project teams want to pursue full credit for Energy and Atmosphere credit Optimize Energy Credit they must follow option 1 for the Energy and Atmosphere prerequisite Minimum Energy Performance. This option requires the use of building energy modeling in order to demonstrate a designated percentage improvement over the baseline energy performance. For example, New Construction projects need to demonstrate a 5% improvement over the baseline energy performance prerequisite. This credit option estimates future building energy performance through energy simulations of unregulated loads. (United States Green Building Council, 2014, p. 335)

5 Research Methodology

This study uses life cycle costing (LCC) to evaluate data surveys of 15 green roof properties; 6 of which are located in Holland and 7 of which are located in Switzerland. To calculate LCC of a green roof the additional monetary costs and savings of a green roof are calculated as a NPV by discounting cash flows of a green roof investment. The NPV calculation presented can be used for evaluating many different building component investment options. If the NPV of a particular project is positive then the expected cash flows will exceed the costs. Negative cash flows for a green roof include the additional cost of a green roof compared to a conventional flat black roof. The positive cash flows to consider in this calculation include cost savings when compared to a conventional roof, which include reduced energy consumption, storm water fee reductions and municipal subsidies. For comparison the NPV of a conventional black roof is presented for Switzerland and Holland.

5.1 Life Cycle Costing

Investment decisions in engineering systems are not base the initial costs but rather the sum of costs throughout the product life cycle (e.g. operation, maintenance, logistics, etc.). Life cycle costing (LCC) is a cost estimation and comparison method used to assess alternative investments by considering the entire life cycle of systems. LCC applications are widespread and unstandardized due to the complexity of industrial systems. “No single life cycle cost model has been accepted as a standard model in the industrial sector” (Dhillon, 2010, p. 43). There are many different life cycle costing models used to estimate investment opportunities of all types ranging from building components to industrial system research and development strategies. Regardless of the LCC model is chosen, it must be as accurate as possible or otherwise may lead to serious budget implications. (Dhillon, 2010, p. 43)

One aim of Life Cycle Costing (LCC) for real estate construction is to influence investments in order to reduce future operational costs. According to the British Standards Institution Glossary of Building and Civil Engineering Terms definition, LCC is “a technique for determining the total cost of an asset over its operating life, including acquisition, operation, maintenance, modification and disposal” (Swiss Chapter of International Facilities Management Association, 2011, pp. 25-26). LCC is a tool for evaluating the monetary costs and benefits of a building or building component but does not consider environmental or social costs.

5.1.1 *IFMA Switzerland Life Cycle Cost tool*

The NPV calculation presented in this research is only one piece to the puzzle of a complete LCC methodology. LCC for a building is possible to gain a complete and comparable economical evaluation for different building designs. The LCC tool developed by IFMA Switzerland is in the form of a Microsoft Excel document and is a comprehensive investment tool that considers all elements of a building. According to the IFMA Switzerland eBKP-H standards (2009) an element group such as a roof, is a collection of several related elements. (Swiss Chapter of International Facilities Management Association, 2011, p. 25) The method used for LCC calculations was developed by IFMA Switzerland in conjunction with GEFMA (German Facility Management Association) and is based on international standards (ISO 15686-5(2008)).

> This technical publication targets those professionals active in the real estate life cycle who take investment decisions or are involved in the design and optimization of properties or individual building parts and systems. This target group includes property owners and their agents (e.g. project, asset and property managers), investors, developers, designers, consultants, building contractors (e.g. in the context of public-private partnership tendering), and facility managers. (Swiss Chapter of International Facilities Management Association, 2011, p. 5)

By entering specific product information for a particular future building design, the tool will automatically calculate the total LCC of the building. A lower LCC indicates the preferred option for economic sustainability aspects of the building. “According to ISO 15686-5 (2008), the LCC covers the cost for planning, design, and construction as well as operation and the processes at the end of the life cycle” (Swiss Chapter of International Facilities Management Association, 2011, p. 8). A resulting LCC of any building design is an estimate meant to guide monetary investment decisions.

5.1.2 *Net Present Value*

The NPV method is one form of dynamic LCC analysis that accounts for the effects of time on money over the life cycle of a building or building component. (Swiss Chapter of International Facilities Management Association, 2011, p. 25) A NPV is calculated by estimating all future cash flows of a particular project and discounted back to a one single price relative to the present day. To determine the future cost of a product or service paid today, the present value formula is used. This formula provides the future cost in terms of a particular year. “PV = $\frac{\mathrm{FV}}{(1+\mathrm{I})^t}$ where PV is the present (discounted) value, FV is the future value, I is the interest rate and t is the number of years" (Ainger & Fenner, 2014, p. 297). Another way to think of the present value equation is to multiply the future cash flow by a discount rate. The discount rate would then be $\frac{1}{(1+I)^t}$ and he NPV is then the sum of all PV over the time period in consideration.

The NPV concept can easily be understood by examining the question "If I pay $100 today with the promise of $110 paid back in one year, what is the value for me today?" The cash flows are negative $100 today and positive $110 in one year. The NPV of a $100 investment today, a guaranteed $10 profit in one year with a 4.4% interest rate would be approximately $5.36. This is the amount worth in today's dollar value to make the investment (see Table 2 below). Since green roofs generate savings from municipal subsidies, tax reductions and reduced energy, but no positive cash flows, the resulting NPV is negative. The NPV calculation method presented is used to determine the LCC of green roof properties surveyed in this research. It is important to note that the LCC method is a contributing factor to economic sustainability; there are no considerations in the model for environmental and social benefits.

Table 2: Net Present Value Example

	A	B	C	D
1		Cash Flow	Discount Rate	Present Value
2	Years			
3	0	-100	1	-100
4	1	110	0.95785441	105.363985
5				
6	Net Present Value			5.36398467
7				

The lifetime longevity of an element decreases the LCC, thus improving the resulting calculation. The purpose of a LCC assessment for a building element, such as a conventional roof, aims for monetary investment optimization and optimization of design appraisal. (Swiss Chapter of International Facilities Management Association, 2011, p. 7) "In sum, the NPV method tells us which capital projects to select and how much value they add to the firm" (Parrino R. , Kidwell, David, & Bates, 2014, p. 289) Five–steps to calculating the NPV of a project include:

1. Determine the initial cost of starting the project
2. Estimate the project's future cash flows over its expected life.
3. Determine the riskiness of the project and the appropriate cost of capital

4. Compute the project's NPV
5. Make a decision (Parrino, Kidwell, & Bates, Essentials of Corporate Finance, 2014, p. 291)

Following the 5 steps above, the NPV of a green roof can be calculated based on estimated cash flows. The resulting NPV considers the additional cost premium of adding a green roof installation. This can be visualized as everything above the waterproofing because a conventional roof also consists of a waterproofing layer. Thus, the cash flows include installation costs (materials, labor, etc.), maintenance costs, repair costs, municipal subsidies, storm water tax fee reductions and energy savings. The analysis in this research paper is applicable to all green roof buildings with no discrepancy of occupancy types or market sectors. This project seeks to bring the LCC concept within sustainable real estate to a wider audience and promote future sustainable construction. The NPV determined in this research proposes average life cycle costs expected for green roofs in Switzerland and Holland.

5.2 Real Estate Data Survey

To create a consistent LCC model 7 green roofs in Switzerland and 6 green roofs in Holland, of varying area, substrate depth, plant type and age are documented. Also, both new construction projects and renovated green roofs are evaluated with no discretion to building occupancy type. The data survey considers guidelines for how to measure design and construction costs according to Swiss eBKP-H construction cost classification. The NPV figure for each property is divided by the total area for a single cost per square meter (€/m^2) figure for comparability. Figure 10 (below) shows the range of survey responses in Switzerland and Holland, based on the area of the green roof.

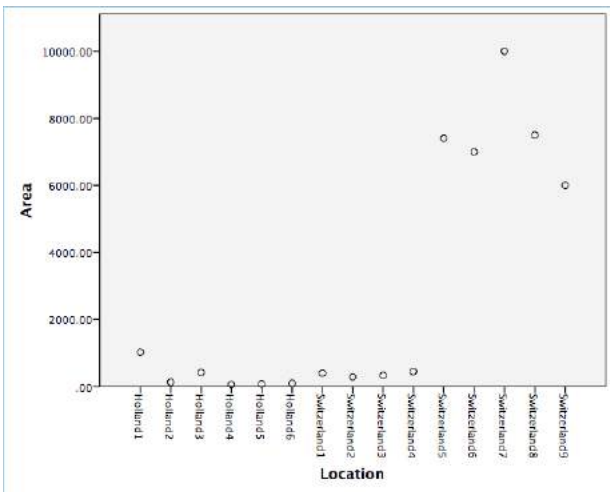


Figure 10: Survey sample area distribution

5.3 NPV survey calculation spreadsheet

The NPV calculation used to evaluate the NPV of every green roof sample in this research is exemplified below (see Table 3 below). The NPV is conducted over a 50 year time period with a discount rate of 4.4%. For the anonymous example presented in Table 3, the initial construction cost for the green roof is 13,000 Euros seen as a negative cash flow in cell B3. The governmental subsidy for this green roof is shown in the same row as a positive cash flow in cell C3. The repair and maintenance costs were determined by the facility manager contact. These negative figures are represented in columns D and E as annual negative cash flows expected after the first year. The energy savings approximation, a calculation determined by the roof area is shown in column F. The discount factor used to approximate the future value these cash flows in today's terms is shown in column H. The total cash flow per year is shown in column I and column J excluding and including energy savings respectively. The sums of column I and column J are shown in cells B57 and B61 respectively. This is the range of cost in today's terms for the 50-year life cycle of a green roof building component in Holland. Cells B58 and B62 show this total is divided by the roof area (m^2) which is a value directly comparable to the calculated NPV of all other green roofs in this study.

Based on a similar study of green roofs by the United States General Services Administration (2011), the green roof NPV was calculated using a 4.4% interest rate over a period of 50 years. (p. 111) A sensitivity analysis is considered by using two different energy savings estimations outlined (see section 7.4, p. 67). This approach provides a range of values for the NPV estimate. Also, for comparable figures between Holland and Switzerland, all NPV figures are presented in Euro currencies. To convert the Swiss NPV figures from Swiss Francs (CHF) to Euros (€), the average of the currency exchange rates over the past 8 years is determined (see section 6.4.1, p. 63). Also, for estimating the conventional roof NPV, the premium costs of labor and material in Switzerland are accounted for with a 6.5% increase (see section 6.4.2, p.63). The influence of green roof municipal incentives and mandates in Holland and Switzerland is used to calculate the location based NPV figures. A comprehensive literature review accompanied with conversations with industry professionals and municipal government agents were used to determine the exact figures used for these cost savings.

Table 3: Proposed green roof LCC structure - Net Present Value calculation in Microsoft Excel

	A	B	C	D	E	F	H	I	J
2	Year	Initial construction	subsidy	repair	maintenance	energy savings	Discount factor	No energy savings Discounted Cash Flow	Discounted cash flow including energy savings
3	0	-13,000	12,600	0	0	0	1	-400	-400
4	1			-400	-700	281.4	0.957854406	-1053.639847	-784.09962
5	2			-400	-700	281.4	0.917485063	-1009.23357	-751.05327
6	3			-400	-700	281.4	0.87881711	-966.6988215	-719.39969
7	4			-400	-700	281.4	0.841778841	-925.9567256	-689.08016
8	5			-400	-700	281.4	0.806301572	-886.9317295	-660.03847
9	6			-400	-700	281.4	0.772319514	-849.551465	-632.22075
10	7			-400	-700	281.4	0.739769649	-813.746614	-605.57543
11	8			-400	-700	281.4	0.708591618	-779.4507797	-580.0531
12	9			-400	-700	281.4	0.678727603	-746.6003637	-555.60642
13	10			-400	-700	281.4	0.650122225	-715.134448	-532.19005
14	11			-400	-700	281.4	0.622722438	-684.994682	-509.76059
15	12			-400	-700	281.4	0.596477431	-656.1251743	-488.27643
16	13			-400	-700	281.4	0.571338536	-628.4723892	-467.69773
17	14			-400	-700	281.4	0.547259134	-601.9850471	-447.98633
18	15			-400	-700	281.4	0.524194573	-576.6140298	-429.10568
19	16			-400	-700	281.4	0.502102081	-552.3122891	-411.02076
20	17			-400	-700	281.4	0.480940691	-529.0347597	-393.69805
21	18			-400	-700	281.4	0.46067116	-506.7382755	-377.10541
22	19			-400	-700	281.4	0.4412559	-485.38149	-361.21208
23	20			-400	-700	281.4	0.422658908	-464.9247988	-345.98858
24	21			-400	-700	281.4	0.404845697	-445.3302671	-331.40669
25	22			-400	-700	281.4	0.387783235	-426.5615585	-317.43936
26	23			-400	-700	281.4	0.37143988	-408.5838683	-304.06069
27	24			-400	-700	281.4	0.355785326	-391.3638585	-291.24587
28	25			-400	-700	281.4	0.340790542	-374.8695963	-278.97114
29	26			-400	-700	281.4	0.326427722	-359.0704945	-267.21373
30	27			-400	-700	281.4	0.312670232	-343.9372553	-255.95185
31	28			-400	-700	281.4	0.299492559	-329.4418154	-245.16461
32	29			-400	-700	281.4	0.286870268	-315.5572945	-234.832
33	30			-400	-700	281.4	0.27477995	-302.2579449	-224.93487
34	31			-400	-700	281.4	0.263199186	-289.5191043	-215.45485
35	32			-400	-700	281.4	0.2521065	-277.3171497	-206.37438
36	33			-400	-700	281.4	0.241481322	-265.6294537	-197.67661
37	34			-400	-700	281.4	0.231303948	-254.4343427	-189.34541
38	35			-400	-700	281.4	0.221555506	-243.7110562	-181.36534
39	36			-400	-700	281.4	0.212217917	-233.439709	-173.72159
40	37			-400	-700	281.4	0.203273867	-223.6012538	-166.39999
41	38			-400	-700	281.4	0.194706769	-214.1774462	-159.38696
42	39			-400	-700	281.4	0.186500737	-205.1508105	-152.6695
43	40		-19454.4	-400	-700	281.4	0.178640553	-3671.849373	-3621.5799
44	41			-400	-700	281.4	0.17111164	-188.2228044	-140.07199
45	42			-400	-700	281.4	0.163900039	-180.2900425	-134.16857
46	43			-400	-700	281.4	0.156992374	-172.6916116	-128.51396
47	44			-400	-700	281.4	0.150375837	-165.4134211	-123.09766
48	45			-400	-700	281.4	0.144038158	-158.4419742	-117.90964
49	46			-400	-700	281.4	0.137967585	-151.7643431	-112.94026
50	47			-400	-700	281.4	0.132152859	-145.3681448	-108.18033
51	48			-400	-700	281.4	0.126583198	-139.241518	-103.62101
52	49			-400	-700	281.4	0.121248274	-133.3731015	-99.253837
53	50			-400	-700	281.4	0.116138194	-127.7520129	-95.070725
54									
55									
56	**No energy savings**								
57	Project NPV	-25971.88993							
58	Project NPV/m2	-61.83783316							
59									
60	**Including energy savings**								
61	Project NPV	-20319.19192							
62	Project NPV/m2	-48.37902838							

