Green Roofs: A Community-Centric Feasibility Assessment for Easton, Pennsylvania

David Alpert

Daniel Figler

Brynn Fuller-Becker

Gaby Greenfield

LAFAYETTE COLLEGE

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Dr. Benjamin Cohen
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Introduction

Background

Easton, Pennsylvania was founded in 1752 and is located on the eastern side of Pennsylvania, on the border of New Jersey (Hindash, 2018). During the Industrial Revolution, Easton emerged as a commerce hub, serving as a large port for transportation via rivers and railways. Today, Easton is used as a residential and commerce area, the home of Lafayette College, and a common location for residents commuting to New York City for work. Easton's past and present have sparked its development an urban area, leading to several common urban environmental issues.

Easton's main environmental concerns include the urban heat island effect, air quality, water quality, produce access, and flooding. Each of these issues is partially caused by the increase of impervious surfaces, common with urban development. Impervious surfaces are areas that cannot absorb water. They often replace vegetation and other natural landscapes, erasing many of the benefits that they provide.

Urban areas with a high density of impervious surfaces often experience the urban heat island effect. The evaporation of water from grass removes latent heat from the surrounding air, effectively cooling the air around it. However, urban areas that lack natural vegetation and grass often experience a spike in temperature compared to a less urban counterpart, due to this lack of latent heat absorption. Trees and vegetation also help to filter out pollutants from runoff and precipitation; both air pollution and noise pollution have become more prevalent in the city as it has developed. Additionally, with the increase in population density, and subsequent decrease of natural landscape and vegetation, residents of Easton have decreased access to fresh produce.

Paramount to these concerns is Easton's issue of flood control and urban development. Easton has a long history of flooding due to the prevalence of impervious surfaces and its geographic location. In 1955, Hurricanes Connie and Diane swept through Easton, causing $10 million in damages and claiming 70 lives (Frantz, 2015). More recently, there were massive floods in 2004, 2005, and 2006 (Rhodin, 2011). In events of high precipitation, water which would normally be absorbed into the ground is impeded, and instead sits on the surface of the city causing damage and flooding (Arnold, 1996).

One popular proposed solution to the many environmental problems raised with the increased prevalence of residents in urban areas is green roofs. Green roofs are not new to urban infrastructure and building design; originally implemented as moss on rooftops to help with insulation, a green roof is "an extension of the existing roof which involves, at a minimum, high-quality waterproofing, root repellent system, drainage system, filter cloth, a lightweight growing medium, and plants" (Green Roofs for Healthy Cities, n.d.). They either partially or fully cover roofs in vegetative material, and are engineered to manage the weight, runoff, and root systems associated with the vegetation. Technological advancements and design improvements of houses eventually eliminated the need for green vegetation as a means for insulation. In the 1960s, they resurfaced within urban design as a relatively inexpensive, sustainable, and innovative way to attenuate the negative impacts of modern housing materials. Today, green roofs are used as an urban planning tool; they can be specifically catered to individual building specifications and the intended goals of the building owner and community. Intensive data collection, interviews, diligent technical planning, and economic assessments are used to craft optimal green roofs for each building's wants and needs.

The benefits of green roofs are expansive and multifaceted. Predominantly, green roofs help to improve primary urban environmental issues, such as air quality, stormwater management, sound attenuation, produce availability, and aesthetics (General Service Administration, 2011). However, green roofs can also be designed to help improve secondary urban issues, which do not directly impact the natural environment but can positively improve individuals within the buildings and areas surrounding green roofs. These secondary improvements include reduction of energy costs, job creation, community development, education, and thermal performance in buildings (ZinCo, 2013). When properly planned and designed, green roofs serve as an economically and environmentally sustainable solution to many of the adverse issues presented within the built urban environment.

Figure 1. An Intensive Green Roof with Areas for Community Members to Gather. Adapted from *Baltimore Convention Center*, Greenroofs.com, 2018.

Problem Definition

Many, if not all, of the environmental issues experienced by the city of Easton could potentially be addressed by the implementation of green roofs. However, in order to evaluate whether green roofs are a viable solution for Easton specifically, we must consider the social, political, technical and economic contexts of Easton and how they may intersect with green roof infrastructure.

