North Carolina Guide to Green Roofs

Bass Connections: Energy and the Environment Capstone
Final Report
sites.duke.edu/ncgreenroofs

Figure 1: Cover Page of North Carolina Guide to Green Roofs on Desktop

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Executive Summary

We have created a website, *North Carolina Guide to Green Roofs*, to inform people, specifically in North Carolina, about the benefits of green roofs and best practices for their upkeep. Our team hopes that we can spread this information to increase the implementation of green roofs across the state and to lower their high failure rates. The topics we chose for our website include Native and Regional Plants, Green Roof Structuring, Irrigation Tips, Local Examples, and NCDEQ Guidelines, as well as an explanation of our experiences speaking with local green roof owners. We chose these topics based on a Pugh Matrix that we scored with our goals for the website. We then went through a process of beta testing by sending a survey with questions about the educational component and ease of use of the website. We provide in this report an overview of our research and experiences with local green roofs that have made up the content of our website. We plan to promote this website to people in the North Carolina area who are looking to build or sustain their own green roofs.

Introduction

Motivation

Green roofs are an established energy and environmental technology that provide multiple benefits, however there is a lack of cohesive and localized resources for those looking to install or learn more about them. Some of the benefits of green roofs are increasing recreational green space in urban areas, reducing energy and heating costs for buildings, and improving stormwater treatment. However, it has been shown that green roofs tend to fail, preventing this technology from reaching its true potential. Even here in North Carolina (and on Duke's campus), the green roof longevity rate has been less than stellar. Therefore, having a centralized resource guide tailored to localized needs, guidelines, and weather, could improve the installation, maintenance, and overall success rates of green roofs in North Carolina. This report will detail the process and research findings used to help develop a Duke website with resources specialized to the region along with testimonials regarding multiple green roofs in North Carolina and at Duke to find out what makes a green roof successful.

Background Information

Green roofs pose a relatively innovative approach to conserving energy and reducing heat all while simultaneously bettering the aesthetic of urban centers worldwide. Yet, on average green roofs tend to have a high failure rate in the long-term. A case study on vegetated roofs in Portland, Oregon revealed that green roof failure averaged 2.94% annually, while industry experts measured the average total failure rate at 20.17% per year (Thurston 2017, v). This disparity in failure rate goes to emphasize the lack of uniformity and common practice in the vegetated roofing industry. Furthermore, these shortcomings in the longevity of green roofs range from deficiencies in technical design to poor asset management. Although green roofs are expected to last at least 20 years after inception, the study found that in 52 of the sites observed partial failures started arising after only 5.96 years on average (Thurston 2017, 126). It is evident that a major failure of green roofs currently is the lack of data collection and knowledge about the breakdown of previous green roof projects. To help in this regard, our team wanted to learn, organize, and spread information concerning green roofs with a focus in North Carolina. Through our online site, NC Green Roofs, we hope to educate prospective green roof developers on important aspects of green roof construction as well as create a platform to share information in our blog section of the website. Overall, the task of designing and maintaining a green roof is extremely extensive and requires a strong database to provide information about green roof procedures.

Technical Design

Website Design and Platform

NC Green Roofs is hosted on Duke University's Sites@Duke service. This service is a way for students to host websites or blogs at no additional cost. The service uses Wordpress, a visual-based website development software. Our team ultimately decided to use Sites@Duke and Wordpress to minimize costs of website maintenance, allow for ease of editing across all members of the team, and keep website technical details simple. Within Wordpress, we tested several different design templates, ultimately settling on the theme *Lovecraft*. Since our scope of research and target market only pertains to North Carolina, we used a photo of the green roof on the Durham County Main Library as the cover photo for our website. Upon opening the website, there is a greeting message from our team outlining the purpose and mission of the website.

The website has six primary pages - each covering different aspects of green roof ownership or construction in North Carolina. Within Wordpress, there are two different forms of posting information: posts and pages. Posts (as seen on the opening page of the website) are timestamped, appear in reverse chronological order, and have an author attached. In our initial design of the website, we attempted to turn all of our research information into individual posts on the website that would be on different pages and could be sorted. However, upon creation of the website, we discovered that Wordpress does not allow posts to exist solely on pages - all posts would appear on the main page and continue to appear in reverse chronological order. This was not acceptable for our layout as we were not posting information that was connected to time.

As a workaround, our team decided to organize all of our information into six primary categories, which would become the static pages on our website. Each page would have our research presented in a static form, such that they were not disconnected from the page like a post. Each team member wrote and edited the content for their sections of research using the page functionality in Wordpress. We modified each page such that the content would appear in full-width as opposed to a 3/5ths width with a sidebar that is only relevant for posts. Lastly, photos on each of the pages were modified to be larger than the default settings in Wordpress and feature more prominently on each page.

Topic Selection Process

Once our team decided that we were going to create a website aimed at educating North Carolinians interested in owning/operating a green roof, we needed to establish what content we were going to research and ultimately present on the website. We decided to brainstorm several criteria and a list of potential topics and features. Each goal for our website received a weight and our team then scored each feature (column headers) on its ability to achieve the listed goal (row headers).