6 Data Collection

The data analyzed through life cycle costing in this study was collected from green roof property managers in Switzerland and Holland. Surveys that were returned with missing cost data were estimated using material cost books and professional interviews. The missing cost data exemplifies a common problem faced by professionals that conduct life cycle costing and must consult many different sources for accurate and reliable information. (Dhillon, 2010)

6.1 Data Surveys

In May 2014 the test surveys were sent to 6 green property managers in Switzerland. This was done to ensure the wording and questions asked in the survey would be understood and answerable by facility representatives with access to the data needed. After receiving all responses, the surveys were modified based on the answers provided and sent to green roof property managers in Holland and Switzerland. To be specific about the green roof Life Cycle Cost (LCC), the additional material components of a green roof, separate from a conventional roof are specified in the data survey (see Table 4, page 64). In October 2014 follow up data surveys were sent to the contacts in Switzerland and received responses from 4 out 5 previous respondents. The data survey answers are used to calculate the Net Present Value (NPV) for each green roof sample. All data concerning the green roof facility operator specifics such as respondent's name, organizational name and work position are kept confidential to protect the privacy of respondents.

6.2 Cost approximations

Many of the Switzerland survey respondents did not include initial construction costs. However, Heinz Sigrist (2014) gave the estimation ranges below for determining which was used to approximate the initial construction costs of green roofs in Switzerland. The average costs are as follows:

- Protection and/or drainage layers: 8.5 CHF/m^2
- Substrate: 17.5 CHF/m^2
- Seeds: 4.5 CHF/m^2
- Maintenance work 1 time per year for first 3 years: 4 CHF/m^2 (Sigrist, 2014)

The total sum to 30.5 CHF/m^2 for the initial construction materials costs and 4 CHF/m^2 for the first 3 years; 34.5 CHF/m^2 is also considered for the replacement cost at year 40. The maintenance costs of 4 CHF/m^2 to ensure 75% coverage in 2 years is not required, only recommended by the SFG. However, the maintenance cost component of 12 CHF/m^2 maintenance for three years is included in the initial construction cost cash flow approximation to account for the initial construction labor costs. A total of 46.50 CHF/m^2 is approximated for the initial construction costs of Switzerland survey respondents who didn't answer this particular question. The one respondent from Switzerland who answered the initial construction cost had installed a 400 m^2 green roof for a total 20,000 CHF equaling 50 CHF/ m^2, which provides assurance that the estimation is approximately accurate.

The average decommissioning costs of the waterproofing layer at the end of its lifetime is 45CHF/m^2 and disposal costs to a special landfill equate to 250 CHF/m^3. (Sigrist, 2014) This process is required for a typical roof as well and for proper comparison reasons the disposal and decommissioning costs will not be included in any of the NPV calculations. Only the material costs of 34.50 CHF/m^2 is considered for replacement in year 40 at the end of the green roof life cycle. Based on this analysis, the estimated replacement costs for green roofs in Holland will be done the similarly by converting to the Euro and accounting for the exchange by an increase in labor unit costs for an approximate 46.32 €/m^2.

6.3 Reliability and Validity

A historical statistical record of currencies and average exchange rates are considered in the data analysis to account for fluctuations in the economy. Additionally, an increased materials cost due to the increased cost of goods and labor in Switzerland is justified in the results section and accounted for in the NPV calculations. This research is non-discrimitory to green roof property types and many of the survey responses were returned unidentified.

A key step to ensure data reliability was ensured by translating the survey questionnaires into German (see Appendix 1: German Real Estate Survey, pg. 106) and Dutch (see Appendix 2: Dutch Real Estate Survey, pg. 108). The data received was analyzed first with all samples for location based descriptive statistics. One outlying data point in Holland is identified and removed from the subsequent analysis. This is because the survey respondent included waterproofing and insulation costs in the survey response, which is not consistent with the other survey samples. One extreme outlying data point is identified in Switzerland but no reason is justified for its removal. The subsequent descriptive statistics are presented with the inclusion of this outlying data point and a second time with the removal of the outlying data point. The data analysis assesses the mean NPV including and excluding outlying data point. However, no statistical data tests are evaluated in the analysis due to a limited number of sample sizes. Also, for privacy reasons the respective industries of the green roof samples are not identified.

The price correlation is location specific and more samples are needed in future research. Typically, nonparametric statistical tests are ideal for small samples but they miss differences between groups that may actually exist. Additionally, non-parametric tests are well suited for ordinal and ranked data (Pallant, 2011, p. 213); the data calculated as NPV (€/m^2) is a scale data and there is no current benchmark that can justify price ranges for grouping for different categories.

6.4 Net Present Value Comparison

The NPV values for Holland and Switzerland were calculated using the relative municipal subsidies or tax reductions in the respective countries as of November 2014.

6.4.1 Exchange rates

The exchange rates referenced in this research consider the annual average rate over the past 8 years. The history of monthly exchange rates can be accessed online at The Swiss Statistic Web site (2014). Taking the average of all monthly average exchange rates from January 2008 to September 2014, a total of 81 months, the resulting exchange rate is inferred: 1 CHF = 1.342717 Euros = 0.983495 USD. Using this exchange rate the annual energy savings of 0.5 CHF/m2 from a green roof is converted to 0.67 Euros. (Federal Statistics Office, 2014)

6.4.2 International labor and material cost considerations

For comparison purposes, the NPV of a conventional roof is also calculated in this research to compare with the results of green roof NPV. To calculate a conventional roof NPV in Switzerland and Holland, the German book of material costs Baukosten Bauelemente (2013) is used to calculate material costs. A direct labor cost comparison between Switzerland, Holland and Germany is used to approximate the maintenance and materials costs for standard roofs in the respective countries. This is the cost paid by employers, which includes salary and social security requirements. Switzerland has the third highest cost to employees in Europe at 37.10€/m^2, Germany is fifth at 34.28€/m^2 and the Netherlands are ranked ninth with 32.75€/m^2. (Generis AG, 2012, pg. 70; as cited in Institut der deutschen Wirtschaft, 2009)

Using a ratio calculation based on the highest employer labor unit cost being Norway at 43.64€/m^2 it is determined that employers Switzerland pays 85% of this cost, Germany pays 78.6% of this cost and the Netherlands pay 75% of this cost. (Generis AG, 2012) With this information the flat roof NPV determined from the German construction estimates can be approximated. Switzerland has labor costs 9.98% higher than the Netherlands and 6.5% higher than Germany. To consider the differences in cost for the Netherlands, the NPV is discounted 6.5%. To consider the differences in the material costs in Switzerland, first sums in German values are converted from Euros to Swiss Francs and then increased by 6.5% to account for a labor rate increase.

Table 4: Real Estate Data Survey

Data Questions	Data Type
Company	
Work Position	
Specific work tasks/department	
Roof Age	______________ years
Area	______________ m^2
Average operations cost per year Total costs includes watering, fertilizer, vegetation and other material costs	______________ CHF/year
Average maintenance cost per year Technology repairs (mechanical repairs, plumbing repairs directly associated with reactive and preventative maintenance and labor costs)	______________ CHF/year
Are the above figures calculated with or with out tax?	__________ with tax ___________ without tax
Native or foreign plants?	______________Native ______________Forgeign
Approximate substrate depth (please choose one)	_ 2-6 cm _ 6-10 cm _ 10-15 cm _ 15-25 cm _ 25-60 cm
New construction or renovation? (please choose one)	_______________New _______________Renovation
Initial cost of construction? (Cost includes vegetation, substrate, seeds and labor)	_______________CHF
Has the roof been renovated?	_______________ Yes _________________No
Cost of renovation? Please specify what has been renovated	___________________
Is your green roof accessible by employees or residents?	______________ Yes/No

7 Results

The purpose of this thesis research is to answer the question proposed in the introduction.

How are green roofs defined as successful in Switzerland and Holland and how can these successes be compared in terms of economic costs and benefits?

Therefore, the specific green roof valuations for Switzerland and Holland are detailed below. The exact monetary cost and benefit of green roofs varies depending on specific region and green roof design. For example, the energy saving benefit of green roofs is highly dependent on the climate, location, substrate thickness, vegetation type, utility rates, building age and whether or not the green roof is irrigated. (Sailor & Bass, 2014) Intensive green roofs were not evaluated in this research but do have a higher life cycle cost due to additional material quantities, maintenance requirements and structural implications. Also, intensive green roof material providers were not willing to share cost information. It is important to note that the true monetary cost and benefits of a green roof property is not enough for a strategic investment consideration. Sustainable investments consider economic, social and environmental trade offs and more. The LCC analysis presented of extensive green roof NPV calculations must be used in conjunction with a social cost benefit analysis and environmental cost benefit analysis.

7.1 Waterproofing longevity

The lifetime increase to 40 years for the waterproofing layer is reported to be the greatest cost saving factor of a green roof. (United States General Services Administration, 2011). Similar to other studies, the following cash flow analysis considers a 40 year lifetime of a green roof (Keeler & Carter, 2008) in comparison to a conventional black roof with the average life span of 25 years. (CRB Schweizerische Zentralstelle für Baurationalisierung, 2012) Both locations will be assumed to have the same lifetime expectancy of the waterproofing membrane.

7.2 Storm water fee reductions

One primary motivation for city municipalities to incentivize green roof construction is storm water retention benefits. Rain that falls upon a conventional roof runs to the street and eventually the public sewer system. Rain that falls upon a green roof is absorbed by the vegetation and substrate. The storm water benefit of green roofs alleviates the public sewer systems and effectively reduces replacement costs of public utilities. The exact storm water fee reductions are directly correlated with the size of the green roof and are credited to the green roof property on an annual basis.

7.2.1 Switzerland storm water fee reductions

The Basel Water Protection Act (WPA) took effect January 1, 2001 and reflects charges of dealing with storm water to be paid by real estate property owners. The storm water fees charge property owners to cover the state's cost for construction, operation, maintenance, and replacement of sewer systems. The fees include a cleaning fee (CHF 1.20/m^3) for water discharged to the sewer, and a drainage fee. The drainage fee is composed of two fees; one for the discharge of waste water (CHF 0.75/m^3) and a fee for the derivation of storm water (CHF 0.90/m^2) which includes property area that diverts water directly to the sewer. (Bau- und Verkehrsdepartement des Kantons Basel-Stadt Tiefbauamt, 2012, pp. 2-3) Vegetated roofs directly connected to the sewer system, including extensive and intensive green roofs receive a 50% reduction on the derivation of storm water fee. Therefore, green roof properties in Basel receive an annual savings of 0.45 CHF/m^2. (Bau- und Verkehrsdepartement des Kantons Basel-Stadt Tiefbauamt, 2012, p. 12) Green roof property owners in Bern receive a 10% - 50% reduction in sewage charges resulting in an annual savings of 0.10 CHF/m^2 – 0.50 CHF/m^2. (Schönerman, 2007) An annual savings of 0.45 CHF/m^2 is calculated in the NPV cash flow analysis for green properties in Basel, Bern and those with unspecified locations.