Within Easton's social context, there are several factors to be considered in order to mitigate unforeseen consequences due to green roof installation. The first, and likely the most important, social consideration is identifying what issues community members feel need to be addressed. In order for a solution like green roofs to adequately address environmental issues in a way in which the community supports, the issues must be defined by the community members themselves. Another social consideration is the urban trajectory of Easton. Although the environmental movement in Easton encourages sustainability and environmentalism, it is still a growing urban city. In order for green roofs to be effective, those working toward implementing them must keep in mind that the city will continue to expand and urbanize, and future environmental initiatives must account for this.

Easton's political context is also important to consider before pursuing green roof implementation. A large political consideration in Easton regarding green roofs is how to draft policy in a manner that incentivizes their installation in an equitable way across the city. To do this effectively, the distribution of flood plains and average household income must be referenced. A policy which does not mitigate an upfront cost would likely not be ideal for Easton because many of the households that experience the most severe environmental issues are of lower socioeconomic status and likely do not have the economic resources to install a green roof (Frankel & Goldman, 2017). Furthermore, a policy that requires the installation of green roofs to address environmental concerns does not account for the variability within the city of Easton and the possibility that green roofs may not be ideal.

Technically, there are several considerations necessary prior to green roof installation. The viability of a green roof on a specific building is dependent on many of the building's characteristics. In Easton, zoning codes specify maximum building heights in each district. Additionally, the historic district, located in downtown Easton, has very strict codes regarding new buildings and renovations. Each construction project must be drafted and passed by a committee prior to the project commencement. Finally, the slope of a roof and the maximum dead load that it can withstand are technical barriers for green roof installation. Before a green roof is pursued, a building must be extensively analyzed to determine if a green roof is viable.

The economic costs of green roof design and construction are driven by the type of green roof, the scope of each component, and the aspects of the roof. Macroeconomic factors will also certainly affect green roof cost. Green roofs cost between $10.00 and $30.00 per square foot to install. Maintenance costs range from $0.75 to $1.50 per square foot. Traditional roofs, however, typically cost between $7.00 and $12.00 per square foot (Learn How Much It Costs to Install a Flat Roof, 2018). One of the largest benefits of green roofs is their long lifespan of 30 to 50 years compared to traditional roofs that typically last between 20 and 30 years (Feng, 2018).

Solution

We do not believe that green roofs are a "one size fits all" solution to Easton's environmental problems, nor do we believe that we should be the determinants of whether or not green roofs are right for the neighborhoods of Easton. Rather, we hope to provide all of the necessary resources for communities to decide whether or not green roofs are the right solution to their environmental problems, given their resources, values, and contexts.

Addressing and Overcoming Challenges

In order to provide necessary information to help Easton solve their environmental problems, we will need to accurately determine what these issues are. We hypothesize what these issues may be, but will need to determine if these match the thoughts and opinions of community members. This raises issues within survey development and implementation given time and financial constraints. In order to address these challenges, we will use data to determine the environmental issues of each neighborhood in Easton via the Easton Matters Report. The report surveys 311 residents of Easton to get an understanding of the city's identified environmental issues. Although the sample size and format of the study partially restricts the accuracy and breadth of the results, we believe that this survey will act as a useful tool for determining community perceptions given our constraints.

One major challenge of adding green roofs is funding and ownership. Green roofs can be installed on private or public buildings; private buildings are generally easier to install, while public buildings provide several financial and political obstacles. The private sector faces the brunt of financial costs while the general public reaps the majority of the benefits. Maintenance requirements differ significantly between private and public ownership. Ultimately, green roof implementation feasibility varies widely on building ownership. We worked to consider this dichotomy when developing our framework, so that our tool may ultimately be used for buildings of both ownership types.

Finally, time served as a significant challenge towards developing a solution. The feasibility of implementing a green roof, much less reaping the environmental benefits of green roofs, within the one academic semester significantly limited our project's goals. To overcome this, we will develop a framework that can be utilized now or in the near future, and allows community members to utilize our resources at their convenience.

Goals and Recommendations

Our goals approaching this project include considering the relevant contexts of Easton concerning green roofs, in order to determine if green roofs are ultimately "worth it" for Easton. Our overall goal is not to implement a green roof "by any means necessary," but to critically assess if the installments of green roofs are the best option to solve the environmental issues identified by the community. Our ultimate product is a neighborhood-specific framework. The framework accurately considers the many aspects that are relevant to green roof implementation, provides our recommendation, and keeps the community members as the ultimate decision makers. By producing this framework, we will provide all of necessary information and resources to enable community members and civic leaders. With this information, they can determine if green roofs are "worth it" for them and their communities.