Goals	Weight	Plant selection based on region / climate	Regulations (building codes)	GIS Mapping and Helioscope (helping pick a location)	Cost calculator	Data integrable (watering/rain/solar/light)	Irrigation System Tips	List of what makes a successful green roof	Policy Recommendations for Local Governments	History of Green Roofs	Potential for solar panels	Information about infrastructure changes	Blog / testimonials	Forum for troubleshooting	Tips on finding volunteers
Success over time (feasibility and resiliency)	5	5	4	5	4	5	5	5	2	3	1	5	3	5	1
Cost effective/Cost Saving	4.5	3	1	1	5	2	4	1	1	1	3	3	1	2	1
Environmental benefits (ecological diversity, air quality)	4	5	1	3	1	4	5	1	2	1	1	1	1	2	1
Aesthetic design	1	2	1	3	1	2	3	2	1	1	2	2	1	1	1
Water efficiency	3	4	4	3	4	5	5	3	2	1	1	5	1	2	1
Energy saving	4	2	2	3	4	3	2	1	2	1	5	1	1	2	1
Government support	2	1	4	1	4	1	1		5	2	2	1	1	1	1
Local institution or community outreach (information for schools, other groups)	3	1	5	2	5	1	1	5	4	2	1	4	2	2	5
Community building	1	1	1	1	1	1	1	2	3	3	1	1	3	1	5
Recreational benefit and community health	3.5	5	1	2	1	1	1	4	4	3	1	1	4	1	3
Score		104	77	81.5	103	88.5	98.5	79.5	76.5	55	59	82	56.5	69.5	54

Table 1: Pugh Matrix of Website Features

From our original Pugh Matrix, plant selection based on region, a cost calculator, data integrable (live data monitoring tools) and irrigation system tips were essential to achieve the overall goals of our website. However, over the course of the project, we realized that the Wordpress platform limited our ability to dive deeper into data based features. We decided to pivot this part of the work into an interview/experiences portion focused on local examples of green roofs in North Carolina.

In our final version, we include research on native plant species, irrigation tips, green roof structuring, local examples, North Carolina Department of Environmental Quality (NCDEQ) guidelines for green roofs, and narrative experiences about interviews we conducted with local owners/operators of green roofs. Each of these topics aims to provide foundational information about green roofs to someone interested in obtaining a green roof on their home or commercial building. As with our mission, these topics do not aim to be substitutes for a professionally licensed contractor. Our website and research routinely encourage potential green roof owners to seek out professional guidance on their green roof and to use our website as a learning tool as opposed to a construction manual.

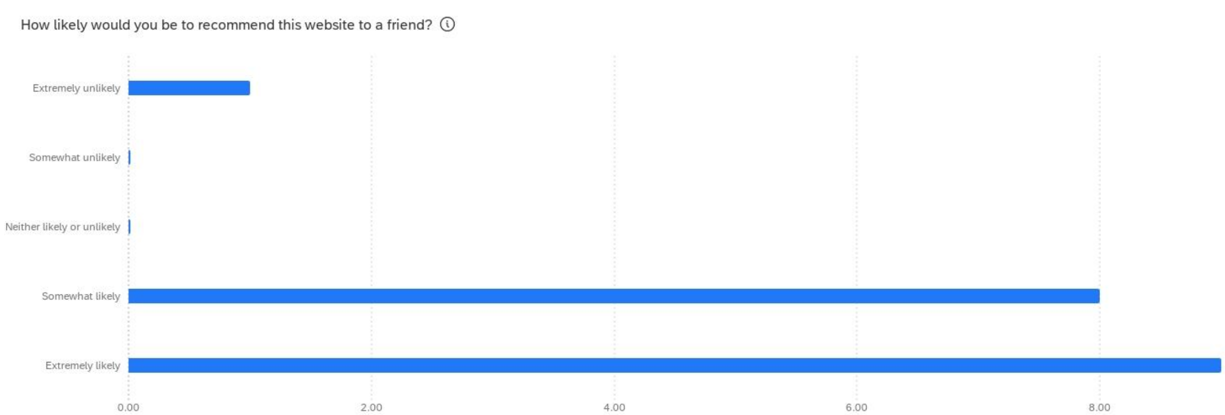
Beta Testing

We decided to beta test our website to ensure the quality of the site and end-user experience. Furthermore, we wanted to hear feedback from individuals about the information they learned on the site and if there is anything else that they think should be added.

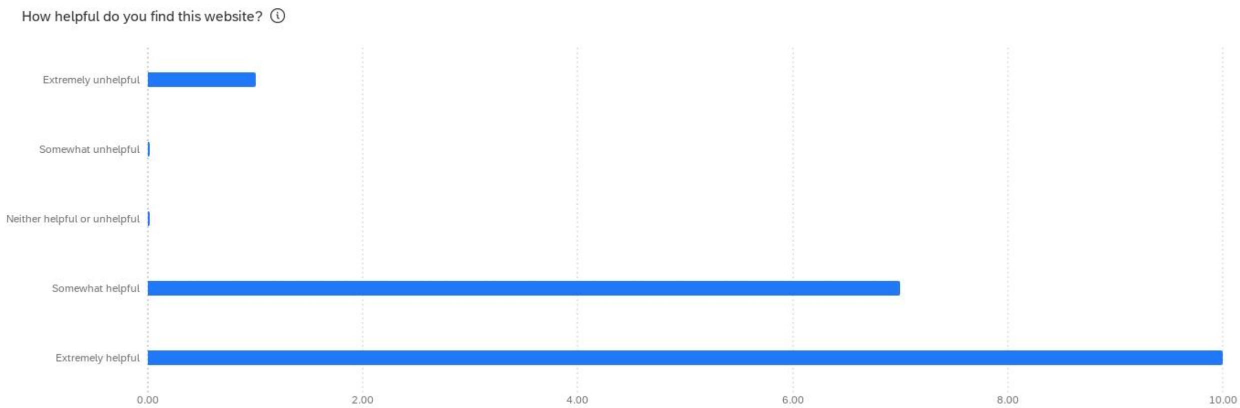
We utilized a Duke Qualtrics form to create our beta test due to its ease of use, cost, and end-user experience. We asked our beta testers seven questions, two of which were free-response and five that were multiple choice. The questions were asked as followed:

1. How likely would you be to recommend this website to a friend?
2. How helpful do you find this website?
3. How easy was this website to navigate?
4. Do you feel better informed about green roofs?
5. Did you like the interface and design of the website?
6. What recommendations do you have for us?
7. Any additional thoughts or questions?

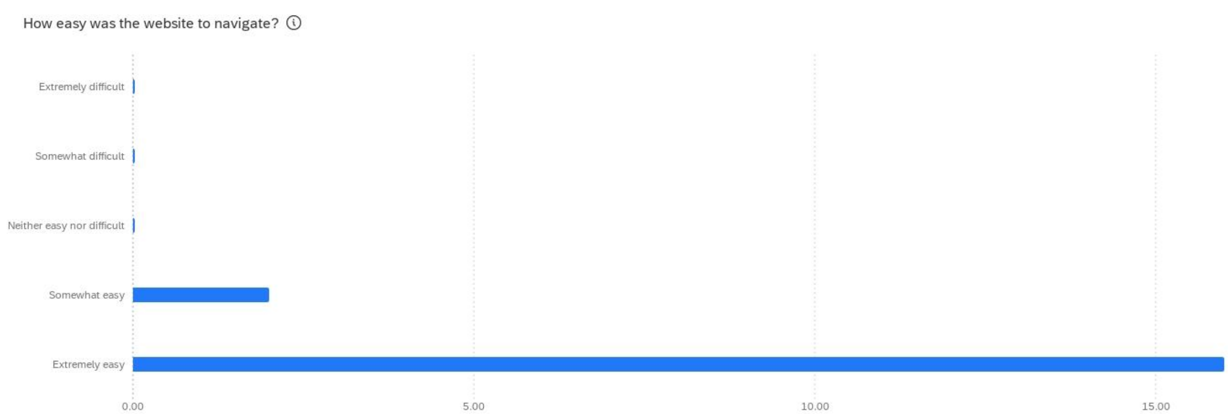
The first five questions were multiple choice with five possible answers: extremely unlikely, somewhat unlikely, neutral, somewhat likely, and extremely likely. The adjective used changed for each question respectively. The last two questions were free-response and allowed users to provide commentary.



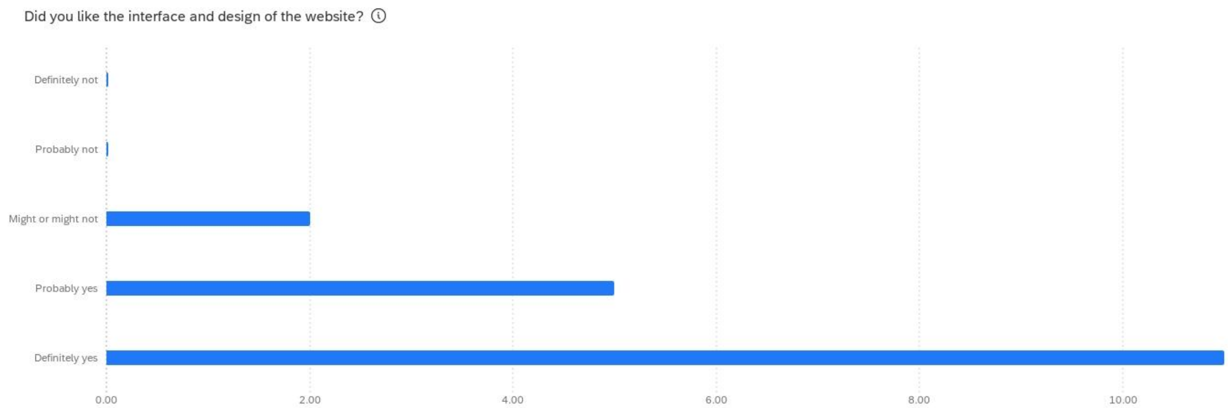
5.6% of beta testers were extremely unlikely to share the website with a friend
44.4% of beta testers were somewhat likely to share the website with a friend
50.0% of of beta testers were extremely likely to share the website with a friend