7.2.2 Holland storm water fee reductions

According to John Jacobs, Strategic Advisor for the Water Board in Rotterdam, there is no storm water fee reduction as a cost saving benefit for green roof property owners. (Jacobs, 2014) However, in both Amsterdam and Rotterdam the current green roof plan will end in 2014 and this is possibly the time for a new subsidy program. (Brouwer, 2014; Ravesloot, 2014)

7.3 Municipal Subsidy Programs

Municipal agendas for a one-time subsidy for green roof construction vary depending on location. Regardless, green roof subsidies in Switzerland were offered for a limited time and initiated widespread green roof construction.

7.3.1 Switzerland green roof subsidies

A campaign to increase green roofs in Basel, Switzerland was started in 1996 after it was proven that green roofs provide habitats for regional endangered beetles. The municipality funded 20% of the initial cost for construction or renovation if homeowners installed green roofs on their property and followed specific design guidelines including use of local substrate and native plant seed mixtures. (Brenneisen, The Benefits of Biodiversity from Green Roofs - Key Design Consequences, 1997)

The Canton of Basel initiated a test period for green roof designs starting in the mid-1990s with two subsidy programs. This time worked as a test period for architects and distributors to bring down the costs of green roofs and the government mandate came into effect in 2002 with little resistance. (Brenneisen, From Pilot to Mainstream: Green roofs in Basel, Switzerland, 2010) Minimal resistance to the mandates were achieved through green roof contests, public leaflets, continuous education programs with the Swiss Green Building Council and implementation of a quality standard for green roof suppliers (Mees, 2014, p. 58). These programs were used to jump start green roof construction and today the subsidy program is no longer in affect. Therefore, no discount in the form of a one-time subsidy for construction costs are considered for the Switzerland NPV calculations.

7.3.2 Holland green roof subsidies

The Green Roof Program is the only official program in the official Rotterdam Water Plan. The Green Roof program was implemented in 2008 in the form of a one-time payment of 25€/m^2 for all green roof construction. This subsidy was intended to initiate the Green Roof Program and over 120,000m^2 of green roofs have been constructed under the subsidy and over 200,000m^2 have been completed by the end of 2014. The Green Roof Program was intended to jump start the green roof initiative and would ideally lead to a system in which the positive effects of green roofs are promoted by rewarding owners of real estate which has a green roof installed (e.g. storm water tax reduction for green roof property owners). (Van Roosmalen, 2014)

According to a Strategic Advisor in the Water Department for the city of Rotterdam there is currently a one-time 30€/m^2 subsidy for green roof construction. There is no annual storm water tax reduction for diverting rain from the roof to pervious ground. (Jacobs, 2014) From 2010- 2014 the city of Amsterdam has imposed a one time subsidy between €25 m^2 for small roofs to €50/m^2 to the biggest roof. (Brouwer, 2014)

7.4 Energy Savings

In 1996 the city of Basel aimed to promote green roofs and better flat roof insulation. During this time over 100 green roofs were planted with a total area of approximately 85,000m^2. The estimated energy savings is 4 million kilowatt hours (kwH) or about 0.5 million liters of heating oil. (Mathys, 2007) The energy savings from a green roof cannot be easily generalized considering the many influencing factors. All of the estimations must be site specific in order to consider local energy prices, climate regions and green roof specifications. Several techniques will be briefly discussed below to describe the process to estimate the cost savings of green roofs. All survey respondents maintained extensive green roofs and the energy savings are calculated the same.

7.4.1 Energy Savings option 1 – Modern Insulation technologies

The increased insulation of a green roof is much more effective for old buildings with poor insulation values. However, modern buildings may see hardly any insulation benefits. “Modern buildings, built to the 2006 UK building regulations will have much higher U-Values associated with better roof insulation so green roofs will save no, if very little, energy” (Castleton, Stoven, Beck, & Davison, 2010, p. 1590). This approach would suggest that new buildings built after 2006 will have hardly any added insulation benefit from green roofs. For comparability, the results include a NPV calculation of green roofs in both countries with no energy savings.

7.4.2 Energy Savings option 2 – Energy Savings Calculator

The Green Roof Energy Calculator (GREC) is a comprehensive tool used to estimate energy savings for green roofs. The initial purpose of this tool was to estimate on the effect different green roof designs would have on HVAC loads. GREC module was developed at Portland State University from 2004-2007 and in 2007 became has been an official module of the Energy Plus software. The GREC “represents all aspects of heat transfer and moisture transport in a vegetated canopy… It also accounts for precipitation and irrigation” (Sailor & Bass, 2014, p. 38).

However, there are several limitations of the GREC including the fact that “GREC presents results for only two specific buildings – a 4 story apartment building and a 3-story office building” (Sailor & Bass, 2014, p. 56). The GREC output is highly dependent on location, building type, age, substrate depth, LAI and whether or not the roof is irrigated. The fact that dependent variables include location and LAI the GREC predicted energy savings could not be used for the NPV of green roofs this report. The location possibilities for the report include 100 North American cities; dependent variables are based on historical weather patterns and energy price data. Additionally, the LAI is a measurement that requires on-site evaluation and was beyond the scope of the data survey. (Sailor & Bass, 2014) The GREC is an online database and is a recommendable resource for green roof savings in the United States but was not used for this research.

7.4.3 Energy Savings Option 3 – A rough approximation

Green roof insulation against temperature fluctuations in the environment results in a lower heat loss in the winter and increased cooling during the summer. For this an annual savings of 0.5 CHF/m^2 per year can be used to estimate reduced energy consumption. (Schönerman, 2007) An annual savings of 0.5 CHF/m^2 translates to 0.67 €/m^2 based on the previously mentioned conversion factor (1 CHF = 1.342717 Euros = 0.983495 USD). The results section includes this energy savings potential as one option for the green roof NPV calculation

7.5 Conventional roof NPV

The lifetime of a conventional flat roof skin in Switzerland has an expected lifetime ranging from 15 – 40 years with an average of 25 years. (CRB Schweizerische Zentralstelle für Baurationalisierung, 2012, p. 43) In the NPV cash flow analysis conventional roof will be replaced two times in the 50 years life cycle cost analysis. The materials included consist of everything above the bitumen waterproofing consisting of a vapor barrier, polystyrene foam insulation and a layer of plastic film sealing. The construction materials cost book Baukosten Bauelemente (2013) defines the cost of a flat roof for installation, including labor and materials, ranges from 91€/m^2 – 100€/m^2 with an average of 96€/m^2. (BKI Baukosteninformationszentrum, 2013, p. 499) Based on the previously mentioned conversion factor (1 CHF = 1.342717 Euros = 0.983495 USD) the NPV cash flow calculations for the average installation cost of 96€/m^2 is converted to 71.50 CHF. Accounting for the 6.5% increase in labor unit costs paid by the employer, this sum becomes 76.15 CHF/m^2 for initial labor and material costs of a flat black roof in Switzerland.

With no scheduled maintenance and only installation and replacement costs after 25 years, the NPV of a flat black roof is -102 CHF/m^2 in Switzerland and -128 Euros €/ m^2. This is a strong underestimate for the NPV of a black roof considering that it has no annual maintenance costs and is only replaced after the expected lifetime of 25 years.

7.6 Holland green roof NPV calculation

For Holland, no water tax reduction was included because this is not offered in either Rotterdam or Amsterdam. However, green roofs are subsidized as a one-time payment in both Rotterdam and Amsterdam. Several properties remained private in their responses so a specific location could not be determined. In this case, the one-time subsidy offering in Rotterdam of €30/m^2 was used for the calculation of all five properties that remained confidential about their location. The energy savings in Holland were calculated using the energy savings option 3 of the above mentioned approximation method, annual energy savings of 0.5 CHF/m2 converted to 0.67€/m^2. For comparability, the NPV was also calculated with no energy savings due to the fact that new constructions may have little energy savings resulting from a green roof.

Amsterdam offers a one-time subsidy ranging from €25/m^2-€50/m^2 for big roofs and small roofs respectively (Brouwer, 2014); the exact formula to determine this calculation was not disclosed. The one property respondent located in Amsterdam was a commercial property and had a green roof area over 1,000m^2. The NPV considers this to be a large roof and qualified for the subsidization of €25/m^2 in the NPV calculation.

7.7 Switzerland green roof NPV calculation

For Switzerland, no subsidy for green roofs is offered as of November 2014 but there is an annual water fee reduction for green roofs resulting in a savings of 0.45 CHF/m^2. One survey respondent in Switzerland included sales tax in the cost calculations. For comparison purposes a sales tax of 7.8%, as cited by the Swiss Federal Tax Administration (2014) is used to discount the costs. Between 2004 and 2014 this was the average sales tax in Switzerland. (Trading Economics, 2014)

7.8 Limitations

One important consideration for the result evaluation is the small sample size of responses doesn't provide enough data for a highly accurate data analysis. The scatter plot (Figure 10, pg. 58) shows the responses from Switzerland and Holland and their respective green roof sizes. Overall, a majority of the responses from Switzerland maintained green roofs 6,000m^2 or larger, whereas the responses from Holland maintained green roofs 420m^2 or smaller. This sample size disparity will be addressed in the data analysis section below by first analyzing small green roofs (less than 1000m^2). 2 survey responses from Holland and 3 survey responses from Switzerland indicated no access was permitted to the green roof. Seven responses indicated partial access was permitted to owners and authorized personnel. Three of the responses permitted accessibility to all building occupants, one of which is in Switzerland and two are in Holland. All of these green roofs consist of strictly native plants or a combination of native and foreign plants. Typically, green roofs are considered to be either intensive or extensive. (Snodgrass & McIntyre, 2010, p. 21) All of the green roof samples in this research have substrate 6-15cm thick and are considered extensive green roofs for the analysis. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002)

8 SPSS Statistical Data Analysis

SPSS is popular statistical data analysis software used for quantitative research. For the green roof survey statistical data analysis, the NPV per square meter including the energy savings benefits is analyzed. Two outliers were identified in the sample set by using the Box Plot function in SPSS. Outliers are data points that SPSS considers to be significantly higher or lower than other data points in the sample. "Each distribution score is represented by a box and protruding lines (called whiskers). The length of the box is the variable's interquartile range and contains 50 per cent of the cases." (Pallant, 2011, p. 67) If a data point is 1.5 box lengths away from the box edge then SPSS considers it an outlier. If a data point is 3 box lengths away from the box edge it is considered an extreme outlier. (Pallant, 2011, p. 64) In the Box Plot below, the circle indicates an outlying data point while the asterisk signifies extreme outliers. (Pallant, 2011, p. 79)

8.1 Statistical data analysis approach

Some statistics writers suggest removing the extreme outliers while others suggest changing the value. (Pallant, 2011, p. 64) The statistical data analysis in this research will be presented including all data points and secondly without the outlier. The outlying data point is an inaccessible green roof composed of native plants from Holland. According to the industry contact, the high cost is most likely due to the inclusion of special styrofoam constructions made on the inclined roof as specified by the architect. Unlike the other responses, this sample NPV included insulation and waterproofing costs. For this reason, all final conclusions for Holland, native plants and inaccessible green roofs will **exclude** this data point.

The extreme outlier in Switzerland did not specify a probable reason for the excessively NPV. The outlying data point from Switzerland is an inaccessible green roof composed of native plants. The final conclusions for Switzerland, native plants an inaccessible green roofs will consider a statistical data analysis including the extreme outlier as well as a statistical data analysis excluding the outlier.

8.2 Small roof comparison

There are no outlying data points when comparing only small roofs less than 1,000 m^2 (see figure 11 below). The mean NPV of the nine small green roofs in Holland and Switzerland combined is -98.78€/m^2 with a standard deviation of -52.16€/m^2. The mean of small green roofs in Switzerland is -104.08 €/m^2 with a standard deviation of -60.68 and the mean of small green roofs in Holland is -94.55€/m^2 with a standard deviation of -51.27 (see Appendix 4: Small roof (less than 1000m^2) descriptive statistics, p. 112). However, the median value for Switzerland is less than the median value for small green roofs in Holland, indicated by the black line in the box plot. (Pallant, 2011, p. 79) The mean of large roofs in Switzerland (greater than 1000m^2) is -71.38 €/m^2 with a standard deviation of 16.12. This analysis confirms that the cost per square meter of green roofs decreases with an increase in roof size.