Social Context

Environmental scholars and sustainable builders praise green roofs as a tool for mitigating the negative impacts of our built environment and resource exhaustion, as well as to create sustainable urban infrastructure (Li, 2004). Green roofs help to do this by managing and retaining stormwater runoff, reducing the urban heat island effect, improving water and air quality, and providing additional urban green spaces.

The aforementioned environmental issues are a result of centuries of decisions and actions made by individual citizens, stakeholders, and community leaders. Predominantly, they are rooted in two main events, the industrial revolution and the resultant environmental movement. The industrial revolution increased anthropogenic emissions, urbanization, and many consequential environmental issues seen in urban areas. The environmental movement helped to create many of the solutions to environmental issues, such as green roofs.

Environmental Movement

During the 18th and 19th century, the United States, and the world as a whole underwent significant economic, technological, cultural, and social changes known as the Industrial Revolution. The development of industrial processing and civic development increased greenhouse gas emission in our atmosphere (Zachos, Dickens, & Zeebe, 2008). Converting the earth's emitted light into heat and re-emitting it as heat, greenhouse gas emissions have increasingly grown with technological advancements and increased production (Lashof & Ahuja, 1990). The global CO_2 emissions over 264 years, broken by world region is shown below in *Figure 2.* Although not fully recognized until 1980, the impacts of greenhouse gas emissions and global warming negatively impact almost every ecosystem in the world (Hansen 1998). Beyond widespread global impacts, climate change impacts individual countries, states, and cities. The impacts of climate change affect communities and individuals of lower socioeconomic status more than affluent ones, a concept known as environmental injustice (Ikme, 2003). Starting in the 1960s and 1970s, research of greenhouse gas emissions on our current and future globe and their effects sparked the environmental movement (Dunlap, 2014).

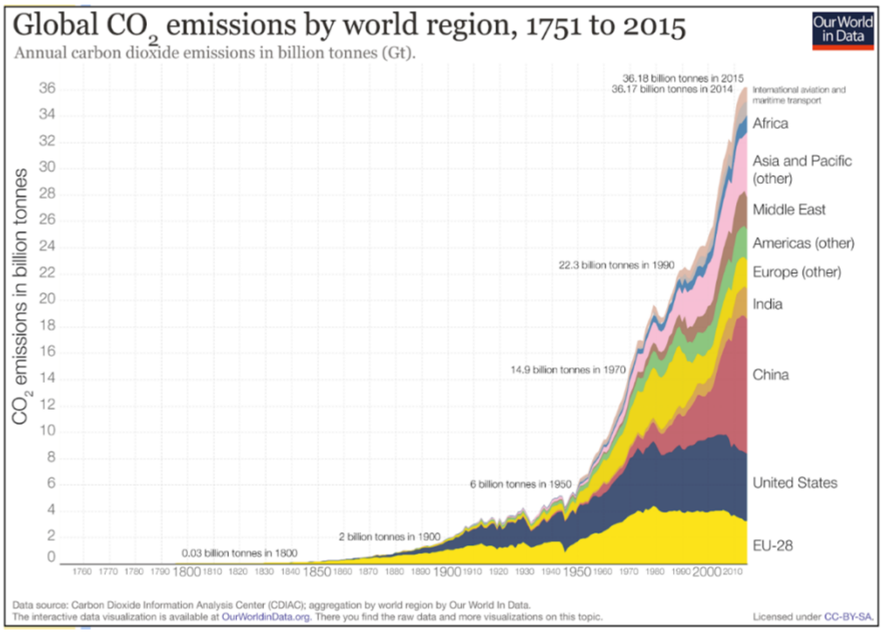


Figure 2. Global CO2 emissions over 264 years, broken up by world region. Adapted from *The Carbon Dioxide Information Analysis Center*, by H. Ritchie, and M. Roser, 2018, Retrieved from https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Driven predominantly by research and political activism, the environmental movement has two main purposes. First, it works to mitigate existing negative consequences of human activity on earth. Second, it creates new solutions to replace existing ones which produce less environmental harm. Mitigations and solutions exist within each major sphere of our society: social, political, technical, and economic. Additionally, they span among multiple scales: from individual, to corporate, to city-wide, to national, to global. Mindful development and effective implementation of mitigation and prevention strategies help to diminish the existing negative impacts of climate change, while specifically working to ensure those impacted most receive the most aid.

