

Application of a Green Roof on the College of Architecture, Planning, and
Landscape Architecture

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Abstract

In the United States, commercial rooftops are too often an afterthought, serving only to house HVAC systems and other utilitarian building components. Rooftops are the most underutilized valuable spaces in buildings. They comprise a great deal of real estate that could help boost a building's energy efficiency, aesthetics, and even the wellness of occupants. Buildings are the leading contributors to energy consumption in the country, and implementing green roofs could significantly mitigate this energy use, so costly to society in so many ways. This proposal studies the benefits of implementing a green roof on the College of Architecture, Planning, and Landscape Architecture (CAPLA) in Tucson, Arizona. Extensive research was conducted on the implementation of a green roof in this hot arid region, as well as a survey among a pool of 50 occupants. The conclusions drawn: a green roof would be utilized by occupants, and would bring about benefits including cleaner air, an expanded roof lifespan, and reduced heat island effect. Conclusions also demonstrate that the cost of implementing a green roof might not be offset by energy savings alone, but when considering the benefits and costs to society, a green roof ultimately proves beneficial economically as well.

Introduction

Buildings are responsible for about 40% of all energy consumed in the United States, and green roofs can mitigate energy usage (eia.gov, 2016.). The majority of consumption is heating, cooling, and electric lighting (USGBC) Green roofs are roofs covered with vegetation and a growing medium on top of a waterproofing membrane. Integrating a green roof equips buildings with the capacity to reflect an increased amount of sunlight and decrease the amount of heat absorbed, while providing an additional habitable space for occupants. There is a misconception that green roofs only have *green vegetation*; however, they come in a variety of colors and types. A typical green roof consists of the roof, a vapor control layer, insulation, root-resistant waterproofing, a retention layer, water retention layer, lightweight substrate, and vegetation layer (Castleton, 2010). A green roof offers a building and its surrounding environment many benefits including storm water management, improved water run-off quality, improved urban air quality, extension of roof life, and a reduction of the urban heat island effect (Castleton, 2010). Green roofs also provide improved insulation: according to one model on well-insulated buildings, energy use can drop from 48% for non-insulated to 2% for well-insulated buildings (Simmons, 2015).

Green roofs also reduce noise pollution, create small-scale wildlife habitat, reduce air pollution by absorbing CO₂, and can control temperature variations of a building, which reduces the heating and air conditioning load (Bianchini, 2012). They are often perceived as aesthetically pleasing in addition to increasing the roof's lifespan (see Table 6). The vegetation increases the roof's lifespan because it protects the rooftop from direct exposure to the sun, which is particularly destructive in hot arid environments. In managing storm water run-off, a green roof can act as an absorber, limiting run-off, a filter-cleaning run-off, and collected runoff

can provide soil nutrients for irrigating other plants on site (Bianchini, 2012). Green roofs additionally drain run-off at a slower rate, allowing storm water time to drain to the disposal body without flooding (Bianchini, 2012).

There are two categories of green roofs: extensive and intensive. Intensive green roofs involve a deeper substrate that allows plants with deeper roots to survive. They require a higher initial investment and involve more maintenance (Castleton, 2010). Extensive roofs have a thinner layer of soil, may grow succulents and mosses, and are self-sustaining. They require minimal maintenance and involve a lower investment (Castleton, 2010). In Tucson's desert conditions, an extensive roof would be most successful. Tucson's climate is hot and arid, which leaves rooftops exposed to harsh climatic conditions. Extensive roofs here could incorporate succulent vegetation, which is highly drought-resistant. There is a misconception that green roofs are uncommon on the west coast due to the heat and lack of moisture. A successful implementation of a green roof on the College of Architecture, Planning, and Landscape Architecture (CAPLA) will benefit the university by reducing energy use and costs, afford students the prospect of an enjoyable place to study or relax, and bring greater awareness of this important concept in improving the sustainability of the built environment to campus.



Figure 1: Render of the College of Architecture, Planning, and Landscape Architecture by Patricia Horn

Literature Review

Extensive Roofs

Extensive roofs have a thin layer of soil, may grow succulents, mosses, and other vegetation, and are self-sustaining. A typical green roof for extensive purposes is composed of a roof layer, fabric filter, and growing media with vegetation. Microclimates on roofs that require drought-tolerant vegetation are important: roof slope and orientation may influence the intensity of the sun and substrate moisture content, and vents from HVAC systems and chemicals from industrial buildings may influence the growth of plants as well as cause them to dry (Castleton, 2010).