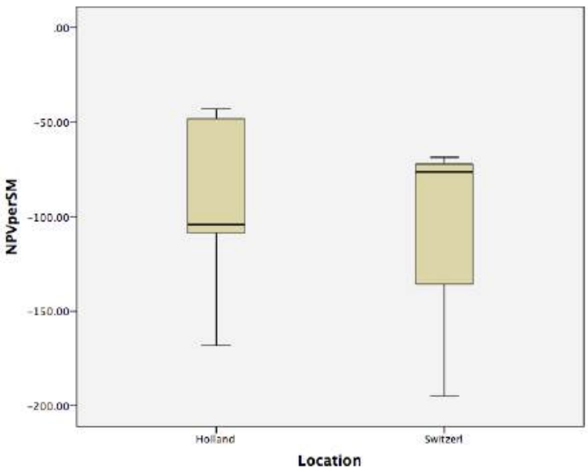


Figure 11: Small roof (less than 1000 m^2) box plot

8.3 Location based descriptive statistics analysis including outliers

A preliminary location based descriptive statistical analysis of the NPV per meter squared (€/m^2) was conducted with all data points included; three separate descriptive statistic analysis were done to consider both countries combined and for each individual location. The box plot (see figure 12 below) indicates one outlier in the Holland data set and one extreme outlier in the Switzerland data set.

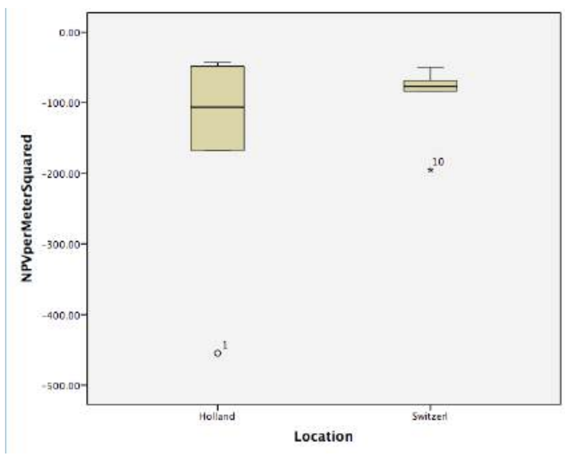


Figure 12: Location based box plot including outlier and extreme outlier

Prior to outlier removal, the mean NPV of green roofs in Holland and Switzerland combined is -113.38€/m^2 with a standard deviation of 103.51. The mean of Holland samples is -154.57€/m^2 with a standard deviation of 154.00 and the mean of Switzerland is -85.92€/m^2 with a standard deviation of 42.51 (see Appendix 5: Location based descriptive statistics prior to outlier removal, p. 113).

8.3.1 Location based outlier removal descriptive statistics excluding outliers

After removing the one outlier from the Holland data set and the one extreme outlier from the Switzerland data set, the mean NPV of both countries is -80.85€/m^2 with a standard deviation of 33.08. The mean NPV of Holland is -94.55€/m^2 with a standard deviation of 51.27 and the mean NPV of Switzerland is -72.29€/m^2 with a standard deviation 12.47 (see Appendix 6: Location based descriptive statistics after outlier removal, p. 114).

8.4 Accessibility based descriptive statistics including outlier

Green roof accessibility contributes to maximizing the social value. As seen in the LEED v4 (2014) green rating system, health care facilities that consist of an accessible green roof are eligible for an additional 2 points. (United States Green Building Council, 2014) A box plot of accessible and inaccessible green roofs in this survey (see Figure 13 below) indicates one outlier in the inaccessible data set. According to a preliminary data analysis, inaccessible green roofs come with a lower NPV. A box plot shows that there is one outlying data point for inaccessible green roofs. The mean NPV of inaccessible green roofs in this study is -85.12€/m^2 with a standard deviation of 42.59. The mean NPV of accessible green roofs is -98.54 €/m^2 with a standard deviation of 52.83 (see Appendix 7: Accessibility based descriptive statistics prior to outlier removal, p. 115).

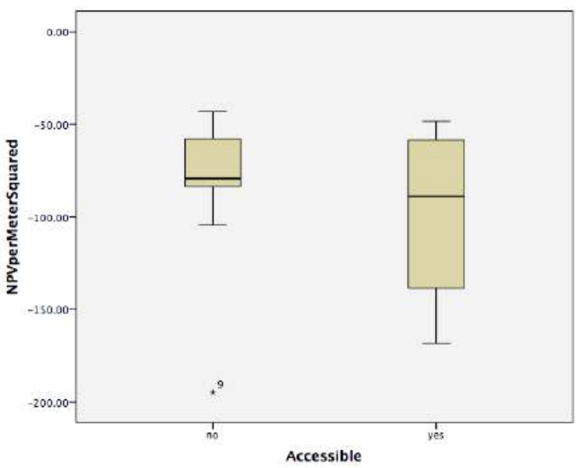


Figure 13: Accessibility based box plot including outlier

8.4.1 *Accessibility based descriptive statistics excluding outliers*

After removing the outlying data point, the mean NPV of inaccessible green roofs is even lower (see Figure 14 below) at -72.99 €/m^2 with a standard deviation of 19.19. The mean of accessible green roofs remains at -98.54 €/m^2 with a standard deviation of 52.83 (see Appendix 8: Accessibility based descriptive statistics after outlier removal, p. 116). These descriptive statistics further confirm that accessible green roofs come with a higher NPV.

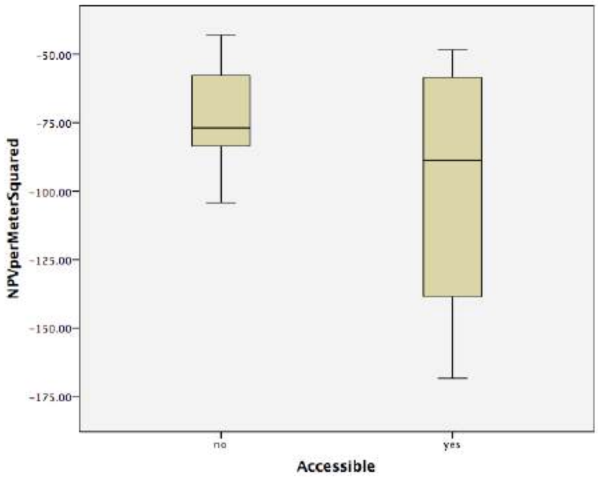


Figure 14: Accessibility based box plot post outlier removal

8.5 Preliminary plant based descriptive statistics including outlier

All green roofs surveyed in this study state the plant palette consists of either native plants or a combination of native plants and foreign plants. There were no roofs consisting of strictly foreign plants. A box plot comparing green roofs with native plants and foreign combined with native plants shows the native plant roofs have one outlying data point (see Figure 15 below). A preliminary statistical data analysis determines that green roofs composed of native plants have a mean of -99.57 €/m^2 with a standard deviation of 53.51. The mean of green roofs consisting of foreign and native plants have a mean of -83.13 €/m^2 with a standard deviation 40.14 (see Appendix 9: Plant based descriptive statistics prior to outlier removal, p. 117).

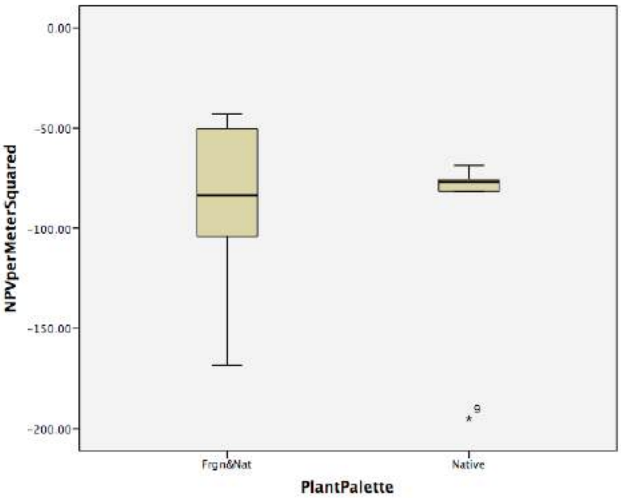


Figure 15: Plant based box plot including extreme outlier

8.5.1 Plant based descriptive statistics excluding outlier

The outlier was then removed from the plant based statistical data analysis and a box plot shows no more outlying data points (see figure 16 below). The resulting mean NPV of green roofs consisting of only native plants is -75.73 €/m^2 with a standard deviation of 5.32. The mean NPV of green roofs consisting of foreign and native plants remains at -83.13 €/m^2 with a standard deviation of 40.14 (see Appendix 10: Plant based descriptive statistics after outlier removal, p. 118). These results agree with the hypothesis that higher biodiversity from native plants results in lower maintenance costs (Cantor, 2008) and thus a lower NPV. However, more samples are needed to conclude that this is correct.

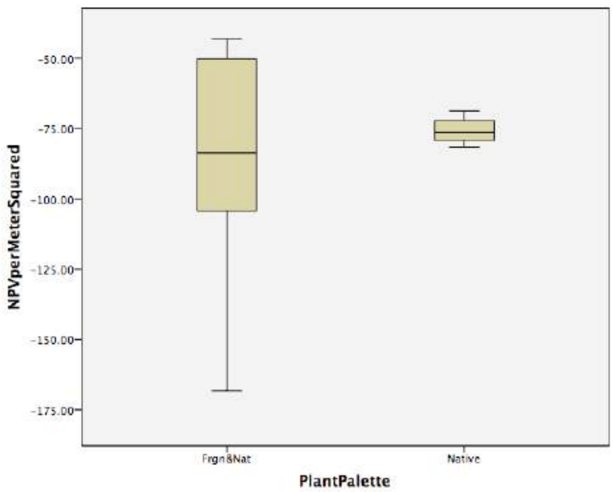


Figure 16: Plant based box plot excluding outlier

9 Future opportunities with new technology

The field of construction and property management is rapidly along with technology. Green roofs are a building component making them intimately tied with emerging trends in building and construction. In this section of the thesis research exploratory techniques are documented for capturing existing building conditions of a green roof and ways to use this information, along with NPV cost data determined from the data analysis. In order to explore opportunities for cost evaluations with modern technologies this research includes a case study Building Information Model (BIM) of a building with an extensive green roof. One modern tool used for extracting the data needed for a complex building's energy analysis is through Building Information Modeling (BIM). BIM is an emerging workflow technology that has been identified as a technique optimizing a building's life cycle phases. Besides the convenience a virtual building model, a BIM contains the data required for energy simulations in a more convenient format than compared to conventional CAD drawings. (Stumpf, Jenicek, & Kim, 2011; Manning & Brew, 2015)

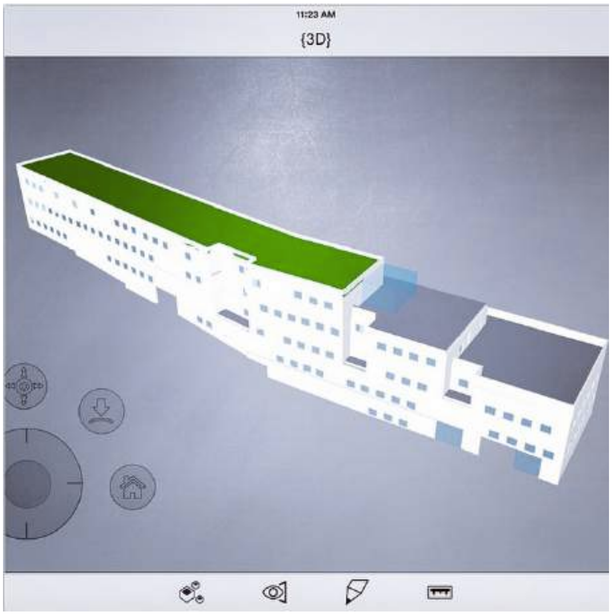


Figure 17: Building Information Model (BIM) of ZHAW RA campus in Wädenswil, Switzerland

9.1 3D Scanning and Building Information Modeling (BIM)

Incorporating BIM in construction and design processes has immediate cost and time saving impacts through the coordination of designers and contractors by facilitating clash detection before they occur on the construction site. Also, it is also important to remember one crucial component of BIM is the **management** of building data throughout the life building's life cycle. (Bell, 2013; Manning & Brew, 2015) BIM applications for green roof management are presented in this study to highlight relevant applications for budgeting maintenance costs and enabling planned preventative maintenance (PPM) roof schedules. This research study exemplifies a BIM green roof application based on the dimensions captured from a 3D scanner. In general, the first step for 3D scanning to BIM projects is a set predefined objectives and level of detail needed. This helps to create a scan plan to minimize costs, time and maximizing client deliverables. (United States General Services Administration, 2009, p. 2)

Life cycle costing (LCC) is one component of a whole life costing (WLC) (see Appendix 11: Definition of Whole-Life Cost per ISO 15686-5 (2008) Swiss Chapter of International Facilities Management, 2011), pg. 119) which is an emerging approach to sustainable construction. For example, one major environmental cost consideration for WLC in the construction industry is the reduction of carbon emissions. Building Information Modeling (BIM) has the potential to enable accurate carbon costing and support many other aspects of WLC. The emergence of BIM has the potential to significantly support WLC throughout a building's life cycle by considering maintenance schedules and resolving design issues prior to the construction phase. (Caplehorn, 2012, pp. 15-126)

The United Kingdom is currently leading the way in terms of BIM mandates and standard development. The U.K. "Government will mandate BIM for all centrally procured Government contracts from 2016" (HM Government, 2013). This mandate aims to help the U. K. achieve 4 lofty goals in the construction sector by 2025 including 50% reduction of time from inception to building completion, 33% decreased costs, 50% decreased emissions and 50% improvement in construction exports. (HM Government, 2013) BIM standards are currently being developed in order to help implement the mandate. Level 2 BIM aims to provide building operators with reliable, current, verified and accessible asset information in the building's construction phase. This will enable building operators to work efficiently and make informed decisions in regards to social, economic and environmental sustainability. The Level 3 BIM extends to the operations throughout building's lifecycle where a majority of costs arise. By achieving Level 3 BIM, building operators can manage services and assets more effectively while minimizing energy consumption and tracking real time efficiencies. (Manning & Brew, 2015) The BIM exemplified in this research is the ZHAW Institute für Facility Management located in Wädenswil, Switzerland, also known as the Seifensträuli. (see Figure 17 above) To create the BIM, the building was first scanned using a FARO Focus 3D X 330 laser scanner (see Appendix 13: Seifensträuli registered point cloud, pg. 121). Next, the scan point clouds were registered using Autodesk Recap software and the respective BIM was developed using Autodesk Revit software (see Appendix 14: Seinfensträuli BIM, p. 122)

3D scanning to BIM is an unstandardized workflow developed in this research to translate a green roof structure's exact dimensions into a convenient, usable 3D model. 3D scanning is one form of 3D imaging that is used to accurately document the built or natural environment. 3D point clouds produced from 3D scanning of existing buildings provide a higher level of detail attainable than compared to conventional methods. The 3D point cloud can then be developed into a BIM to accurately reflect the building's current conditions. 3D scan to BIM workflows have the potential to create accurate, usable models that can be used to plan, track and maintain operation costs. (United States General Services Administration, 2009) This is particularly helpful for property owners that have limited access to building plans or an accurate database for specific building data.