City/Civic Planning

Impacts of climate change differ based on population distribution and land type, predominantly between urban and rural areas (International Panel on Climate Change, 2018, p. 109). A rural area is a geographic location which lies outside of towns and cities. Some of the predominant characteristics of rural areas are: low population densities, small settlements, and agriculture as the main source of occupation (Mondal, 2014). On the other hand, an urban area is a geographical location such as a town or city. Characteristics of urban areas are high population densities, well developed infrastructures, and a largely built environment (rather than natural).

Many United States citizens who once lived in rural areas have now moved to cities (Urbanization in the United States, n.d.). With this shift comes many benefits, including a multitude of resources (schools, hospitals, grocery stores, etc.), job opportunities, access to public transportation, and community spaces. However, with these benefits come some significant downsides. The dense population in urban areas often leads to very high levels of pollution, including significant air and noise pollution from factories and vehicles. The many buildings, roads, and sidewalks have removed the natural landscape, such as grass and trees. Although it may not seem initially problematic, the growth of impervious surfaces leads to an increased risk of flooding. Easton is no exception to these issues.

Impervious Surfaces

Out of the four neighborhoods in Easton (College Hill, West Ward, Downtown, South Side), approximately 40% of the urban environment is covered by pavement (Frankel & Goldman, 2017). In particular, 57% of the Downtown neighborhood is covered with pavement, making it particularly susceptible to the urban heat island effect and flooding (Frankel & Goldman, 2017) as visualized in *Figure 3* and stated in *Figure 4*.