Vegetation that is successful on an extensive green roof must have easy reproductive traits and high-density ground cover. These types of vegetation are important because they reduce potential erosion, and the ability of the plant to be self-sustaining reduces maintenance and the need to re-plant. Sedum is the most common vegetation to plant on an extensive rooftop. Sedums are succulents, storing their water in their leaves. They grow horizontally rather than vertically, and create layers on the roof, which enables the roof to have optimal vegetative coverage without hindering the membrane of the rooftop. Utilizing plants with a high water-use-efficiency can reduce transportation, which is one attraction of Crassulacean Acid Metabolism (CAM) plants, characterized by low stomatal conductance and minimal nighttime transpiration (Simmons, 2015). CAM plants open leaf pores in the darkness to exchange oxygen and carbon dioxide, which helps water conservation during drought conditions. CAM plants are most popular in the construction of green roofs because they help clean the air, but are light in weight (Bianchini, 2012).

Make-up of a Green Roof

Each layer of assembly contributes to function (McIntyre, 2012):

1. Roof deck, insulation, waterproofing
2. Protection and storage layer – the “root barrier” protects the roofing membrane from any root penetrations or organic material which could cause decay
3. Drainage layer – ensures the drainage of any excess of water off the roof, preventing a waterlogged system or a significant increase in weight
4. Root-permeable filter layer – prevents the drains from becoming clogged with organic material and growing medium
5. Extensive growing medium – creates a suitable growing environment in an extreme rooftop setting. Composed of various blends of organic and aggregate materials
6. Vegetation and plants

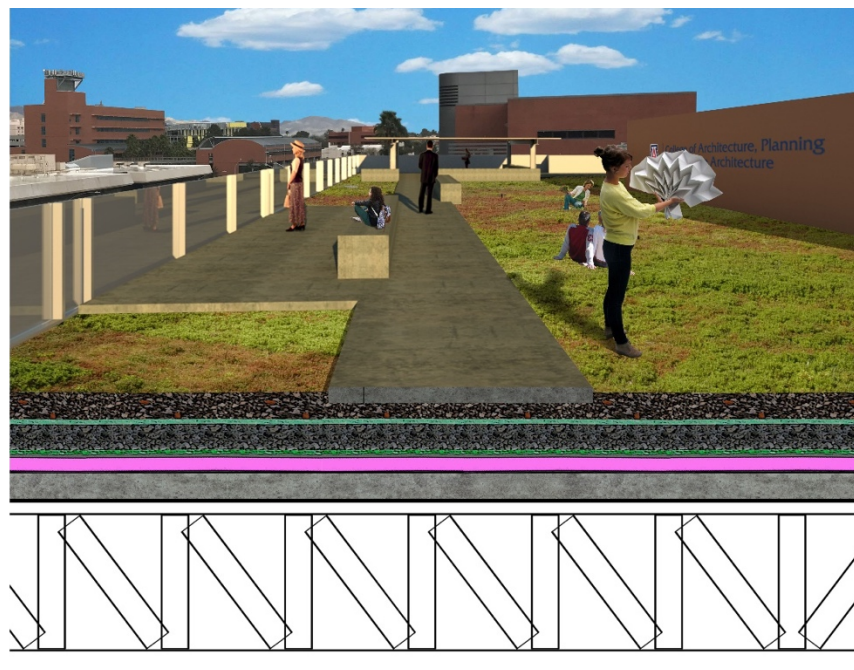


Figure 2: Green Roof Layers - Patricia Horn

Energy Savings

The United States Green Building Council estimated that commercial and residential construction buildings release 30% of greenhouse gases and consume 65% of electricity in the USA annually (Bianchini, 2012). Heating and cooling systems make up 54% of total energy use in buildings; this energy maintains internal building temperatures (Castleton, 2010). According to the US Energy Information Administration, Arizona's air conditioning energy consumption of 25% is more than four times the national average of 6%. Energy loss occurs throughout a building through walls, floors, attic, windows, and doors (EIA, 2016).