9.2 Green roof BIM application

Building Information Management (BIM) is an emerging technology that can be used throughout the building life cycle; it can be used to optimize building designs and track costs for operations and maintenance. With the use of BIM building operators can track LCC data of a building for cost optimization. A BIM can be continuously updated to estimate lifecycle costs in regards to a specific building component. This is an example of how facility managers can use BIM to schedule preventative maintenance services and optimize building performance. Revit 2015 is one software program identified that can be used for these tasks. (Hore, Kehily, & Woods, 2014) The workflows used to achieve this in regards to green roofs are outlined below.

A BIM can also be simulated for energy analysis as exemplified by the Los Angeles Community College District Building Information Modeling Standards (LACCDS) Version 3.0 (2010, pg.7) which identifies energy simulations and LCC calculations as an integral part to achieving low operation costs and environmental impact for the college's facilities.

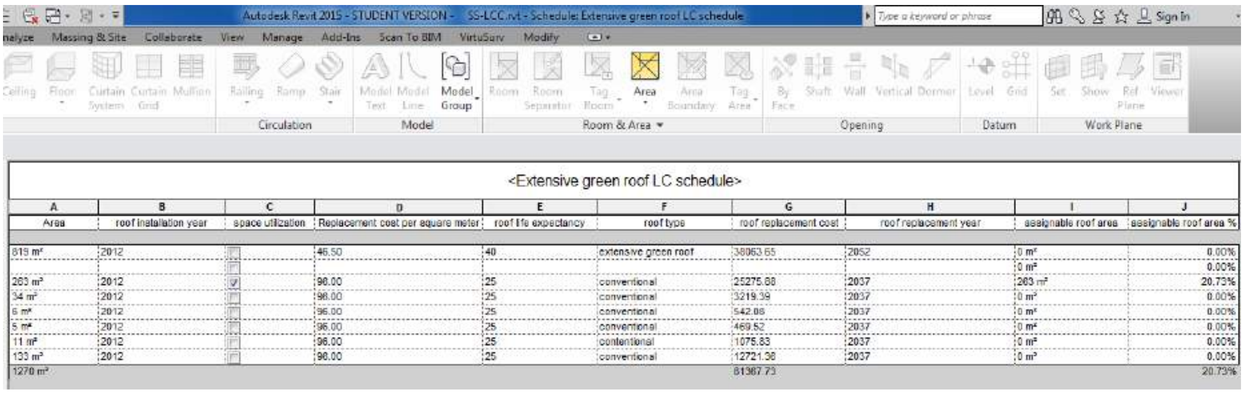
> In order to achieve net zero energy goals for its campuses, all new construction shall need to be designed in a way that energy and material use can be greatly reduced and then measured and verified by a building's users and facilities management teams once it is occupied. As such, energy simulation and life-cycle cost calculations shall be based upon information extracted directly from BIM technology and validated by energy modeling, whole building commissioning requirements and LEED Certification.

This is one example for how BIM can be integrated in a project at early stages in a way that also earns potential LEED credits. However, the inclusion of green roof energy savings in BIM simulation is not so straightforward considering that an insulation factor is not enough to account for a green roof's energy savings. To properly simulate a green roof's energy savings the model must consider many factors including vegetation density, substrate depth, climate, location, utility rates, building age and whether or not the green roof is irrigated. (Sailor & Bass, 2014) This is an emerging area of research necessary to properly estimate the effects of green roofs on energy savings and cost reductions. (Theodosiou , 2009)

9.3 BIM and building component maintenance schedules

Revit 2014 is versatile software developed by Autodesk and is capable of economically evaluating a building over its lifetime. (Hore, Kehily, & Woods, 2014) In the workflow below one technique is exemplified for how it's possible to enter, track and maintain building components using the schedules function within Revit. This particular workflow makes it is possible to create schedules, compare costs and effectively plan preventative maintenance schedules. (Katz, 2011) The extensive green roof schedule (see Table 5 below) can be used to compare the maintenance costs for a building a green roof design and a building with a conventional black roof (see Appendix 12: Conventional Roof Schedule, pg. 120).

Table 5: Extensive green roof schedule programmed in Autodesk Revit



<Extensive green roof LC schedule>

A	B	C	D	E	F	G	H	I	J
Area	roof installation year	space utilization	Replacement cost per square meter	roof life expectancy	roof type	roof replacement cost	roof replacement year	assignable roof area	assignable roof area %
819 m²	2012	☐	46.50	40	extensive green roof	38063.65	2052	0 m²	0.00%
		☐						0 m²	0.00%
263 m²	2012	☑	96.00	25	conventional	25275.88	2037	263 m²	20.73%
34 m²	2012	☐	96.00	25	conventional	3219.39	2037	0 m²	0.00%
6 m²	2012	☐	96.00	25	conventional	542.06	2037	0 m²	0.00%
5 m²	2012	☐	96.00	25	conventional	469.52	2037	0 m²	0.00%
11 m²	2012	☐	96.00	25	contentional	1075.83	2037	0 m²	0.00%
133 m²	2012	☐	96.00	25	conventional	12721.38	2037	0 m²	0.00%
1270 m²						81367.73			20.73%

9.3.1 Autodesk Revit workflow

The workflow below describes the steps to plan and track maintenance costs for an extensive green roof and can be adapted to any specific building component.

- Open existing Revit model

- In the Project Browser window right click 'Schedules/Quantities' and select 'New Schedule/Quantities…'

- Choose data required from the Available fields list and add it to the Schedule Fields list (e.g. Area). In this example for tracking life cycle data it's also necessary to Add Parameters and Calculated Values.

- Click Add Parameter and type ‘roof installation year’ in the Name field; select Common from Discipline drop down menu; select Integer from the Type of Parameter drop down menu. Click OK.

- Click Add Parameter and type ‘material cost per square meter’ in the Name field; select Common from Discipline drop down menu; select Currency from the Type of Parameter drop down menu. Click OK.

- Click Add Parameter and type ‘roof life cycle’ in the Name field; select Common from Discipline drop down menu; select Integer from the Type of Parameter drop down menu. Click OK.

- Click Calculated Value and type ‘roof replacement year’ in the Name field and ‘roof installation year + roof life cycle’ in the Formula field. Click OK.

- Click Calculated Value and type ‘roof replacement cost’ in the Name field and ‘((material cost per square meter)*Area)/1m^2 in the Formula field. Click OK.

This material was originally adapted from material created for Autodesk University Copyright © (2011) Autodesk, Inc. (Katz, 2011).

The workflow described is not a standard software function and must be programmed into Revit as described. The convenience and usability of enabling planned preventative maintenance schedules should not be undermined. Successful green roofs and conventional roofs are not maintenance free and require planned preventative maintenance schedules. The scheduling and notification of maintenance schedules enables maintenance budgeting and improves management with the convenience of a virtual building model. The management processes of BIM are highly effective for complex facilities (e.g. healthcare, sports facilities, museums, etc.). Maintenance requirements, updates, statuses and cost comparisons can be recorded and stored for future assessment.

10 Discussion and Outlook

The thesis research presented focuses on the monetary costs and benefits of green roof systems. The only green roof survey responses evaluated in the Net Present Value (NPV) calculations were extensive green roofs with 6-15 centimeters of substrate. Today, the cost of extensive green roofs in Switzerland and Holland is less than the cost of a conventional flat roof. These findings provide confirmation that extensive green roofs in Switzerland and Holland are economically sustainable.

10.1 Comparing conventional sustainability benefits

Green roofs are an integral component to sustainable construction because they provide an unique opportunity to synchronize social, economic and environmental benefits. The Leadership in Energy and Environmental Design version 4 (LEED v4) green building rating system has integrated green roofs into the rating system due to a variety of environmental and social benefits. A review of the LEED v4 credit criteria concludes that biodiverse extensive green roofs merits 2 exclusive points compared to accessible (typically intensive) green roof which merits 1 exclusive point. However, an accessible biodiverse intensive green roof satisfies both credits and is the most preferred option. (United States Green Building Council, 2014) Alternatively, the DGNB sustainable rating system prioritizes multifunctional building components. In the context of green roofs, this means that the DGNB values intensive green roofs higher than extensive green roofs due to social accessibility. Therefore, the best solution for all green roof designs is an intensive green roof composed of native plant species. This design option optimizes the social and environmental benefits while simultaneously minimizing maintenance costs. One sample roof in Switzerland was an accessible green roof consisting only native plants. The NPV of this accessible green roof is -79.28 €/m^2 which is lower than the average NPV of all green roofs in Switzerland. An accessible green roof composed of native plants is the optimal green roof design and this particular green roof would make an interesting case study for further investigation.

However, not every roof or green roof can be made accessible to the building occupants. With the proper structural integrity and safety precautions an accessible green roof is the most preferred option. For inaccessible flat roofs, biodiverse extensive green roofs are highly preferred due to superior environmental contributions. Furthermore, it may be unrealistic for renovation projects to engineer the structural integrity for accessible green roofs. Although accessible green roofs are highly preferred, biodiverse extensive green roofs are possible in more building design situations and contribute highest to environmental benefits. (Brenneisen, 2009; Tschander, 2007)

The green roof sustainable benefits that contribute to social, environmental and economic benefits (storm water retention, reduced UHIE, energy savings and air quality improvement) are attributable to both extensive and intensive green roofs. The following analysis assumes that extensive and intensive green roofs contribute equally to all of these benefits. However, this is an area of high debate. For example, contrasting reports on water retention between extensive and intensive substrate depths are highlighted in the preceding literature review (see section 2.6.3). Furthermore, in wet climate zones that highly value water retention qualities of a green roof, a water storage system (e.g. a cistern) or other multiple water use services used in conjunction with a green roof is most recommended. (Hui & Chan, 2011; Maksimović, Kurian, & Ardakanian, 2015)

Also, green roof energy savings is highly complex and dependent on existing building conditions. It has been determined that a green roof with a thicker substrate does lead to higher energy savings (Sailor & Bass, 2014). However, the overall energy saving properties of green roofs may be minimal, especially for new buildings with modern insulation. The addition of green roofs on old buildings would have the most impact due to newer and superior insulation technologies available on the market. (Castleton, Stoven, Beck, & Davison, 2010) Incidentally, this has a direct impact on the estimated energy and cost savings provided by green roofs for building owners. For this reason, a range of NPV is given. The lower value includes an estimation approximating energy savings and the higher NPV assumes that green roofs contribute to no energy savings (see section 7.4).

For homes in particular, green roofs have reportedly created a more comfortable living environment as result of thermal insulation. According to Auke Brouwer (2014) who works in the Urban Planning Department in Amsterdam, homeowners in the city of Amsterdam have reported a cooler sleeping environment during hot summer periods as a result of their green roof installations. The addition of green roofs on older homes increases occupant comfort and wellbeing. However, this doesn't necessarily translate to a direct monetary savings. A monetary savings is only seen if the home uses an air conditioning unit or avoids the purchase of an air conditioner as a result of the green roof. In an effort to create a usable tool for rating green roofs, the energy saving benefits as well as other benefits such as air purification and urban heat island reduction are assumed to be satisfied equally by extensive and intensive green roofs.

10.1.1 Biodiverse extensive green roofs

Biodiverse extensive green roofs are composed of native plant species and contribute highly to environmental benefits such as habitat creation and biodiversity. The analysis below applies to extensive green roofs composed of native grasses and herbaceous plants. Due to the fact that extensive green roofs are typically non-accessible the social benefit of a green space amenity is left unchecked (see Figure 18 below). The superior quality of a biodiverse extensive green roof is the potential to maximize the overall biodiversity contribution of an unused roof space.

