ADAPTING A GREEN ROOF IN TUCSON, AZ

HOT AND ARID URBAN CLIMATE

SHEA CUTTER

SBE 498 – SENIOR CAPSTONE THESIS

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Abstract

Buildings that implement a green roof on their rooftop generate economic and environmental benefits throughout its lifetime that a conventional roof cannot. A space that would normally not be utilized is transformed to benefit the building's operations and occupants. However, there is little research on green roof applications in hot and arid urban climates. This paper is based on an extensive literature review on the current capabilities of green roofs to generate enough savings and benefits to a building to combat the initial installation fee. Finding the Net Present Value (NPV) of the cost of installation and benefits of a green roof is used to create a benefit analysis. In order for more research to be done in hot and air urban green roofs there needs to be a market for it. This research paper uses a benefit analysis to break down the economic feasibility of the investment based on the savings and benefits received after construction. The site location used to generate the data for this proposal is on the College of Architecture, Planning, and Landscape East building (CAPLA East). The analysis demonstrated that a 5,000 square foot extensive green roof would be economically feasible based off of the NPV of the savings and benefits created after construction. Furthermore, the research identified that the plants best fit for the weather conditions of a green roof are the drought-resistant plants found in the Sonoran Desert that Tucson is a part of.

Introduction

With our climate changing at alarmingly fast rates and population growth putting stress on our resources and environment, it is important that we adapt our vision of urban development for the future. Green roofs can reduce the effects of solar radiation on building interiors and in return reduce air conditioning expenses and help to protect water resources (Hoff, 2005). Utilizing green roofs to counteract Tucson's growth moving forward is research that has yet to be understood. With no sight of urban development coming to a halt we are restricting the space available for forestry and vegetation to act against urban heat islands. Green roofs function the same way ecosystems do to benefit the environment; just in an urban setting. In the face of global change, the compounding effects of urban heat islands and more frequent and extended heat waves further threaten the resilience of desert cities to cope with increasing temperatures (Middel, 2015).

The environmental and economic benefits are why building owners are investing in green roofs compared to a conventional roof. Some important financial impacts of green roofs that do not directly affect the building owner, investor, or occupants include the greenhouse gas savings (GHG), market-based savings, and community benefits. Including these benefits that come as a result of this installation gives a financial overview of a green roof as an investment with an expected return (US GSA 2011). Breaking down the benefits of this design in terms of financial gain helps investors understand how green roofs generate payback throughout its lifespan.

The Tucson, Arizona the climate is considered hot and arid. Discovering a plant selection that can survive in the extreme temperature fluctuations and an average of 11.9 inches of rain per year is challenging. In addition to dramatic seasonal and daily climate variations, rooftop plants typically grow in just four to twelve inches of substrate (Fusco, 2013). Green roofs are typically highly porous and well-drained meaning that they are also nutrient poor. These conditions create abysmal growing conditions for many plants (Fusco, 2013). The challenge is finding the plants that will survive in these growing conditions to generate the economic and environmental savings from the landscape.

This research is based on a 5,000 square foot green roof on the CAPLA East building and compared to a white roof with a 0.65 albedo. The green roof design will have a 5-inch growing medium taking up only 30% of the available roof space. This roof design is how we will generate the NPV of the cost benefits and savings.

Literature Review

History of Green Roofs

The modern green roof originated at the turn of the 20th century in Germany (Bioscience 2007). The green roofs were introduced to deal with the damaging effects of solar radiation on roof structures and also functioned as a fire-retardant structure. The environmental benefits that the green roofs provided for urban areas made it increasingly popular in Germany during the 1970s when there was a growing concern for the environment in urban areas (Bioscience 2007).

Key Factors for Retrofit

Some issues that we face with trying to implement green infrastructure in Arizona's dry climate is the restricted water supply needed to irrigate a green roof. Which is why this thesis looks into using drought-resistant vegetation as a method to deal with irrigation restrictions.

Vagase and Dunnett (2010) demonstrated the importance of identifying the right plant species for arid environments. Their work laid the foundation for adapting green roofs to the southwest. Finding the right type of vegetation to not only survive in Tucson, but also require less water for irrigation is important when it comes time to create an extensive green roof to test. In order to create an effective green roof for the sample that will be tested during this research the case study on green roof models for building energy simulation by D.J. Sailor.

In order for green roofs to become a part of buildings in Tucson, Arizona it needs to create enough economic benefit for the building conditions created by the green infrastructure. An economic analysis for this study will consider the performance of green roofs to benefit energy reduction. Finding the cost-benefits of implementing a green roof in Tucson will depend on the ability to reduce the energy load on buildings by reducing surface temperatures. Bianchini and Hewage (2012) use a probabilistic social cost-benefit analysis for green roofs. Since there has already been extensive research on the economic benefits of green roofs in urban areas where the climate provides enough water to promote plant growth this thesis will look into how creating drought-resistant green roofs can create enough economic benefits for energy reduction. The cost-benefit analysis will then take into consideration all of the costs of implementing green roofs and maintenance can be outweighed by the economic benefits of having green roofs.