Recognizing and addressing areas where buildings experience unwanted heat gain or loss is the first step in solving the problem. Green roofs offer the potential for energy savings by reducing heating and cooling loads in a building, storm water management, and reducing air pollution and noise. Green roofs also improve a city's carbon footprint by converting carbon dioxide into oxygen through photosynthesis (Jaffal, 2012). Evapotranspiration generates a process called evaporative cooling. Dry climates experience increased benefits from evapotranspiration. Green roofs reduce heat loss in winter and heat gain in summer, and the hotter and drier the climate, the greater the effect of vegetation on urban temperatures (Alexandri and Jones, 2008).

Key Factors for Retrofit

A building's potential for green roof retrofit is the key factor when assessing energy savings:

1. Green roofs can significantly reduce energy use in buildings with poor insulation values, both in summer cooling and winter heating. When the roof is wet, it absorbs heat, which reduces temperature fluctuations. Dry roofs act as an insulator, which decrease the flow

of heat inward through the roof. This results in less energy needed to cool the interior of the building. In winter, the insulator effect means less heat is escaping the building through the roof. In summer, the vegetation reduces the surface and ambient air temperature, lowering the cooling demand inside the building (Bell, et al., 2008).

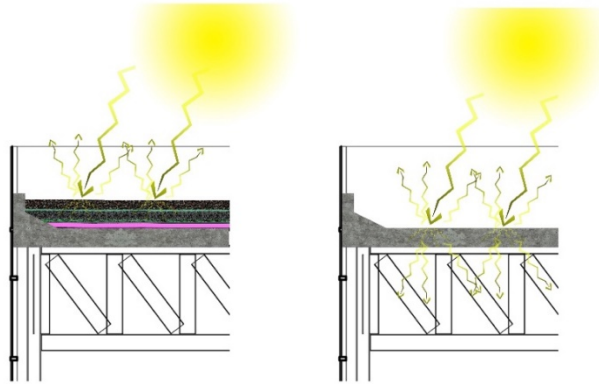


Figure 3: Insulation of a Green Roof (left) compared to a conventional roof (right) - Patricia Horn

2. The moisture content of the soil affects the extent of heat lost through evapotranspiration. In cases of wet soil, heat is drawn out of a building through evapotranspiration. The conductivity of the soil also increases with moisture content, meaning dryer soil conditions offer better thermal insulation.

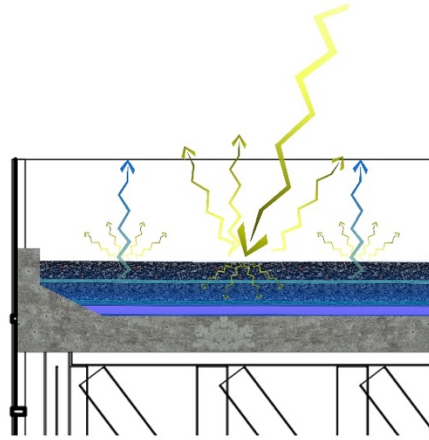


Figure 4: Evapotranspiration effect of a Green Roof - Patricia Horn

Methodology

This capstone will investigate the application of a green roof on the CAPLA building in Tucson, Arizona. Research consisted of a mixed-methods approach. This included extensive research of current literature on the benefits of a green roof as qualitative data, and the collection and analysis of prior research incorporating quantitative data in determining predicted costs and performance benefits. A survey was also circulated among faculty and students of CAPLA, and 50 occupants responded. The survey consists of yes or no questions, as well as a ranking portion for uses of the roof.

Data and Results

In recent years, there has been a move toward green/sustainable construction in designing buildings. The United States Green Building Council promotes the “design and construction of buildings that promote environmentally responsible, profitable, and healthy places to live and work.” These practices not only contribute to energy savings, but also reduction of emissions, and re-use and recycling of materials (Bianchini, 2012). LEED, Leadership in Energy and Environmental Design, is a green building rating system that encourages an integrated design approach to improve the sustainability of buildings. LEED targets include reductions in energy use and improvements in indoor environment quality.

Energy Savings

The data collected in Blackhurst, et. al. (2010) considers the replacement of only 30% of a building’s roof with a green roof, and predicts the associated energy and cost savings over a 30-year horizon. The building types assessed were single-family, multifamily, and commercial. CAPLA is a commercial building, and can accommodate a green roof on more than 30% of its surface.