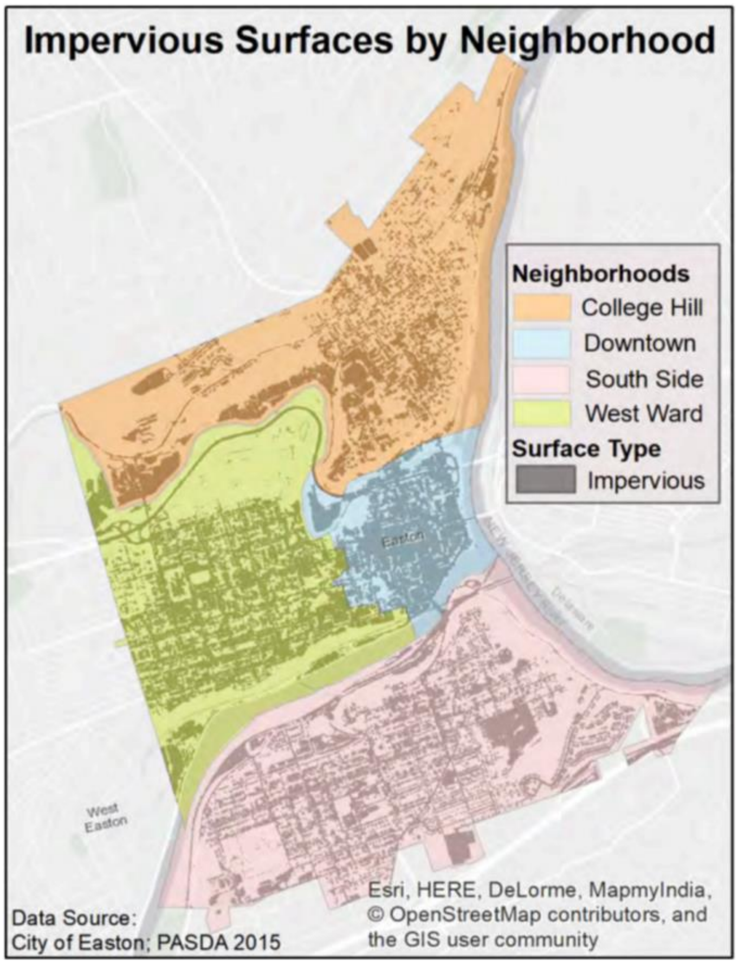


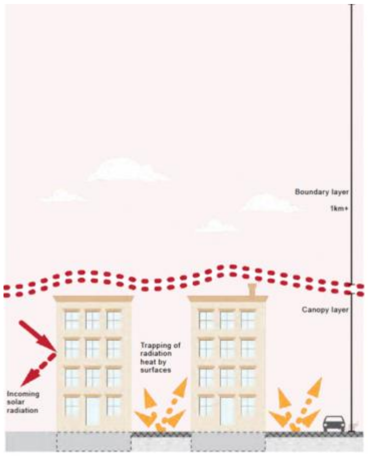
Figure 3. The proportion of land covered by impervious surfaces shown in gray, with neighborhoods of Easton distinguished by color. Adapted from *The Vulnerability Assessment for the City of Easton,* Nurture Nature Center for the City of Easton, 2018.

Neighborhood	Impervious Area	Neighborhood Area Total	% Impervious
West Ward	1,092,782 m2 (270 acres)	2,702,664 m2 (668 acres)	40.4%
Downtown	527,239 m2 (130 acres)	924,260 m2 (228 acres)	57%
South Side	1,323,103 m2 (327 acres)	3,671,539 m2 (907 acres)	36%
College Hill	800,957 m2 (198 acres)	3,151,508 m2 (779 acres)	25.4%

Figure 4. The total area of impervious surfaces in Easton neighborhoods. Adapted from the *Vulnerability Assessment for the City of Easton,* by the Nature Nurture Center for the City of Easton, 2016, Retrieved from https://www.easton-pa.com/geninfo/eva2018.pdf

The Urban Heat Island Effect

An urban heat island is an area that is significantly warmer than areas around it (especially during the summer), caused by modified land surfaces. There are two main causes to the urban heat island effect: surface properties and human activity. Approximately 60% of surface area in cities are roofs and pavement. These surfaces are usually darker in color, and therefore not as absorbent to incoming heat (National Geographic, 2011). Previously present landscapes like grass, which removes heat from the surrounding air, is replaced with surfaces such as asphalt and concrete that do not absorb heat as effectively as natural surfaces (Oke, 1982). Rather than absorbing heat from the atmosphere, the surfaces re-emit heat energy back into the urban environment, increasing air temperature. This is demonstrated in *Figure* 5, below. Additionally, the human activities associated with urban environments, such as air conditioning, manufacturing, transportation, produce excess heat which is then emitted into the atmosphere. In conjunction, these two features contribute to heat production and a lack of heat absorption in urban areas, as seen in *Figure 6.* (Akbari, 2009).



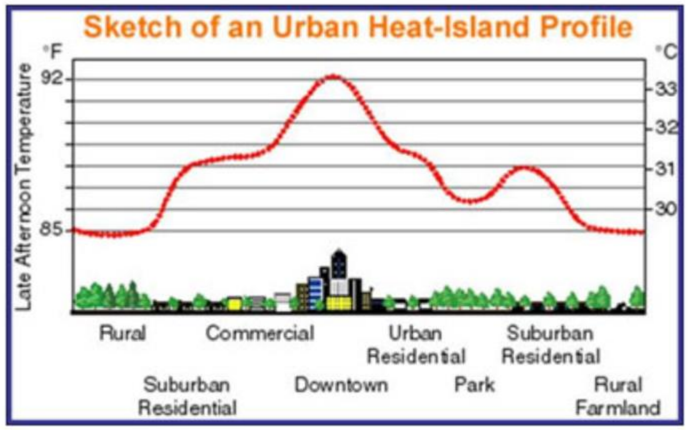


Figure 5. The sources and impacts of incoming solar radiation on heat in urban areas, known as the urban heat island effect. Adapted from *Urban Heat Islands*, by General Service Administration, 2011, General Services Administration.

Figure 6. A sketch of an urban heat-island profile. Adapted from *The Energetic Basis of the Urban Heat Island,* by T. R. Oke, 1982.

The urban heat island effect impacts more than just temperature in urban areas. Increasing air temperature in cities leads to increased overall energy use (mainly through more air conditioning), impaired air quality (the formation of smog), and increased illness (through aggravating respiratory illness) (Urban Heat Islands, n.d.). Mitigation strategies of the urban heat island effect include increasing tree coverage and vegetative cover. (Heat Island Cooling Strategies, 2016).