In order to qualify for maximum credits, several best management practices must be satisfied to ensure the biodiverse extensive green roof's long-term success. First, a biodiverse extensive green roof must be naturally seeded with native herbaceous plants and composed of native substrates. Also, the substrate should be uneven throughout the roof area to ensure maximum biodiversity contributions. For example, concentric ring of substrate mounds can be formed throughout the roof area. Also, a maintenance schedule must be made at the start of the project to account for two annual site inspections. Other necessary maintenance specifications for the first two-year installation phase are detailed in section 2.7.3.

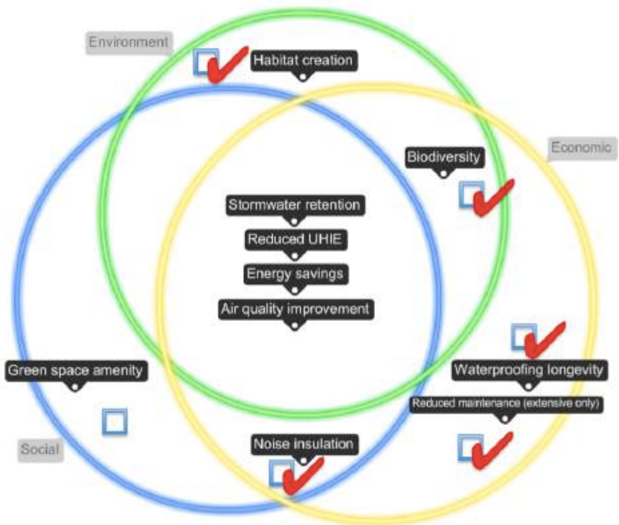


Figure 18: Biodiverse extensive green roof benefits

10.1.2 Sedum extensive green roof benefits

Sedum extensive green roofs are ideal for particular climates with extreme weather patterns. This is because Sedums can effectively withstand long periods of drought and harsh climates found on the roof. Sedum extensive green roofs constitute a total of 3 checks for noise insulation, waterproofing longevity and reduced maintenance (see Figure 19 below).

Sedum extensive green roofs are low cost due to low maintenance factors, which can be seen as an added bonus. Sedum green roofs may require little to no maintenance as compared to a biodiverse extensive green roof that requires a minimum of 2 site inspections per year. However, studies have indicated that typical Sedum green roof substrates leach nitrogen and phosphorus from in the rainwater runoff. (Hathaway, Hunt, & Jennings, 2008) These potential affects would negatively impact the total environmental costs.

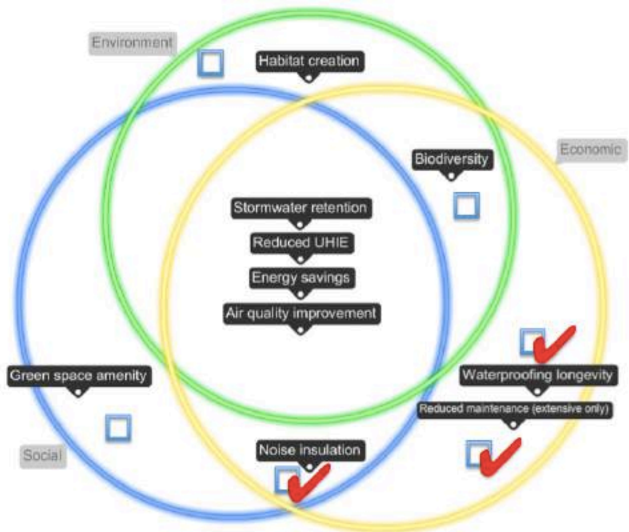


Figure 19: Sedum extensive green roof benefits

10.1.3 Intensive green roof benefits

Intensive green roofs are different from extensive green roofs due to the fact that they are composed of thicker substrates and have higher plant diversity (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002) and potentially highest biodiversity. (United States General Services Administration, 2011) However, the high amounts of biodiversity can only be associated with an intensive green roof if it contains a wide variety of native and foreign plants (e.g. not just turf grass). Unlike biodiverse extensive green roofs however, intensive green roofs with strictly foreign plant species have minimal biodiversity benefits (Brenneisen, 2009; Gedge, 2003) and higher LCC costs due to maintenance and irrigation. (Snodgrass & McIntyre, 2010; United States General Services Administration, 2011) Most importantly, they are accessible by the building occupants. For this reason, the green space amenity is marked with a check (see Figure 20 below) along with the general green roof benefits of waterproofing longevity and noise insulation. The added social benefits for an accessible green roof is an important area of future research, especially in environments of high stress such as health care facilities and office environments.

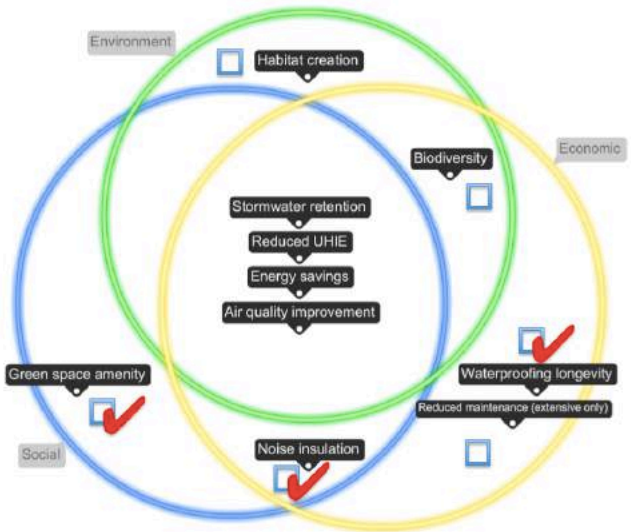


Figure 20: Intensive green roof benefits

Both extensive and intensive green roofs provide the benefits of noise insulation and waterproofing longevity. Therefore, the fundamental difference of a high quality intensive green roof design is that it provides building occupants with a green space amenity. Likewise, the fundamental difference of a high quality extensive green roof design is that it provides environmental benefits of habitat creation, increased biodiversity and reduced maintenance costs.

Biodiverse extensive green roofs that are composed of native grasses and herbaceous plant species are superior to intensive green roofs in terms of ecological and economic benefits such as habitat creation, promotion of biodiversity and reduced maintenance costs. Intensive green roofs are superior to extensive green roofs in terms of social benefits because they provide building occupants an outdoor recreation and relaxation space. Both green roof designs have waterproofing longevity and noise insulation benefits so these points are not considered in this comparison. This evaluation of conventional sustainability benefits results in 3:1 checks of sustainable benefits for a biodiverse extensive green roof compared to an intensive green roofs. This simple analysis of conventional sustainability benefits concludes a biodiverse extensive green roof is three times as valuable compared to an intensive green roof.

To accurately value the restorative benefits of biodiverse extensive green roofs on inaccessible flat roofs, this thesis research proposes for the United States Green Building Council to increase the LEED v4 Sustainable Sites credit Protect or Restore Habitat from 2 points to 3 points. As a result, an inaccessible biodiverse extensive green roof would merit 3 exclusive points, instead of just 2 exclusive points when compared to an accessible green roof potentially composed of non-native plant species in LEED v4. This adjustment would more accurately weight biodiverse green roofs in LEED v4 and give LEED building investors a higher incentive to pursue this credit option for inaccessible roofs, ultimately having an improved ecological impact. Accessible green roofs in LEED with a connection to biodiversity would then be eligible for 4 exclusive LEED points, further encouraging the synchronization of social and environmental benefits.

Additionally, a biodiverse extensive green roof has all the benefits of a Sedum extensive green roof plus the 2 extra benefits for habitat creation and increased biodiversity. However, Sedum extensive green roofs are advantageous in climates with extreme weather patterns. Compared to an intensive green roof, Sedum extensive green roofs have the same amount of sustainable benefits. Therefore, a Sedum extensive green roof should merit no exclusive points in the LEED rating system. The only situation a Sedum extensive green roof should merit the same rating, as a biodiverse extensive green roof is when the project is located in a climate with extreme weather patterns where no other plant species can survive harsh roof conditions.

10.2 Comparing costs

In order to accurately compare the economic costs a green roof with a conventional roof, all material costs above the waterproofing must be considered. Every roof must contain waterproofing and this cost can be disregarded in the calculation. In particular, this research compares the LCC of extensive green roofs with a conventional roof in Switzerland and Holland. As a result of this research, the average economic cost in Holland of an extensive green roof is -94.55 €/m^2 annually. In Switzerland, the average economic cost for an extensive green roof is -85.92€/m^2 annually. This cost can provide investors in these locations with a realistic expectation for green roof costs over a 50-year period. Intensive green roof cost data is still needed for a LCC comparison to determine the approximate costs necessary for the added social benefit of a green space amenity. The LCC of intensive green roofs is not evaluated in this research due to a lack of samples and pricing transparency with intensive green roof materials providers.

This study shows an extensive green roof NPV decreases as area increases. Also, inaccessible green roofs have a NPV 14%-26% less than accessible green roofs. More studies are needed to confirm that green roofs composed of strictly native plants result in a lower NPV compared to green roofs with native and foreign plants. Today, the cost of installing an extensive green roof in Switzerland and Holland today is cheaper than a conventional flat black roof. The calculated mean NPV of green roofs in Switzerland is between -85.92€/m^2 and -100.65€/m^2; a conventional flat roof in Switzerland is calculated to cost -137.09€/m^2. The calculated mean NPV of green roofs in Holland is between are between -94.55 €/m^2 and -107.93 €/m^2; a conventional flat black roof costs -128.18€/m^2.

One approach to optimize the LCC of a building component is through planned preventative maintenance (PPM) schedules. A Building Information Model (BIM) can be developed for any real estate property to guide strategic decisions and is exemplified (see section 9, pg. 77) in this research to evaluate operation costs for future planning and budgeting purposes. By comparing maintenance schedules for green roofs and conventional roofs, a BIM workflow is recommended to compare and optimize LCC.

10.3 Green roof operational agenda strategy

Alternative views of strategy include benchmarking and defining best management practices. (Porter, 1996) The performance of a building or building component can be benchmarked in many different ways. Benchmarking is effective at measuring and improving a building's performance. This can is best done by carefully choosing the right indicators. Next, these indicators can be compared to "establish realistic targets and timescales against which improvements in performance can be achieved over time" (Roaf, Horsley, & Gupta, 2004, p. 49).

10.3.1 Biodiverse extensive green roof benchmarking indicators

A high quality biodiverse extensive green roof is 75% covered with at least 20 different indigenous plant species witihin 2 years. (Schmid, 2007; Sigrist, 2014) This benchmark simultaneously optimizes biodiversity while lowering the maintenance costs. However, the counting of 20 different indigenous plants requires an educated professional and is not necessarily possible by a typical building operator. Therefore, the successful green roof benchmark can be simplified to make sure the roof area is more than 75% covered with leafy herbaceous plants and native grasses (see Figure 5, pg. 17) after 2 years. Alternatively, a green roof with less than 75% covering would be considered an unsuccessful green (see Figure 21 below) and should be addressed by facility managers.

10.3.2 Green roof best management practices

At a minimum, two annual inspections of green roofs must be made to inspect leakage concerns and to keep the gravel strips, roof borders and other roof outlets clear of vegetation. Watering should be limited to periods of drought. Foreign vegetation such as tree seedlings, especially thistles or rhizome forming species (e.g. couch grass, reeds, bamboos) that could puncture the waterproofing membrane must be removed. (Schmid, 2007) In order to optimize biodiversity, create varied topography and only local substrates. Other best management practice measures to increase biodiversity are outlined below.

- The original design of a green roof can include depressions to collect rainwater for a short period of time.
- Incorporate wood boxes for birds bats and trap nests for bees.
- Add tree branches and rocks to alter the roof topography and moisture retention.
- Change the substrate depths to encourage species movement and promotes heterogeneity. (Hui & Chan, 2011))

Figure 21: Low quality extensive green roof (not included in data analysis)

10.4 Proposed benchmarking tool to evaluate sustainable green roof benefits

According to many experts, the options for green roofs primarily include intensive and extensive designs. (Werthmann, 2007; Cantor, 2008; Hathaway, Hunt, & Jennings, 2008; Snodgrass & McIntyre, 2010; United States General Services Administration, 2011; Kuba, 2012; Shah, 2012) Both of these green roof designs are evaluated and compared (see Figures 18, 19 and 20 above) to propose improvements for the LEED v4 rating system in how green roofs rank in credit evaluation. The optimal green roof design for an inaccessible roof is a biodiverse extensive green roof. Alternatively, Sedum extensive green roofs are designed for lightweight performance criteria. An optimal intensive green roof has limitless designs yet is assumed to be accessible to the building end-users. However, with the many options relevant to green roof designs there needs to be a more holistic approach to categorize the sustainable effectiveness and potentials of green roof systems.