Table 1: Reductions in Storm-Water Runoff from Green Roof Installations over a 30-Year Planning Horizon

Building type	Runoff reductions (million gal.)	Public benefits
		Market value of runoff reduced (\$1,000)
Single family	540	\$1,200
Multifamily	33	\$74
Commercial	67	\$150
All categories	640	\$1,500

(Blackhurst, et. al., 2010)

Table 2: Reduced Electricity Use from Green Roof Installation over a 30-Year Planning Horizon

Building type	Electricity use reductions (MWh)				Private benefits	Public benefits
	Private		Social		Market value of energy savings (\$1,000)	Market value of energy savings (\$1,000)
	Direct energy savings	UHI energy savings	CSO energy savings	Total		
Single family	4,700	67,000	530	67,000	\$210	\$7,200
Multifamily	790	11,000	32	11,000	\$34	\$1,200
Commercial	3,500	28,000	67	28,000	\$150	\$3,100
All categories	9,100	110,000	640	110,000	\$390	\$12,000

Table 2 indicates that the energy cost savings within a building that has 30% of its roof area retrofitted with a green roof are predicted to be much lower than the value of public benefits through reduced expenses incurred due to urban heat island effects (Blackhurst, et. al., 2010).

Table 3: Greenhouse Gas Reductions from Green Roof Installation over a 30-Year Planning Horizon

Building type	GHG reductions (MT CO ₂ eq)				Total GHG mitigation	Public benefits
	Direct energy mitigation	UHI energy mitigation	CSO energy mitigation	Sequestered		Market value of CO ₂ mitigated (\$1,000)
Single family	3,300	47,000	370	390	51,000	\$630
Multifamily	530	7,700	20	24	8,300	\$130
Commercial	2,300	19,000	46	49	21,000	\$340
All categories	6,100	74,000	436	470	81,000	\$1,100

Table 3 examines the value of greenhouse gases mitigated due to a 30% surface-area green roof retrofit (Blackhurst, et. al., 2010).

Cost

Table 4: Cost of Green Roof Application

Extensive Roof Costs	Per square foot
New construction cost	\$10.00-\$15.00
Retrofit cost	\$1.03-\$1.66 annualized over 30 years
Maintenance cost	\$0.75-\$1.50 (decreases over time)

(Wong, et al., 2011)

The area of CAPLA's roof capable of being retrofit with a green roof is approximately 10,850 ft² (~70%).

Survey

60 CAPLA occupants were asked to complete a survey regarding retrofitting CAPLA with a green roof, and 50 responded. This sample is a biased sample because it consisted of friends and acquaintances, as well as their friends. The conclusions drawn may not be statistically significant due to the given population of the CAPLA community and how many participants there were in this survey. This survey consisted of two parts. There was a yes/no question regarding interest in CAPLA installing a green roof, and additional questions about potential uses. The ranking portion of the survey addressed how occupants predicted students and faculty would utilize a green roof, on a 1-5 Likert scale (one being least likely anticipated use, to five being most likely anticipated use).

Table Five presents the results of the yes/no questions regarding whether the CAPLA community would like to have a green roof. Results overwhelmingly demonstrate an interest in

a green roof. Only a few people stated that they would not use the green roof space, and the entire sample feels CAPLA would benefit from a green roof.