Easton has experienced five heat waves between 1997 and 2014, as shown in *Figure 7*. The Vulnerability Assessment for Easton concludes that these heat waves are regularly occurring events, and are being worsened by sources of heat during daytime activity, and a lack of urban cooling at night. "The West Ward and Downtown are the most vulnerable to extreme heat events, as both areas have the most impervious surfaces as well as the least amount of green spaces and tree canopy coverage, resulting in higher energy usage" (Nurture Nature Center for the City of Easton, 2018).

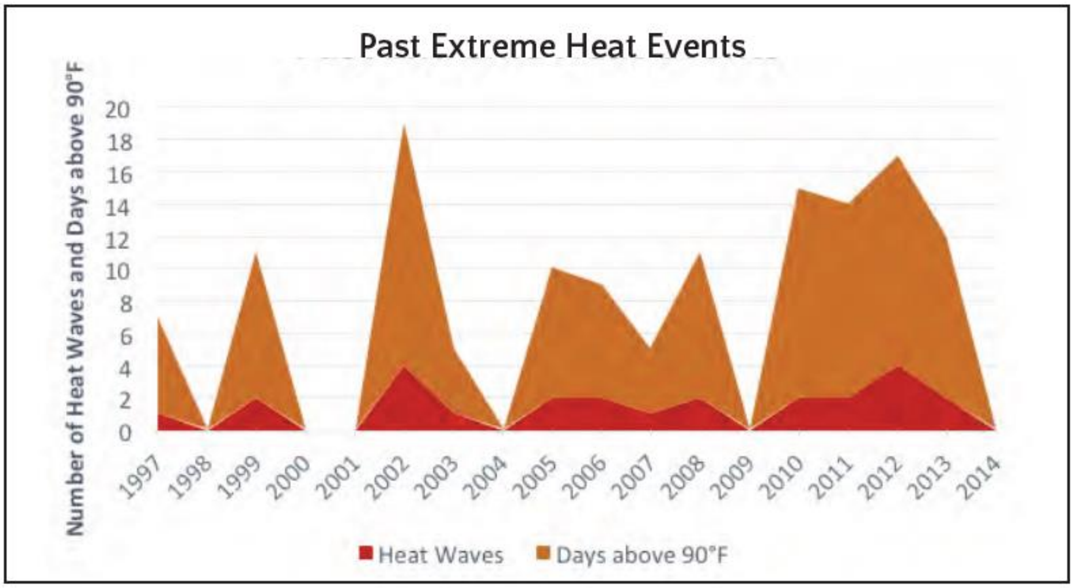


Figure 7. Extreme heat wave events in Easton, Pennsylvania from 1997 to 2014. Adapted from *Vulnerability Assessment for the City of Easton, PA,* by Nurture Nature Center for the City of Easton, 2018.

Flooding

Large rain storms produce a great amount of water, which is usually absorbed and stored through natural surfaces. Once they are removed and replaced with impervious surfaces, such as roads, sidewalks, and buildings, the rain no longer gets absorbed. To compound the issue, urban areas typically do not have very good drainage systems. Therefore, urban areas are very prone to severe flooding. The increased risk of floods impact those within the floodplain (usually closer to rivers and streams), more than those on higher ground.

Easton has a history of devastating floods. In the summer of 1955, Hurricanes Connie and Dianne passed through the Lehigh Valley. Easton had not received significant precipitation in the area before the storms, so was flooded extensively. The water claimed 70 lives and caused over $10 million worth of total damage, including the destruction of Northampton Street Bridge between Easton and Phillipsburg . In total, the flood of 1955 produced flood levels of 43.7 feet, which Easton residents describe as a "measuring stick" for future flooding and damage assessment (Frantz, 2015).

More recently, in 2004, Hurricane Ivan devastated a large portion of the northeastern United States. Similar to the flood in 1955, Hurricane Ivan caused a great deal of structural damage, largely due to the severe winds. However, rainfall led to the flooding of the Delaware River Basin, in which Easton lies. This flood produced 33.45 feet of water in Downtown Easton, which can be seen in *Figure 8*. Cleanup efforts and damage assessments followed shortly after, but without any significant changes. Easton has seen many floods in the years since, such as in 2005 and 2006 (Rhodin, 2011).

Figure 8. Impacts of the 2004 flood in Easton, Pennsylvania. Adapted from *The Delaware River Floods of 2004, 2005, and 2006: Causes and Lessons Learned. In World Environmental and Water Resources Congress 2007: Restoring Our Natural Habitat,* by D. Kucz, 2007.