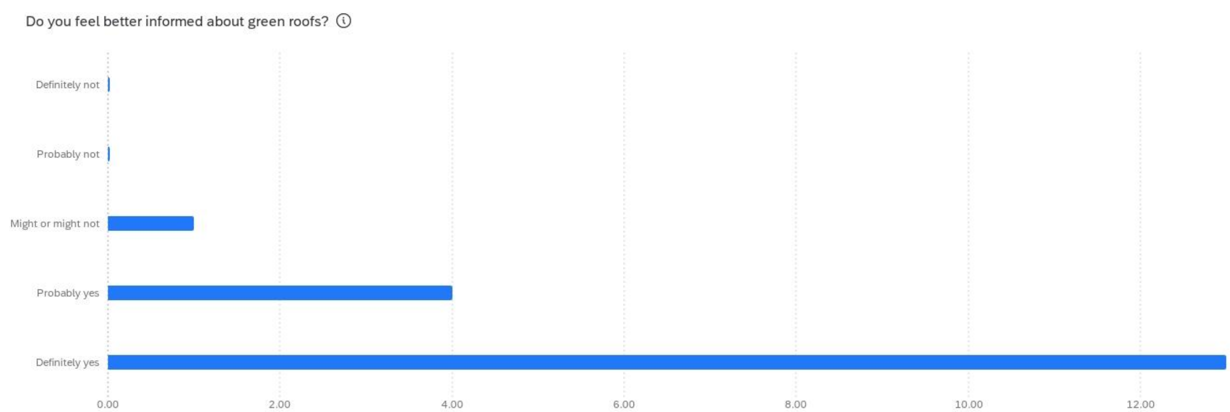
5.6% of beta testers found the website extremely unhelpful
38.9% of beta testers found the website somewhat helpful
55.6% of beta testers found the website extremely helpful



11.1% of beta testers found the website somewhat easy to navigate
88.9% of beta testers found the website extremely easy to navigate



11.1% of beta testers felt indifferent about the interface and design of the website
27.8% of beta testers somewhat liked the interface and design of the website
61.1% of beta testers definitely liked the interface and design of the website



5.6% of beta testers felt indifferent about being better informed
22.2% of beta testers probably felt better informed
72.2% of beta testers definitely felt better informed

The key feedback that we received from the free response portions of the beta testing was to include more photographs throughout the website. One beta tester said best that “adding more media (i.e. pictures, videos, something engaging) could really improve the site!”. We implemented this feedback by including more visuals throughout the site to break up some of the longer pieces of text.

Topics on Website

Native and Regional Plants

North Carolina is home to three primary climatic regions: the Mountains, Piedmont, and Coastal Plains. Rain, temperature, and growing season can vary across the regions (Gilmour 2021).

The Mountains

The Mountains region covers the western part of North Carolina and includes the major cities of Asheville, Boone, and Wilksboro. The Mountains region is the southernmost part of the Appalachian Mountain which runs along the Eastern coast of the United States.

Average rainfall in the mountainous region ranges from 40-80 inches, making it the wettest part of North Carolina. Temperatures during the day range from about 40°F in the winter months to 85°F in the summer months. The region has approximately 175 growing days, compared to the Piedmont and Coastal Plains which each have over 200 growing days (WeatherSpark 2022).

The Piedmont

The Piedmont region extends through the middle of North Carolina and includes major cities such as Greensboro, Durham, Raleigh, High Point, and Charlotte. The Piedmont continues south through Alabama and north to New Jersey, buffering the Appalachian Mountains from the coastal plains.

The Piedmont is a fertile region with level geography and many rivers. Loam and clay-loam typically constitute the soil here, although some areas are higher in sand. The sand content is important to note, as sand loses moisture and heats up faster than loam or clay (“North Carolina - Climate | Britannica”, n.d.).

The region experiences mild weather, although thunderstorms tend to strengthen and develop over the region due to a meteorological phenomenon known as the Piedmont Trough. According to the Piedmont Triad International Airport in Greensboro, the growing season, or the longest continuous period without freezing temperatures, of the region is 224 days on average, from around March 29 to November 8. Temperature in the Piedmont generally stays between 31ºF and 87ºF, rarely going more extreme than 18ºF and 94ºF (WeatherSpark 2022).

Thanks to its stable climate, the Piedmont can sustain many different types of plantlife, including unique native varieties.

The Coastal Plains

The Coastal Plains are home to the famous Outer Banks of North Carolina and include the major cities of Fayetteville and Wilmington. The Coastal Plains line the eastern part of North Carolina and border the Atlantic Ocean.

Monthly average rainfall in Greenville ranges from 2.7 to 4.8 inches, the month with the highest being August, and average annual rainfall in the region ranges from 40-80 inches, making it the wettest in North Carolina. The regional growing period is about 275 days, from late March to early November. Like in the mountains, daytime temperatures range from about 40°F in the winter months to 85°F in the summer months (WeatherSpark 2022).

The Plains receive more rainfall than the mountains or the Piedmont and host temperatures slightly warmer than the Piedmont year round. Still, similar to the Piedmont, the stable climate allows the Plains to play host to many different species of plant wildlife. As with all green roofs, groundcover and sedges will keep the roof weight light and provide a low-maintenance option to engage with the native flora of North Carolina.

Native Plants

Using native grasses rather than *sedum* or stonecrops when populating a green roof can decrease costs, increase longevity, support biodiversity, and build understandings around land justice.

- **Costs**: Estimated to cost \$4.82/ft^2 more to plug sedum than seed native grasses (Sutton, n.d.).
- **Longevity**: Seeded green roofs often reach 80% cover by the end of the first growing season while plugged roofs take 2-3 seasons. They also require less nitrogen and less fertilization. Because native grasses have more underground biomass than sedum, they are heartier during the winter months, although this does mean that more biomass removal is required during routine maintenance (Sutton, n.d.).
- **Biodiversity**: Polyculture green roofs support faunal diversity, and native grasses are capable of well supporting their local ecosystems through pollinators and birds. Seeded roofs do face the same weeding issues and needs as plugged roofs (Cook-Patton and Bauerle 2012).
- **Land Justice**: Planting and cultivating native grasses rather than exotic species can help restore respect and strength of local ecosystems in urban spaces (Dvorak 2021).