Table 5: Social Survey Conducted Among CAPLA Faculty and Students

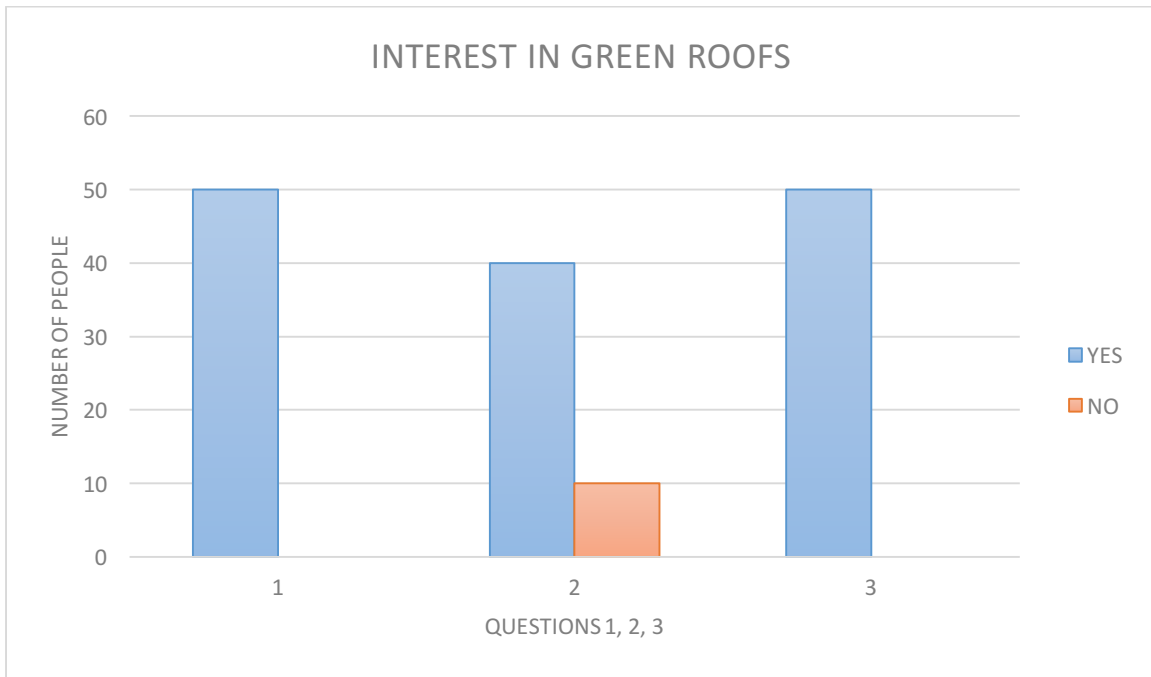
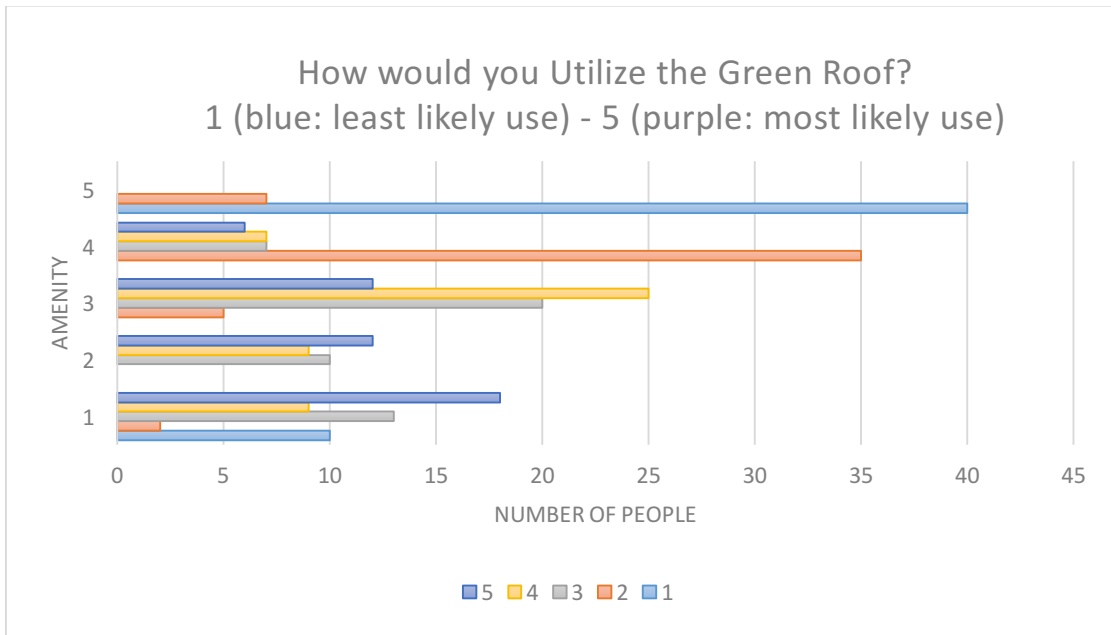


Table Six addresses the ranking portion of the survey. The respondents were provided five potential uses of a green roof space, and respondents were asked to rank how they would expect to use the space in order from one (least likely use) to five (most likely use). The most anticipated uses were options 1-3; these consisted of having a place to hang out, a place to study, and a quiet place. Interest in option 4, a place to garden, was lacking. Option 5 indicated that they would not utilize the green roof, and only a few people stated they would never utilize the space.