Extensive and Intensive Green Roofs

There are two different types of green roofs intensive and extensive. An intensive green roof has the same appearance as conventional ground-level gardens (American Institutes of Biological Sciences, 2007). The intensive green roofs have a higher aesthetic appeal and cost a lot more in time investment and money. This research will work to create an extensive green roof garden. Extensive green roofs are shallower, require less maintenance, and are more strictly functional in purpose than intensive roof gardens (AIBS, 2007). Hot and arid regions are not going to be able to maintain thick or tall vegetation in a rooftop garden and require less maintenance.

Cool Roofs

Tucson has adapted their buildings to avoid excess solar radiation through the use of cool roofs. Cool roofs use light colored reflective material to reflect excess solar radiation that would normally be absorbed into the building envelope by dark roof materials (Garrison and Horrowitz, 2012). Cool roofs, just like green roofs, help to reduce the air conditioning loads of buildings by deflecting excess solar radiation that would otherwise heat the building. Although cool roofs require less maintenance than green roofs, they are not able to address the environmental impacts of urban growth (Middel, 2015). Some of the unintended consequences of cool roofs high reflectivity are the inability to use the roof space during the day, the effect of the reflected solar radiation on the surrounding built environment and increase of heating in buildings during the winter seasons. This design is effective in avoiding excess solar radiation; however, the roof space becomes impossible to use during the day because of the brightness of the reflectivity. The solar radiation that is being reflected has to go somewhere if it is not absorbed and as a result reflects heat onto neighboring buildings causing them to expend extra energy to keep cool (Duhamel, 2014). This reflection also becomes an issue during the winter season when buildings should take advantage of solar radiation in order to reduce the energy needed to heat the space.

Green Roof Benefits

Green roofs act not only as a way to mitigate heat, but also act as a way to clean and protect our water sources and clean air pollutants. Since water resources are limited in Arizona, it is important to take precautions to protect our surface water that can be polluted during storms picking up automotive fluids and debris, metals, pesticides, pet wastes, trash, bacteria, pathogens, and other contaminants (Garrison and Horrowitz, 2012). Using green infrastructure can help stormwater to be returned into the air without pollutants contaminating the water. The vegetation and soil work to capture the stormwater, remove and detoxify the water, and release it back into the atmosphere using evaporation and transpiration. This process is beneficial in improving the quality of our water. Another benefit of green roofs is its ability to improve air quality by removing pollutants from the atmosphere. A study done in Chicago by Jun Yang (2008) looked into the effects of green roofs to improve air quality and found that green roofs can remove 7.87 metric tons of air pollutants annually. Green roofs can act as a natural pollutant extraction design for our buildings in Tucson.

Another environmental benefit of green roofs is how it re-introduces space for habitat conservation. The impervious asphalt and concrete surfaces of our urban spaces have removed the biodiversity that used to be a part of our communities. Creating living roofs do not only help to reduce surface temperatures but bring back habitats within our urban spaces.

The natural landscape of a green roof design also generates financial incentives for building owners and investors by increasing the market value of the property (Bianchini, 2012). Depending on the location of the building there are different incentives offered by the state.

The aesthetic of maintaining a green roof can be costly however the value of the building increases when the green roof is installed allowing the building owner to ask for a higher rent to match the new value of the building (Bianchini, 2012).

Compared to conventional roofs, studies suggest that the average life expectancy of a green roof is 40 years versus 17 (US GSA, 2011). The vegetation helps to minimize the damage of UV rays, wind, and water. The lifetimes of green roofs are difficult to predict because they vary on location and type. Some green roofs do not need to be replaced even more than 50 years after installation.

Methodology

The research in this paper is based on extensive research on current literature on the benefits, cost, and retrofitting green roofs for hot and arid urban climates. The information found is used to help create a cost-benefit analysis of a 5,000 square foot extensive green roof with a 5-inch growing media compared to a conventional white roof with 0.65 albedo. The analysis first finds the NPV the direct financial impacts including the installation, maintenance, energy savings, stormwater savings. This cost-benefit analysis calculates the value and potential of financial benefits from this investment by using the three basic formulas in *Figure 1*. These potential financial benefits include the Internal Rate of Return (IRR), payback period, and Return on Investment (ROI). The IRR is a measure of the expected annual financial benefits yielded by an investment over a given time frame of 6% per year (US GSA 2013). The ROI is the percent of money gained or lost after the initial cost of investment.