Plant Options (Grissom 2013)

Smaller grasses are preferred for extensive green roofs with shallower soil systems. However, there may be aesthetic or ecological needs for mid-size and larger grasses.

Smaller grasses:
- Sideoats grama, *Boutelous curtipendula*
- Purpletop, *Tridens flavus*
- Lovegrass, *Eragrostis sp.*

Mid-size grasses:
- Broomsedge bluestem, *Andropogen virginicus*
- Little bluestem, *Schizachyrium scoparium*

Larger grasses:
- Big bluestem, *Andropogon gerardi*

- Eastern gamagrass, *Tripsacum dactyloides*
- Indiangrass, *Sorghastrum nutans*

Green Roof Structuring

Introduction

The first step in assessing whether or not to build a green roof is determining the purpose of the green roof. Intensive green roofs offer greater flexibility for owners interested in growing a larger variety of vegetation for aesthetic or consumption purposes, but this comes at the cost of greatly increased soil depth, water consumption, and ultimately weight. Extensive green roofs are much more minimalist in design while also providing environmental benefits, but can only sustain specific vegetation tailored to low soil depths and water requirements (Green Roof Plan, n.d.).

Green roofs can be built on flat or slanted roofs, where slanted roofs provide the advantage of requiring less materials due to natural water runoff. After finding a suitable location, the next step is to assess the roof integrity and determine if it is capable of sustaining a green roof. A structural engineer will be needed to fully assess the building's strength ("Everything You Need to Know About Green Roofing" 2019). Some additional considerations may include roof height and local wind speeds to ensure that the green roof and its vegetation can resist potentially damaging uplift forces (Single Ply Roofing Industry 2016).

Pitch

Once a roof has been selected and can sustain the type of green roof you're interested in building, the next step is to build it on a pitch of a minimal degree that will allow excess rain to drain and prevent moisture build up. Ideally, a layer of pitch should be at least a quarter inch thick per foot of run, or a little more than one degree or 2% ("Everything You Need to Know About Green Roofing" 2019).

Waterproofing

Following the pitch, comes waterproofing the green roof. Waterproofing a green roof is extremely important as leaks could severely damage the building. To waterproof the green roof assembly, one must first place a membrane. This membrane is usually an EPDM membrane constructed out of rubber and its two main ingredients are ethylene and propylene. EPDM's versatility and durability makes it an ideal candidate for the bottom layer of the green roof. Its flexibility also enables EPDM to be applied to the roof at a gentle positive slope to help with drainage. There are several other alternatives to EPDM membranes such as: coal-tar, polymer-modified asphalt membrane, butyl rubber membrane, and many others. All of these membranes are sensitive to when ambient temperatures drop below freezing.

Trays

The next step is to now procure or make your own green roof tray. The green roof trays are where your plants will be grown, and each plant tray should be cultivated for at least four months before installing them onto the roof (Kay 2020). It is suggested to purchase a green roof tray from a supplier or contractor, where the materials and design of the tray will be optimized for irrigation and weight. Furthermore, trays from suppliers will contain the proper growth media and soil to meet your green roof needs.

Tray Installation

The final step is to install the trays onto the roof itself. In addition to the waterproofing and pitch redesign, aluminum edging should also be added to help with integrity, keeping the plant trays locked and together, as well as helping with aesthetics of the roof ("Everything You Need to Know About Green Roofing" 2019). Installing the trays depends on the provider, but generally trays can be placed down starting from the bottom of the roof and then should be placed flushed together. Trays may have connectors to assist with this process, and you may also need to consider cutting the trays to ensure that the roof is perfectly covered with your vegetation.

Irrigation Tips

Understanding Irrigation Issues – Green Roofs vs. Conventional Landscapes

Improper irrigation is one of the largest sources of green roof failure and can be difficult to understand given the differences in requirements for green roofs and typical gardens. It is important to understand the different types of soil profiles for green roofs and how these can promote irrigation issues.

Extensive green roofs consist of 2 to 6 inches of soil and grow mostly native plants and sedums, while intensive green roof soil is 6 inches or deeper and functions mostly the same as a conventional garden. The majority of green roofs are extensive (Nektarios 2018). The soil of extensive roofs is more coarse and does not conduct water as effectively as intensive soil which is like traditional garden soil with more organic material. The depth of soil has been proven to be the most important factor in a green roof's ability to retain rainfall ("Green roofs" 2022).

In a typical garden, farm, or natural soil scenario, the soil profile is 4-8 feet deep and has a clay-like texture which directs water through cracks in the soil toward reservoirs that easily absorb and saturate the soil. Most of the differences in moisture that occur in the soil due to uneven rainfall distribution are evened out by this process of redistribution and absorption (Warmerdam 2020). Green roof soil, however, is specially engineered and made high in minerals with less than 8% organic materials. It is much more porous than traditional garden soil and does not compensate for uneven distribution of rainwater in the same way that a natural landscape would. Because of the reduced capillary forces in the soil, most of the water travels downward and leaves large dry areas ("Green roofs" 2022). Green roofs can usually absorb the first inch of stormwater, but a study showed that 30-50% of total rainfall flows through the gaps in the bottom of the trays that contain the plants before saturating the soil (Warmerdam 2020).