Since the Delaware River runs through Easton, Downtown Easton lies within a floodplain. This puts many of the homes and lots of the city's infrastructure at risk of flood damage. Impacts of flooding cannot be easily diminished through engineering solutions or managing infrastructure, but can be mitigated through increasing natural landscapes and developing storm management tactics.

Air Pollution

According to the American Lung Association, the Lehigh Valley in which Easton lies is the 14th most polluted region in terms of particle pollution in the entire United States, increasing from the previous year (Olanoff, 2013). Deteriorating air quality impacts both public health and the economy. Poor air quality contributes to to increased occurrences of asthma, heat exhaustion, and worsening of chronic illness, as well as an increase in public and private spending related to health impacts. Vulnerable populations are most at risk to feeling both of these effects (Nurture Nature Center for the City of Easton, 2018).

Water Pollution

Water quality degrades with increased impervious surfaces and prolonged heat events. Surface runoff from concrete accumulates pollutants present on surfaces of urban areas. A lack of vegetation inhibits the ability for natural water purification, and allows water of lesser quality with potential pollutants to enter waterways (Tong 2002). The prolonged heat events in Easton degraded plant, mammal, and fish populations, and increased algae growth. Both have led to compromised water quality in the area (Frankel & Goldman, 2017).

Easton's Concerns

Environmental mitigation efforts are most effective when they are crafted with careful consideration for their recipients' wants and needs. Within the realm of Easton, this means identifying which aspects of their environment they feel impacts them the most, supplemented with reputable data to ensure that the community's needs overlap with sufficient supporting information. In order to make the most effective solutions for environmental issues identified by the city of Easton, we reviewed the data and perspectives compiled in the Easton Matters Report. The Easton Matters Report was produced in 2016 and organized by Easton's Nurture Nature Center. The report includes responses of: 311 from the individuals from the four distinct neighborhoods in Easton (Downtown, South Side, West Ward, and College Hill), interviews of 16 city officials (representing the mayor, planning department, public works, city council, and city arborist), and 18 representatives of ten Community Based Organizations (CBO). While this sample size is fairly small, particularly for the city officials and CBO's, the responses sufficiently encompass Easton's main environmental concerns. The quantitative results of the survey are shown in *Figure 9* and *Figure 10* below.

Certain environmental concerns are far more important to residents of Easton than others. For Easton as a whole, the most important environmental concern is water quality, with about 23% of the respondents identifying it as a top concern. Air quality is second, with about 20% of the respondents identifying it as a top concern. Flooding, which has historically been a large issue in Easton and the entire Lehigh Valley, is the sixth greatest environmental concern, with about 12% of the respondents identifying it as an issue.

Each neighborhood identified different environmental issues as the most important to them. Downtown identifies food access as their largest environmental concern while the South Side identifies trash and litter as theirs. The West Ward identifies crime and drugs while College Hill identified water quality (Frankel & Goldman, 2017). All of this data is presented below in *Figure 9.*

Table 2: Residents' Major Environmental Concerns, by Neighborhood

	Downtown n=68	**South Side n=60**	**West Ward n=95**	**College Hill n=88**
Water Quality	13% (9)	18% (11)	5% (9)	44% (39)
Air Quality	19% (13)	17% (10)	17% (16)	28% (25)
Food Access	22% (15)	10% (6)	24% (23)	19% (17)1
Trash, Litter	7% (5)	23% (14)	25% (24)	14% (12)
Crime, Drugs	12% (8)	7% (4)	27% (26)	8% (7)
Flooding	15% (10)	7% (4)	2% (2)	15% (13)
Health Concerns	3% (9)	8% (5)	11% (10)	8% (7)
"All"	-	≤3	-	-
"Doing a great job"	≤3	-	-	-
No concerns	≤3	-	-	≤3

Figure 9. Individual Responses to the "Easton Matters" Report of major environmental concerns organized by Easton Neighborhoods. Adapted from the *Easton Matters: Evaluation Report*, by S. Frankel & E. Golden, 2017.