This research has demonstrated the potential for green roofs to be an integral part of sustainable buildings. In an effort to increase the overall sustainability of a green roof in the LEED rating system, this research proposes that additional credits should be eligible for green roof systems that take extra design measures to synchronize sustainable benefits and enhance social benefits. This approach to building sustainability is taken from the German DGNB (2012) sustainable building rating system. Through additional building components such as public art, increased water storage capabilities and the integration of photovoltaic panels a green roofs benefits can be synchronized. Art installations can synchronize public acceptance and interaction on accessible green roofs. This approach will increase social benefits and overall end-user satisfaction. A water storage system should also be an option to increase the rating any green roof. However, more research is needed optimize the design of photovoltaic panels integrated with green roofs.

In a review of green roofs and building rating systems by Hui and Chan (2011) a method to systematically compare environmental benefits of green roofs was proposed. The points are calculated on 6 different criteria including species diversity and richness, substrate type and depth, plant species selection, connectivity to natural vegetation, green roof ratio and ecologically responsible development for a total of 14 points. (See Appendix 15: Proposed assessment system on biodiversity of green roofs (Hui & Chan, 2011), pg.123). The thesis research presented here proposes an updated expansion of this proposed assessment of green roof biodiversity, which includes quantified social and economic benefits. The amendment of the proposed assessment is a green roof sustainable benefit calculator, including 1 additional economic criteria and 3 additional social criteria (see Table 6 below). This tool should be used as a benchmarking system to evaluate and compare the overall sustainable contribution of any particular green roof design, with 15-19 points indicating high quality green roof, 10-14 points indicating a moderate quality green roof and 5-9 points indicating a poor quality green roof.

Based on the green roof design guidelines found in Switzerland, this research also proposes to make adjustments to the *Proposed assessment system on biodiversity of green roofs* (Hui & Chan, 2011) (see Appendix 15, pg. 123) by amending criteria 2 and criteria 3. The points associated with substrate type and depth should be based on the biodiversity optimization requirements in Switzerland, which require a varied topography composed of native substrates. Similarly, the plant selection, which optimizes local ecological benefits would be strictly native plants.

Based on these changes, the proposed green roof sustainable benefits calculator (see Table 6 below) determines an overall sustainability rating of an accessible intensive green roof composed of foreign substrate, native and exotic plant species, with no connection to the natural environment or ecological development program could merit 13 points maximum. Alternatively, an inaccessible biodiverse extensive green roof composed of native plants species, native substrates and is not directly viewable has the potential to merit a maximum of 18 points. The typical biodiverse extensive green roof is approximately 28% more valuable than the previously stated intensive green roof option according to holistic sustainable criteria proposed in the green roof sustainable benefits calculator. Again, this research concludes that inaccessible biodiverse extensive green roofs should receive more credits than currently attributed by the LEED v4 rating system.

Table 6: Proposed green roof sustainable benefit calculator

Green roof sustainable benefit calculator			Points
1	Species diversity and richness	Sedum extensive green roof	1
		Intensive green roof	2
		Biodiverse extensive green roof	3
2	Substrate type and depth	Engineered, flat substrate	1
		Foreign substrate, varied topography	2
		Native substrate, varying topography	3
3	Plant species selection	Exotic species	1
		Both	2
		Native species	3
4	Connectivity to natural vegetation	Yes	1
		No	0
5	Green roof ratio: Ratio of green roof area to building (footprint) area	1:1	1
		2:1	2
		3:1 or more	3
6	Ecologically responsible development: Program to promote awareness, training and proper roof maintenance?	Yes	1
		No	0
7	Does the roof have a rainwater catchment system to store and resuse rainwater?	Yes	1
		No	0
8	Can the roof be viewed and enjoyed from at least one regularly occupied space?	Yes	1
		No	0
9	Is public art integrated into the roof?	Yes	1
		No	0
10	Is the green roof cost effective?	Accessible	1
		Partially accessible	2
		Non accessible	3

An accessible intensive green roof composed of local substrate, native plants, with a connection to the natural environment and positive ecological development can potentially merits 17 points maximum. A partially accessible biodiverse extensive green roof with native substrate and native plant species can potentially merit 19 points maximum and remains the most preferred option. The 2 previously stated designs are not typical green roof designs outlined in the FLL guidelines (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., 2002) and would most likely require an innovative design.

10.5 Comparative analysis

Switzerland and Holland have different geographic descriptions and different priorities for green roof incentives. Switzerland prioritizes ecological benefits of green roofs. Major cities such as Zurich and Basel enforced green roof mandates due to the benefit of the natural environment (Green Zurich City, 2014; Mees, 2014) Also, cities like Basel and Bern in Switzerland have developed a technicality in the storm water fees to provide a monetary savings for green roof property owners. These cities also mandate green roofs on all flat, unoccupied new or renovated roofs, which has a noticeable, beneficial affect on the costs. (Brenneisen, 2010) In Holland, the cost of an extensive green roof is also cheaper than a conventional flat black roof. The city of Rotterdam is leading the way to develop innovative strategies for water storage and delayed storm water runoff to prepare for the likelihood of climate change. (van Peijpe, Boer, Hurtado, Jorritsma, Marin, & Wissing , 2013) Rotterdam has developed two subsidy programs in the past decade to initiate wide spread green roof construction.

The NPV of green roofs in Switzerland falls between -85.92€/m^2 and -100.65€/m^2; a conventional flat roof in Switzerland is calculated to cost -137.09€/m^2. One sample green roof in Holland included insulation and waterproofing costs in the initial construction costs. For this reason the sample has been excluded from any relevant conclusions. Excluding the one outlying sample in Holland concludes a mean NPV of a green roof is between -94.55 €/m^2 and -107.93; the calculated NPV of a flat black roof in Holland is -128.18€/m^2.

Switzerland has a lower NPV for green roofs compared to Holland for two potential reasons. First, green roofs construction costs decrease as the roof area increases. Switzerland survey respondents maintained green roof areas that were on average 1450% larger than survey respondents from Holland. Secondly, the experienced installation methods of contractors due to green roof mandates which has driven down the costs of green roof construction. (Brenneisen, 2010) However, a comparison of small roofs (less than 1000 m^2) shows that the

NPV of small green roofs in Holland is 9.2% less than small green roofs in Switzerland. This shows that Holland has the potential to further decrease costs of green roof construction.

10.6 Future research and outlook

Intensive green roofs are ideal in certain situations due to accessibility. More research needs to be done to find innovative solutions for green roofs to maximize water storage capacity and minimize runoff without leaching nutrients from the green roof itself. If intensive green roofs can be municipal strategy for storm water control to enhance comfort and livability in urban environments, further research is needed conclude that intensive green roofs are more effective than extensive green roofs in reducing rainwater runoff due to the increased thickness of substrate.

Additionally, more research is needed to quantify the social benefits of green roofs for an evidence-based evaluation. The social benefits from accessible green roofs are important to promote future projects that aim to optimize building occupant well being. This research is needed to justify when the premium costs of an intensive green roof is the optimal choice. As highlighted by the DGNB (2012) rating system, in such cases as community development, intensive green roofs are clearly the optimal choice due to their multifunctional characteristics. Multifunctional characteristics of extensive green roofs can also be maximized when combined with photovoltaic panels. (Köhler, Wiaralla, & Feige, 2007) Future studies are needed to further document and verify the increased efficiency qualities of green roofs combined with PV solar panels.

In Switzerland and Holland, extensive green roofs are economically sustainable when considering the added energy savings and storm water fee reductions. This thesis research finds that an extensive green roof in Switzerland costs between 37% - 27% less than a conventional flat roof. In Holland, green roofs are determined to be 16% - 26% less than a conventional flat roof. Switzerland has the lowest extensive green roof NPV as a result of standardized green roof construction practices due to the fact that they are legally required. The green roof mandates in major cities such as Basel and Zurich have seen dramatic drops in green roof costs as a result of increased contractor installation experience. (Brenneisen, From Pilot to Mainstream: Green roofs in Basel, Switzerland, 2010) If green roofs continue to be incentivized in Holland, the same time effects on green roof economic construction costs can be expected. This study shows that extensive green roofs in Switzerland and Holland are economically preferable compared to conventional roofs. Additionally, partially accessible biodiverse extensive green roofs provide optimal environmental benefits as well as many social benefits, making them more sustainable from a holistic viewpoint.

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Appendix

1 German Real Estate Survey

Daten Fragen	Datentyp
Alter der Dachbegrünung	_______________ Jahre
Fläche	_______________ m^2
Durchschnittliche Unterhaltskosten pro Jahr	_______________ CHF/ Jahr
Einheimische oder gebietsfremde Pflanzen?	_______________
Ungefähre Substrattiefe	□ 2-6 cm □ 6-10 cm □ 10-15 cm □ 15-25 cm □ 25-60 cm
Neubau oder Renovation?	________________ (bitte eins auswählen)

Initialkosten für die Erstellung der Dachbegrünung?	_______________CHF
Wurde das Dach renoviert? Kosten der Renovation oder Neubau?	_______________ Ja/Nein _______________ CHF
Ist die Dachbegrünung zugänglich für Angestellte?	______________ Ja/Nein ______________ CHF

2 Dutch Real Estate Survey

Data Questions	Data Type
Organisatie	
Functie	
Afdeling	
Leeftijd van het dak	________________Jaren
Oppervlakte	________________ m^2
Gemiddelde onderhoudskosten per jaar Totale kosten betreffen o.a. bewatering, voeding/bemesting, vegetatie en andere materiaalkosten.	______________€/jaar

Gemiddelde kosten per jaar voor technologisch herstel (mechanische reparaties, reparaties aan leidingen/sanitaire voorzieningen die direct gerelateerd zijn aan reactief en preventief onderhoud en arbeidskosten).	_______________ €/jaar
Zijn de bovenstaande bedragen berekend inclusief of exlusief belasting?	___________ Met belasting ___________ Zonder belasting
Zijn de planten inheems (Nederlands) of uitheems (buitenlands)?	_______________Inheems _______________Buitenlands
Gemiddelde diepte van de voedingsbodem (selecteer a.u.b. één van de opties)	_ 2-6 cm _ 6-10 cm _ 10-15 cm _ 15-25 cm _ 25-60 cm

Betreft het een nieuwe constructie of renovatie? (selecteer a.u.b. één van de opties)	________________ Nieuwe constructie ________________ Renovatie
Wat zijn de initiele kosten van de constructie? (kosten zijn inclusief vegetatie, voedingsbodem, zaden en arbeid)	________________€
Has the roof been renovated? Is het dak gerenoveerd? Wat waren de kosten van de renovatie? Licht toe wat er is gerenoveerd.	________________Ja ________________Nee ________________ € ____________________

3 Green Roof Categories (Cantor, 2008, p. 16)

Characteristic	**Extensive**	**Semi-Intensive**	**Intensive**
Depth of material	6" (15.2 cm) or less	25% above/below 6" (15.2 cm)	More than 6” (15.2 cm)
Accessibility	Often inaccessible	Partially accessible	Usually accessible
Fully saturated weight	Low: 10-35lb/ft^2 (48.8-170.9 kg/m^2)	Varies: 35-50 lb/sf (170.9 - 244.1 kg/m^2)	High: 50 - 300 lb/ft^2 (244.1 - 1,464.7 kg/m^2)
Plant diversity	Low	Greater	Greatest
Cost	Low	Varies	High
Maintenance	Minimal	Varies	Varies (generally high)

4 Small roof (less than 1,000m²) descriptive statistics

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	Location	N	Percent	N	Percent	N	Percent
NPVperSM	Holland	5	100.0%	0	0.0%	5	100.0%
	Switzerl	4	100.0%	0	0.0%	4	100.0%

Descriptives

	Location			Statistic	Std. Error
NPVperSM	Holland	Mean		-94.5500	22.92926
		95% Confidence Interval for Mean	Lower Bound	-158.2118	
			Upper Bound	-30.8882	
		5% Trimmed Mean		-93.3172	
		Median		-104.2100	
		Variance		2628.754	
		Std. Deviation		51.27138	
		Minimum		-168.25	
		Maximum		-43.04	
		Range		125.21	
		Interquartile Range		92.85	
		Skewness		-.523	.913
		Kurtosis		-.559	2.000
	Switzerl	Mean		-104.0800	30.33842
		95% Confidence Interval for Mean	Lower Bound	-200.6304	
			Upper Bound	-7.5296	
		5% Trimmed Mean		-101.0000	
		Median		-76.3600	
		Variance		3681.679	
		Std. Deviation		60.67684	
		Minimum		-194.93	
		Maximum		-68.67	
		Range		126.26	
		Interquartile Range		94.98	
		Skewness		-1.978	1.014
		Kurtosis		3.931	2.619

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
NPVperSM	9	100.0%	0	0.0%	9	100.0%

Descriptives

			Statistic	Std. Error
NPVperSM	Mean		-98.7856	17.38529
	95% Confidence Interval for Mean	Lower Bound	-138.8761	
		Upper Bound	-58.6950	
	5% Trimmed Mean		-96.5412	
	Median		-76.9300	
	Variance		2720.235	
	Std. Deviation		52.15587	
	Minimum		-194.93	
	Maximum		-43.04	
	Range		151.89	
	Interquartile Range		80.04	
	Skewness		-.990	.717
	Kurtosis		-.004	1.400