By understanding the different levels of irrigation required for green roofs, we can create more efficient and manageable landscapes with lower rates of failure.

Choosing the Right Irrigation System for Your Roof

The most common types of green roof irrigation systems are drip and spray. We will discuss the positives and negatives of each to help you in choosing which system is right for you.

Drip irrigation is considered more efficient because the system delivers water directly to the location of the plant, allowing irrigation to specific plants. However, as discussed above, the porosity of the soil prevents drip from providing an even spread, so this type of irrigation is ideal for smaller areas. Though it may appear that drip uses less water, it actually uses about the same amount as spray given the uneven soil absorption ("Green roofs" 2022). Spray irrigation, on the other hand, is less efficient at reaching certain parts of the roof since it can be affected by sun and wind. It is useful for cooling down plants though, which is necessary for proper growth, and takes less time than drip. There are spray systems, like rotating stream nozzles, which produce larger water droplets to counter the effects of wind ("Next Level Stormwater Management – Green Roof Irrigation", n.d.). Your best irrigation type will depend on many factors including your climate, plant species, and roof size and pitch. Typically a combination of both drip and spray is recommended ("Assessing Water Demand of Green Roofs Under Variants of Climate Change Scenarios" 2019).

The level of irrigation required for your green roof depends mostly on the type of plants. Roofs containing mostly native species require less watering than those that are more like gardens, which require more time for regular maintenance. The average green roof needs to be watered about twice a week for about 15 minutes, based on the recommended time of your specific irrigation system. This time though should be adjusted for plant species, climate, and roof size ("Next Level Stormwater Management – Green Roof Irrigation", n.d.).

Some add-ons that can take your system to the next level include weather sensors to control changing irrigation levels and winterizing measures that will help to sustain your roof in colder climates. Additionally, to help with even spread of soil irrigation, you can find geotextile fabrics and other materials that imitate the distribution of typical soil to catch and redistribute excess water (Warmerdam 2020).

Local Examples

Through our research on green roofs in North Carolina, we learned that they are spread throughout the state and mainly on larger, commercial buildings due to the extensive upkeep and maintenance. We included seven examples to serve as a visual inspiration for our readers to get excited about including a green roof. Our examples are located in Durham, Chapel Hill, Asheville, and Beaufort so that readers from across the state have examples that fit their region.

Each example includes the location, date of completion, the kind of green roof system, size in square footage, plant material, architect, and a photograph. We included location and date of completion to give readers an understanding of when and where these examples were built. Additionally, we wanted to share structural information (i.e. the type of system, size, and plant material), so that readers understood the best practices for their region and building type in real-world use cases. The information for the architect is also included so that readers can contact the architect that is closest to them and the creator of their favorite example. Lastly, we included photographs of each green roof to inspire potential dream designs for readers.

NCDEQ Guidelines

To tailor the website to North Carolina, our website includes guidelines dictated by the North Carolina Department of Environmental Quality (NCDEQ). Since the main focus of this website is to improve the success and longevity of green roof projects, adhering to local guidelines is imperative, since the weather patterns and vegetation is unique to the region. This page will be a summary of the key information to maximize the stormwater treatment qualities of green roofs ("C-8. Green Roof" 2017).

North Carolina considers a true green roof to be a roof that is either fully or partially covered in vegetation with a growing medium (soil) over a waterproofing membrane. North Carolina does not consider lined growing containers to be a true green roof.

Major Categories of Green Roofs

1. Shallow: Extensive roof with engineered soil-base growth medium between 2-6 inches.
2. Moderate depth: Semi-intensive roof with engineered soil-base growth medium between 6-1- inches.
3. Deep: Intensive roof with engineered soil-base growth medium greater than 10 inches.

There are two major types of green roof types: intensive and extensive. Intensive green roofs start at a soil depth of 6 inches and make use of much larger plants and vegetables, causing them to weigh as much as 150 lbs/sqft. On the other hand, extensive green roofs have shallower soil depths ranging from 1.6 to 6 inches and make use of specialized grasses and succulents that consume much less water while providing thermal benefits to the building. Furthermore, extensive green roofs are much lighter, ranging from 10 to 35 lbs/sqft. It has been shown that extensive green roofs have longer lifespans and lower energy is needed to grow and maintain them, while still reaping the climate benefits of building a green roof. It is recommended that those who want a lower maintenance space with native plants invest in an extensive roof system as opposed to an intensive roof system.

Growth Media

Per NCDEQ guidelines, the maximum percentage of organic material in growth media cannot exceed 10%. The primary purposes of growth media (the soil mix on top of the permeable layer of a green roof) are to prevent water and nutrient runoff, support plants and greenery, withstand various weather and degradation, be lightweight, and support foot traffic occasionally.

It has been shown that a mix of 80-95% of lightweight aggregate (LWA) and 5-10% organic matter can best achieve these goals. It is not recommended to add additional organic material after plants have been established because it will cause nutrient loading. Garden soil is also not recommended because it causes high runoff.