Furthermore, to determine the financial impact of the social benefits of the building after construction the analysis breaks down the NPV of the GHG savings, market-based savings, and community benefits. The NPV is used to determine the potential profitability of this investment. Lastly, drought-adapted vegetation able to survive in 40-degree temperature fluctuation and nutrient-poor 5-inch growing media were chosen for the landscape. This selection was made through extensive research into horticulture literature on hot and dry climate plants.

Figure 1. Cost Benefit Calculations

Net Present Value Formula:

$$NPV = \frac{F}{(1+i)^n}$$

Where:

n: number of periods in the future of cash flow (50 years in this case)

i: interest rate (6% in this case)

F: future payment cash flow

Return on Investment Formula:

ROI = Net Profit / Total Investment x 100

Internal Rate on Return Formula:

$$0 = CF_0 + \frac{CF_1}{(1+IRR)^1} + \frac{CF_2}{(1+IRR)^2} + \frac{CF_3}{((1+IRR)^3} + \cdots + \frac{CF_n}{(1+IRR)^n}$$

Where:

CF_0: *Initial Investment/Outlay*

CF_1, CF_2, CF_3, CF_n: *Cash flows*

n: Each period (50 years)

Data and Results

Benefit Analysis

This benefit analysis found that the installation and maintenance of a green roof has the greatest negative impact on NPV cost at -$18.2. However, with the cost of energy and storm water savings, we still end up with a positive NPV of $2.5. The greatest positive financial impact came from the real estate value benefits with an NPV per square foot of $120.10. The payback period of 5,000 square foot garden which would only take up 30% of the available rooftop space on CAPLA is only 6.4 years. With an IRR of 5% and RIO of 220%.

Table 1: Benefit Analysis of the direct financial impacts for owners, investors, and occupants

Extensive Roof Costs (per square foot)	
Initial Premium	-$12.1
NPV of Installation and Maintenance	-$18.2
NPV of Stormwater (savings from reduced infrastructure improvements)	$14.1
NPV of Energy (savings from cooling and heating)	$6.6
Net Present Value (installation, maintenance, stormwater savings, energy savings)	$2.5

Table 2: Investment rates and payback period

Investment Rates	
Return on Investment	220%
Payback Period	6.4 years
Internal Rate of Return	5%

Table 3: Social Benefits and financial impacts

Social Benefit Financial Impacts (per square foot)	
NPV of GHG savings	$2.1
NPV of real Estate (value & rent)	$120.1
NPV of Community Benefits	$30.4

Drought Adapted Landscape

The plants able to grow in low irrigation, 5-inch growing media poor in nutrients, withstand 40 degrees or higher temperature fluctuations found in the Sonoran Desert. Tucson, Arizona is a part of the vast Sonoran Desert that has native plants built to withstand harsh growing conditions. Using the Pacific Horticulture Society article on *Green Roofs: Cry in the Sky,* I was able to identify vegetation native and adapted to grow in the 5-inch growing media of this extensive garden. They also need little maintenance which can help to reduce the initial cost NPV.

Table 4: Drought adapted native plants

Drought Adapted Vegetation	
Scarlet Gilia (Ipomopsis aggregate)	
Red Yucca (Hesperaloe parviflora)	
Sulphur Buckwheat (Erigonum umbellatum)	
Cutleaf Daisy (Erigon compositus)	

Plains Pricklypear (Optunia polyacantha)	
Spearleaf Stonecrop (Sedum lanceolatum)	

Conclusions and Discussion

In conclusion, our findings in the analysis found that after the initial cost of installation and maintenance, when accounting for energy and stormwater savings, still result in a positive NPV. However, the greatest financial impact was created by social benefits such as GHG savings, real estate benefits, and community benefits. Meaning that when we look at a green roof as a long-term investment, factoring in these benefits is important when comparing the return on investment to a conventional white roof with 0.65 albedo. The payback of an extensive small-scale roof is only 6.4 years with a high return on investment. Although the initial negative NPV of the green roof from the installation premium, installation construction, and maintenance is daunting, when we look at the longevity of this investment and the benefits provided for the building and investor, they far outweigh the initial cost. The financial impact of the social benefits provides a payback of $763,000 or $152.60 per square foot of building area over 50 years. This analysis supports the general cost-benefit analysis finding that green roofs offer great potential savings and benefits.

This research was able to find out the economic feasibility of installation compared to a conventional white roof and identified the vegetation needed to adapt a green roof for Tucson, Arizona's urban climate. The vegetation can withstand extreme conditions because they already exist in these conditions. They also require little irrigation and maintenance once they are planted.

There were some limitations to this research, such as not creating a physical scale model to test the structural capacity of the East building to support the additional weight of a green roof. With a limited schedule, the model would not have been feasible. However, now that the economic feasibility of this green roof has been identified future research can be done to understand how a model could generate these benefits. Although, there is not a market for green roofs yet in Arizona, more research and physical scale model data could help to create that market. It is important to start identifying solutions to combat the damage of urban development and drought-adapted green roofs can be that solution.

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