Table 6: Social Survey Conducted on How the Space Would be Utilized



Conclusions and Discussion

Commercial buildings are most efficient when all three tenets of sustainability are addressed: environmental, social and economic. Green roofs are economically desirable in reducing the urban heat island effect in hot arid climates like Tucson. By providing additional insulation to buildings, green roofs result in less heat entering through the roof, requiring more air conditioning usage in the summer, and less heat escaping in the winter, requiring less heating energy use in the winter. Implementing an extensive green roof on CAPLA would provide energy savings and other considerable value through public benefits, with a relatively short payback period.

Studies show energy savings alone in commercial buildings may not be enough to justify the cost of a green roof, particularly if the surface area of a green roof is limited to 30% of the total roof area. Through energy savings, the payback period of such a roof may be 60 years or more. (Blackhurst, et. al., 2010). It is not appealing to many owners considering a green roof if the payback period is incredibly long. While evaluating the energy saving benefits, it is crucial to consider the value of the public benefits as well. The public benefits include greenhouse gas reduction, improved storm water run-off, as well as the social benefits of a green roof and the cost savings to society through reducing all buildings' energy use by reducing the urban heat island effect.

According to Blackhurst et al. (2010), the two primary benefits that come from a green roof application. There are the private benefits, which include the economic benefits of direct building energy savings, and the public benefits, including the environmental benefits to the community. The results of the predictive data collected in the tables above show that it is not very cost effective to implement a green roof on a commercial building, or any type of home for

that matter, for building energy savings alone. However, the data collected from the Cost-Effectiveness of Green Roofs only takes into account a green roof only taking up 30% of the entire roof space. This study is conservative in taking into account HVAC systems, hardscapes for people to walk and sit on and other utilities. (Blackhurst, et. al., 2010). On CAPLA's roof, up to 70% of the roof area could be transformed into a green roof. This would result in a green roof being more directly and indirectly cost effective. Even though Blackhurst et. al. (2010) state it is not explicitly cost effective in private benefits (direct building energy savings), they do put a market value on some of the public benefits intrinsic to a green roof. The predicted monetary value of a green roof mitigating urban heat island effect, which provides both private and public benefit, is alone enough to justify the expense of a green roof.

Social benefits of green roofs also encourage a healthy lifestyle and wellness. These benefits are particularly difficult to quantify monetarily, but can include cost savings due to the improved productivity of employee occupants, and a reduction in the amount of sick time taken. Not only can green roofs improve the human thermal comfort of building occupants, it can also improve human thermal comfort outdoors. The survey conducted with the students and faculty of CAPLA addressed whether they thought implementing a green rooftop would be beneficial, and how they personally would utilize the space. The conclusions demonstrate the CAPLA community anticipates benefiting from and utilizing the space through activities like having a place to relax and study.

Limitations

While conducting my research I noticed there was a lack of investigation into the specific application of green roofs in hot and arid regions. This makes some sense because it is easier to implement a green roof in a more temperate climate with a greater amount of rainfall and less

harsh summer temperatures. I felt this hindered my ability to decipher whether or not it would be beneficial to implement a green roof on CAPLA. These limitations offer opportunities for valuable future research in this area of exploration.

Future research may also include looking further into sustainable strategies for implementing a green roof. Shading strategies are important to include in a green roof in this harsh environment, to enhance the comfort and quality of the space for those desiring to enjoy it. Another important consideration in this harsh environment is the vegetation selected. It is important to research vegetation that is highly drought-resistant with shallow roots.

Appendix

Social Survey

1. Would you like a green roof on CAPLA? (College of Architecture, Planning, and Landscape Architecture)?
2. Would you utilize the space?
3. Do you see implementing a green roof as a benefit to CAPLA?

Likert Scale

Rank in order from 1 (least likely use) – 5 (most likely use) how you would expect to utilize a green roof space

___ Most likely wont use it

___ A place to garden

___ A place to study

___ A quiet place

___ A place to hang out

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