Design Volume

The design volume for the roof is equal to the depth of the growth media multiplied by the plant available water (PAW). A green roof can treat a maximum of 1.5 inches of rainfall. Green roof suppliers will know the hydraulic properties of the media. The equation for the design volume (DV) of a green roof is as follows:

$$DV = PAW * \text{Depth of Media} * \text{Area of Roof} * 1/12$$

Minimum Media Depth

The minimum media depth for a non-irrigated roof is 4 inches and for an irrigated roof is 3 inches. Irrigation plans must be included in the Operation and Maintenance plan.

It is essential to include at least 4 inches of media to ensure the health and success of green roof plants, due to hot and dry seasons in North Carolina. 4 inches of media is still considered an extensive green roof (2-6 inches). It is recommended to have a drainage layer under the media.

Vegetation Specification

The vegetation plan should be planted such that there is 75% vegetation cover within two years of planting. This plan will maximize stormwater treatment capabilities and also provide the 'cooling effect' which is one of the many environmental and cost-saving benefits of green roofs. Some ways to improve vegetation success include:

- installing photovoltaic cells or solar panels to reduce sun exposure and intensity
- place walls around vegetation to reduce wind exposure
- create non-vegetated paths to reduce water evaporation

Slope

A slope for a green roof cannot exceed 8% unless there is a container around the roof. Sloped roofs can provide aesthetic advantages since they can be seen from the ground, and since some buildings have sloped roofs they may be required to retrofit. Sloped media however are harder to maintain and are less effective at storing stormwater.

To summarize, these design practices can ensure the longevity and success of new green roofs in North Carolina. Overall, it is important to choose and grow vegetation that will require minimal maintenance, even if these plants do not grow produce or provide exceeding aesthetic value. Using the proper growth medium and depth is also important. Following these guidelines maximizes the environmental benefits of green roofs, including stormwater treatment and building cooling impacts. More information on the structuring of green roofs can also be found in this report.

Quantifying Benefits

Introduction

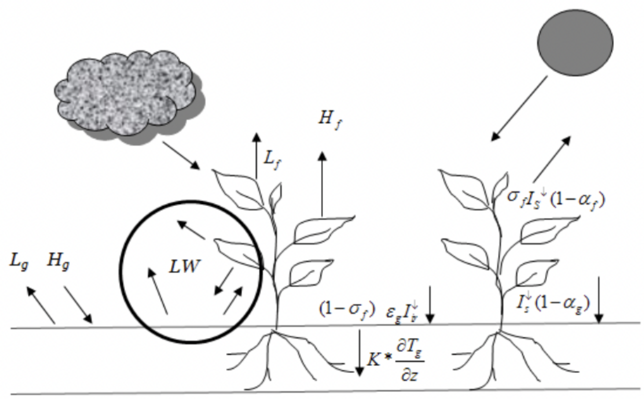
Green roofs have the ability to offer energy and thermal benefits to the buildings they cover. Dr. David Sailor, during his time with Portland State University, developed the "Green Roof Calculator" that is able to quantify the energy savings of a green roof in any major city in the US (Sailor, n.d.). His model makes use of Department of Energy (DOE) reference buildings in these locations to determine what annual electricity and gas loads consist of for office and residential buildings (Sailor, n.d.). Reference office buildings are specifically three story buildings with a floor area of 4,982 m^2 and 1,661 m^2 of roof space (Sailor et al. 2013). Meanwhile, reference residential buildings are four story buildings with a floor area of 3,122 m^2 and 780 m^2 of roof space (Sailor et al. 2013). Furthermore, these buildings are further segregated into "old" and "new" subcategories, where "old" buildings utilize 1980s architecture and insulation (Sailor et al. 2013).

Input Variables

The following variables that users can input into the website calculator are: building location, total roof area, building type, growing media depth, leaf area index (LAI), binary variable for whether the green roof is irrigated, percentage green roof coverage of roof, regular roof type, and option for current electricity and gas prices (Sailor, n.d.). The growing media depth refers to the depth of the media and the LAI refers to the ratio of the total upper leaf surface area to the surface area the vegetation covers, and this value can range from 0 to 6, 6 representing a very dense rainforest (Sailor, n.d.).

Calculator Model and Sourced Data

In order to calculate the thermal and energy benefits of a green roof, Dr. Sailor makes use of the energy balance model from EnergyPlus, a building energy simulator, that combines multiple variables including latent and sensible heat flux as well as shortwave radiation in addition to the user's input variables (Sailor et al. 2013). The other, non-input variables are collected from the location's specific weather data, which is sourced from Typical Meteorological Year 3 from the DOE weather repository in EnergyPlus (Sailor et al. 2013).



Energy Balance Model (Sailor et al. 2013)

Calculator Outputs

The primary outputs of the calculator are the electrical savings, gas savings, and total energy cost savings of the specified green roof in comparison to a dark roof, which is a roof with albedo (reflectivity coefficient) of 0.15, and a white roof, which is a roof with albedo of 0.65 (Sailor, n.d.). The calculator also includes additional output variables, such as average sensible heat flux and latent heat flux to the urban environment compared to conventional roofs and annual roof water balance (Sailor, n.d.).