5 Location based descriptive statistics prior to outlier removal

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
NPVperMeterSquared	15	-454.67	-43.04	-113.3773	103.51469	-2.908	.580	9.342	1.121
Valid N (listwise)	15								

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
HollandNPVperSquareMeter	6	-454.67	-43.04	-154.5700	154.00456	-1.989	.845	4.207	1.741
Valid N (listwise)	6								

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
SwitzeralndNPVperSquareMeter	9	-194.93	-50.25	-85.9156	42.51279	-2.554	.717	7.203	1.400
Valid N (listwise)	9								

6 Location based descriptive statistics after outlier removal

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
NPVperMeterSquared	13	-168.25	-43.04	-80.8508	33.07675	-1.554	.616	3.399	1.191
Valid N (listwise)	13								

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
HollandNPVperSquareMeter	5	-168.25	-43.04	-94.5500	51.27138	-.523	.913	-.559	2.000
Valid N (listwise)	5								

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
SwitzeralndNPVperSquareMeter	8	-83.75	-50.25	-72.2888	12.47300	.974	.752	-.334	1.481
Valid N (listwise)	8								

7 Accessibility based descriptive statistics prior to outlier removal

Case Processing Summary

	Accessible	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
NPVperMeterSquared	no	10	100.0%	0	0.0%	10	100.0%
	yes	4	100.0%	0	0.0%	4	100.0%

Descriptives

	Accessible			Statistic	Std. Error
NPVperMeterSquared	no	Mean		-85.1820	13.46968
		95% Confidence Interval for Mean	Lower Bound	-115.6525	
			Upper Bound	-54.7115	
		5% Trimmed Mean		-81.4261	
		Median		-79.2350	
		Variance		1814.323	
		Std. Deviation		42.59487	
		Minimum		-194.93	
		Maximum		-43.04	
		Range		151.89	
		Interquartile Range		32.98	
		Skewness		-2.137	.687
		Kurtosis		5.634	1.334
	yes	Mean		-98.5425	26.41722
		95% Confidence Interval for Mean	Lower Bound	-182.6139	
			Upper Bound	-14.4711	
		5% Trimmed Mean		-97.4567	
		Median		-88.7700	
		Variance		2791.478	
		Std. Deviation		52.83444	
		Minimum		-168.25	
		Maximum		-48.38	
		Range		119.87	
		Interquartile Range		99.95	
		Skewness		-.845	1.014
		Kurtosis		-.346	2.619

8 Accessibility based descriptive statistics after outlier removal

Case Processing Summary

	Accessible	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
NPVperMeterSquared	no	9	100.0%	0	0.0%	9	100.0%
	yes	4	100.0%	0	0.0%	4	100.0%

Descriptives

	Accessible			Statistic	Std. Error
NPVperMeterSquared	no	Mean		-72.9878	6.39660
		95% Confidence Interval for Mean	Lower Bound	-87.7384	
			Upper Bound	-58.2372	
		5% Trimmed Mean		-72.9170	
		Median		-76.9300	
		Variance		368.249	
		Std. Deviation		19.18981	
		Minimum		-104.21	
		Maximum		-43.04	
		Range		61.17	
		Interquartile Range		29.68	
		Skewness		.195	.717
		Kurtosis		-.408	1.400
	yes	Mean		-98.5425	26.41722
		95% Confidence Interval for Mean	Lower Bound	-182.6139	
			Upper Bound	-14.4711	
		5% Trimmed Mean		-97.4567	
		Median		-88.7700	
		Variance		2791.478	
		Std. Deviation		52.83444	
		Minimum		-168.25	
		Maximum		-48.38	
		Range		119.87	
		Interquartile Range		99.95	
		Skewness		-.845	1.014
		Kurtosis		-.346	2.619

9 Plant based descriptive statistics prior to outlier removal

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	PlantPalette	N	Percent	N	Percent	N	Percent
NPVperMeterSquared	Frgn&Nat	9	100.0%	0	0.0%	9	100.0%
	Native	5	100.0%	0	0.0%	5	100.0%

Descriptives

	PlantPalette			Statistic	Std. Error
NPVperMeterSquared	Frgn&Nat	Mean		-83.1256	13.38140
		95% Confidence Interval for Mean	Lower Bound	-113.9831	
			Upper Bound	-52.2680	
		5% Trimmed Mean		-80.6234	
		Median		-83.6200	
		Variance		1611.557	
		Std. Deviation		40.14420	
		Minimum		-168.25	
		Maximum		-43.04	
		Range		125.21	
		Interquartile Range		57.22	
		Skewness		-1.205	.717
		Kurtosis		1.489	1.400
	Native	Mean		-99.5720	23.92852
		95% Confidence Interval for Mean	Lower Bound	-166.0082	
			Upper Bound	-33.1358	
		5% Trimmed Mean		-95.9911	
		Median		-76.9300	
		Variance		2862.870	
		Std. Deviation		53.50579	
		Minimum		-194.93	
		Maximum		-68.67	
		Range		126.26	
		Interquartile Range		66.01	
		Skewness		-2.194	.913
		Kurtosis		4.855	2.000

10 Plant based descriptive statistics after outlier removal

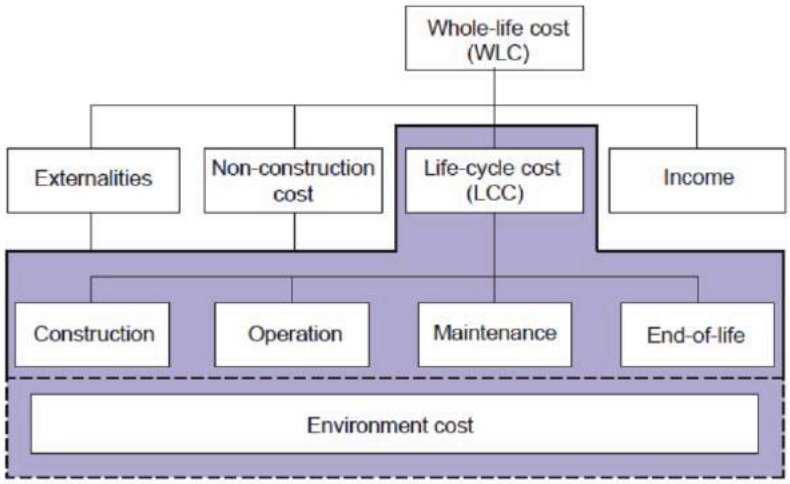
Case Processing Summary

	PlantPalette	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
NPVperMeterSquared	Frgn&Nat	9	100.0%	0	0.0%	9	100.0%
	Native	4	100.0%	0	0.0%	4	100.0%

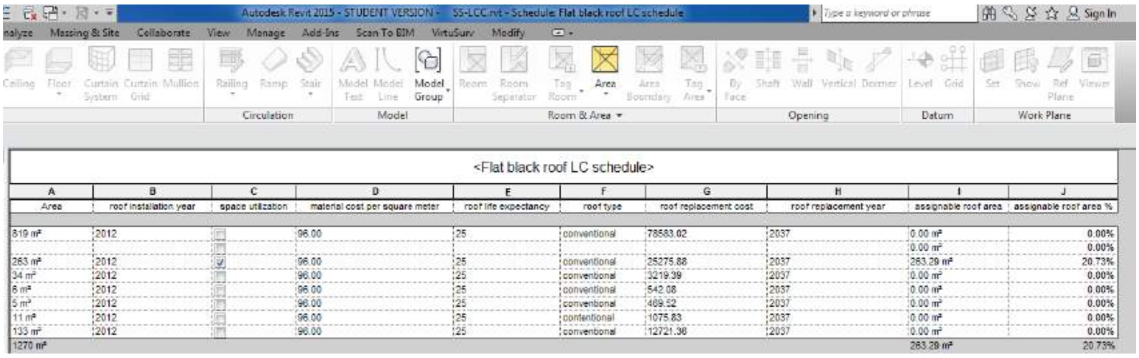
Descriptives

	PlantPalette			Statistic	Std. Error
NPVperMeterSquared	Frgn&Nat	Mean		-83.1256	13.38140
		95% Confidence Interval for Mean	Lower Bound	-113.9831	
			Upper Bound	-52.2680	
		5% Trimmed Mean		-80.6234	
		Median		-83.6200	
		Variance		1611.557	
		Std. Deviation		40.14420	
		Minimum		-168.25	
		Maximum		-43.04	
		Range		125.21	
		Interquartile Range		57.22	
		Skewness		-1.205	.717
		Kurtosis		1.489	1.400
	Native	Mean		-75.7325	2.66213
		95% Confidence Interval for Mean	Lower Bound	-84.2046	
			Upper Bound	-67.2604	
		5% Trimmed Mean		-75.8022	
		Median		-76.3600	
		Variance		28.348	
		Std. Deviation		5.32426	
		Minimum		-81.54	
		Maximum		-68.67	
		Range		12.87	
		Interquartile Range		9.94	
		Skewness		.683	1.014
		Kurtosis		1.547	2.619

11 Definition of Whole-Life Cost per ISO 15686-5 (2008) (Swiss Chapter of International Facilities Management Association, 2011, p. 8)



12 Conventional Roof Schedule

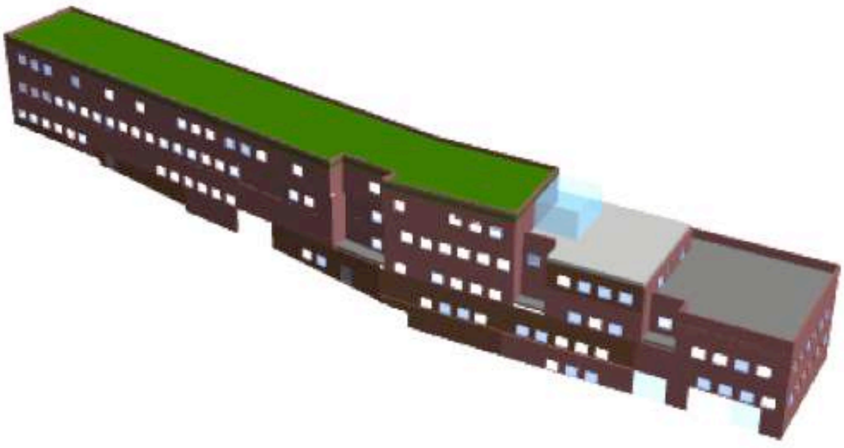


<Flat black roof LC schedule>

A	B	C	D	E	F	G	H	I	J
Area	roof installation year	space utilization	material cost per square meter	roof life expectancy	roof type	roof replacement cost	roof replacement year	assignable roof area	assignable roof area %
819 m²	2012	☐	96.00	25	conventional	78583.02	2037	0.00 m²	0.00%
		☐						0.00 m²	0.00%
263 m²	2012	☑	96.00	25	conventional	25275.88	2037	263.29 m²	20.73%
34 m²	2012	☐	96.00	25	conventbnal	3219.39	2037	0.00 m²	0.00%
6 m²	2012	☐	96.00	25	conventional	542.08	2037	0.00 m²	0.00%
5 m²	2012	☐	96.00	25	conventbnal	469.52	2037	0.00 m²	0.00%
11 m²	2012	☐	96.00	25	contentional	1075.83	2037	0.00 m²	0.00%
133 m²	2012	☐	96.00	25	conventbnal	12721.36	2037	0.00 m²	0.00%
1270 m²								263.29 m²	20.73%

13 Seifensträuli registered point cloud

14 Seifensträuli BIM



15 Proposed assessment system on biodiversity of green roofs (Hui & Chan, 2011, p. 8)

Table 3. Proposed assessment system on biodiversity of green roofs

1	Species diversity and richness	Extensive green roof (EGR): 1 mark Intensive green roof (IGR) : 2 marks Brown/Biodiverse (BF): 3 marks
2	Substrate type and depth	Extensive (E): 150 mm or less: 1 mark Semi-intensive (S): Above and below 150 mm: 2 marks Intensive (I): More than 150 mm Substrate: 3 marks
3	Plant species selection	Exotic species: 1 mark Native species: 2 marks Both: 3 marks
4	Connectivity to natural vegetation	Connection of the green roof to urban landscape? Yes: 1 mark, No: 0 mark
5	Green roof ratio	Ratio of green roof area to building (footprint) area: 1:1 (1 mark) 2:1 (2 mark) 3:1 or above (3 marks)
6	Ecologically responsible development	Programme to promote awareness, training and proper roof maintenance? Yes: 1 mark, No: 0 mark

Total score: 4-7 Fair; 8-10 Good; 11-14 Excellent

Declaration of independent work

I hereby declare that I have independently written this paper with the title *Life Cycle Cost Comparative Analysis - A study on green roofs in Switzerland and Holland*. I declare that I have not used any sources other than those specified. All segments which were taken from sources either verbatim or by analogy (including paraphrasing), I have identified and referenced as such. I understand that failure to do so could lead to legal and/or disciplinary action being taken.

Place. Date	Surname, Forename	Signature
Wädenwil, Switzerland 28.4.2015	Kantor Davis	