Calculating for a Green Roof in Raleigh

From the calculator, it is evident that greater media depths, higher LAIs, having irrigation, and higher green roof coverage help to increase overall energy savings. However, the savings are not extremely significant in the long-term. We modeled an extensive green roof on an old residential building in Raleigh with a roof area of around 600 ft^2, growth media depth of 3 inches, LAI of 3, irrigation, 50% green roof coverage, and normal dark albedo roof for the rest of the roof. For the utility costs, we utilized a $11.62/kWh utility electricity rate to reflect average Raleigh electricity utility costs (Hope 2021). For the gas price, we utilized $1.32/Therm to represent the average January 2022 utility gas rate ("Raleigh, NC Natural Gas Rates" 2022). According to the calculator, this roof would save 56.3 kWh of electricity, 2.2 Therms of gas, or a total of $9.14 per year compared to a dark albedo roof. Compared to a white albedo roof, a white albedo roof would actually save 197.1 kWh more than the green roof. However, the green roof would actually save 15.7 Therms or a net $6.13 dollars per year. Green roofs pose much better benefits overall compared to dark roofs, but white roofs save more electricity while costing much more gas. However, it is important to note that these benefits are relatively small since these are calculated for an entire year. Thus, green roofs have the ability to provide only marginal benefits over normal dark and white roofs.

Green Roof Experiences

Duke Smart Home

The Smart Home is Duke University's on-campus example of sustainable design for a residential space. Built originally in 2007, the Smart Home serves as a residence hall for 10 students each year. Our team is interested in the Smart Home due to their use of a green roof on top of their building. Members from the Green Roofs Bass Connections team met with Amy Yoon, resident and lead gardener at the Smart Home, to discuss the green roof's maintenance and upkeep.

Yoon noted that the green roof was originally built as part of the home in 2007, but underwent a renovation in 2008 to incorporate drip irrigation. This renovation was done by a local North Carolina contractor our team is familiar with, called Living Roofs. Yoon said that drip irrigation was installed to minimize the day to day upkeep of the green roof – which is also difficult to access at the Smart Home.

The issue of access to the roof – and subsequent lack of routine maintenance – persists to this day. Yoon discussed how the gardening team had gone up once this year to the roof and that it was challenging to do so. She sent photos to our team of what they found on the roof. The Smart Home's green roof was originally designed to host sedum – a native plant to North Carolina. Today, there is some sedum but the primary plants visible are weeds.

Additionally, since the Smart Home is maintained by Duke Students – there is a lack of institutional knowledge transferred between the gardeners over their time at Duke. Yoon is a senior and does not yet know who the next gardener will be at the Smart Home after she graduates. She accredited this lack of shared knowledge over the years to be the primary explanation for why the green roof on the Smart Home has not been up-kept.

Durham County Library

We reached out to the Durham County Library for more information about how their green roof was doing and their maintenance protocols. The green roof is currently maintained by Living Roofs, INC. once a month during the blooming season. They are not tracking energy usage reductions or carbon emissions at this time. Overall, the green roof has been a success due to the consistent maintenance and upkeep performed by their contractor.

Grainger Hall Green Roof

The Grainger Hall green roof is managed by GROW (a student-run organization) and Duke University maintenance staff. The roof is split into two sides that are maintained differently. One side is intended to be low maintenance with native plants and a seating area. The designers of the roof wanted to create a sensory garden, so each part emphasizes either sight, smell, touch, or taste. Whereas the second half of the roof is used by GROW to grow crops. The organization has run into issues with student turnover and lack of oversight during the summers due to students leaving for internships. The member of GROW that we spoke to identified that having a key person to help maintain the records and mission of the roof is vital to the success of any green roof.

The green roof is permeable and the collected water is used for toilet water throughout the building. Furthermore, according to a member of the Nicholas School of the Environment, the plan for irrigation “was to create automated water features ” that included regulated flow from Grainger Hall as well as “manual water features,” i.e., hose with faucet.” These features, as well as, the seating area are for larger buildings and unfortunately would not be feasible for a single-family home.

Green Roofs for Healthy Cities

We interviewed the founder and president of Green Roofs for Healthy Cities about the benefits of green roofs and what next steps need to be taken in the industry. In his experience, public policy aimed toward increasing green spaces and improving cities’ climate resiliency are key to increasing the uptake of green roofs. Furthermore, he explained that for green roofs to make a substantial difference in decreasing heat roofs or improving air quality, local governments need to create subsidies and incentives for developers to include green roofs on all buildings. One green roof alone will not be able to solve climate issues and improve climate resiliency.

Target Market

Green roofs are best poised for cities where they are able to help reduce heat island effects. The main consumers are residential apartments, as well as large corporate buildings. In these settings green roofs become multi-purposeful as they can be marketed as a nice amenity for city dwellers. Our website aims to support individuals interested in constructing a green roof, but currently lack basic knowledge about green roofs. Our resources will provide a foundational understanding of green roofs before the individual seeks out a professional contractor.

Conclusion

With more space, expertise, and time, perhaps we would have explored how to help green roofs succeed differently. However, our project to research and compile helpful green roof information for groups looking to establish an installation did reach one major conclusion: the importance of hiring an experienced contractor both to build and to maintain the green roof. Green roofs require deep knowledge of plant types, irrigation systems, structural engineering, and crop planning; weekly, monthly, and yearly upkeep; a resilient ecosystem; roof safety qualifications; all things that very few people have on hand. As is the case with many large, complicated installations: hire professionals to help you see your vision through.

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