Major environmental concerns identified by the 16 city officials differ from those identified by the residents. City officials, who pass legislation and have the potential to create large changes within Easton, believe that the two most important environmental concerns facing Easton are flooding and water quality. Other major environmental concerns they identify are stormwater runoff, access to food, and air quality. The 18 representatives of ten CBO's identify trash as the greatest environmental concern (Frankel & Goldman, 2017). All of this can be seen below in *Figure 10.*

Table 3: Key Environmental Concerns among City and CBO Representatives

Among 16 city officials interviewed, key concerns were:	Among the 18 representatives of CBO interviewed, concerns were:
Flooding (50%)	Trash (50%)
Water quality (50%)	Flooding (39%)
Stormwater Runoff (44%)	Water quality (39%)
Access to Food (38%)	Recycling (33%)
Air Quality (38%)	Stormwater runoff (33%)
Trash (25%)	Trees (33%)
Trees (25%)	Parks (33%)
Walkability (25%)	Crime (28%)
Climate Change (25%)	Access to Food (28%)
Transit Options (25%)	

Figure 10. City Officials and CBO Representative responses to Environmental Issues. Adapted from *The Easton Matters: Evaluation Report,* by S. Frankel & E. Goldman, 2017.

Several environmental concerns frequently surface as top priority among residents of Easton, the public officials, and the CBO's. Flooding, air quality, water quality, stormwater runoff, and food access are environmental concerns by all three groups. Because each of these issues have been previously identified as problems green roofs can solve, we believe that green roofs will help Easton meet its environmental goals and position itself for a sustainable future. Widespread and strategic implementation of environmental solutions in urban contexts are most effectively implemented with policy.

Political Context

Within the political analysis of this report, we will discuss environmental policy and how it has intersected with Easton's political climate. Then, to provide a basis for implementation of green roof policy specifically in Easton, we will evaluate different green roof associations, guidelines, and policies abroad for their effectiveness and alignment with Easton's environmental goals. Finally, we will discuss the differences between public and private investments for green roofs in Easton and how Easton's government can take action toward implementing green roof policy. There are also several political characteristics specific to Easton which could hinder green roof installation. This includes maximum building heights specified in zoning codes and requirements in the historic district mandating any new building or addition be passed by a committee.

Environmental Policy

Environmental policy is crucial to sustainability management. However, producing effective and efficient policies regulating environmental issues is complicated because environmental issues are inherently interdisciplinary, and are defined inconsistently in different disciplines. Due to the malleable definition of environmentalism, environmental policies are also easily manipulated to serve an agenda. This manipulation is observed within the struggle between the general public and private organizations regarding environmental issues. While large organizations attempt to contain the scope of issues and resolve them privately, individuals work to broaden issues and bring them further into the public agenda. However, because large organizations often carry more political weight than the individual, they are able to frame a public concern as a non-issue to avoid addressing it (Cohen, 2006).

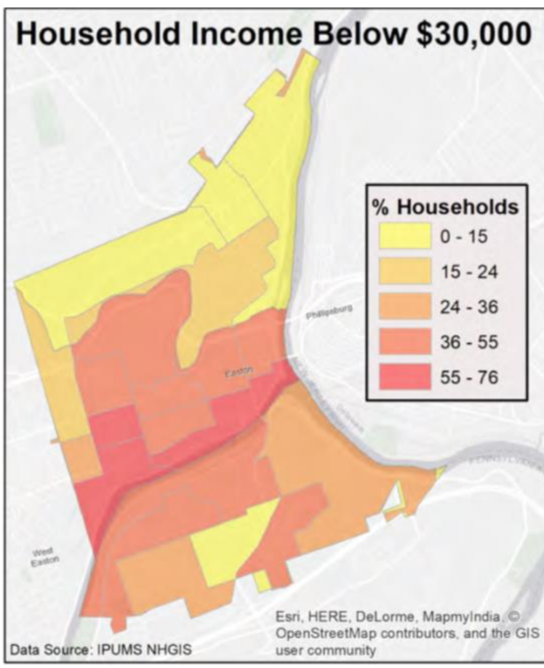
Another problematic quality of environmental policy is its innately quantitative nature. It is invaluable for environmental policymakers to consider the qualitative benefits the public experiences from the environment which evade quantification (Cohen, 2006). Lacking consideration for these qualitative environmental benefits is a common theme within environmental policy which often results in unforeseen social, political and economic consequences. Within Easton, if policymakers do pursue environmental policy regarding green roofs, it is important that they evaluate policies for their non-political and non-technical implications. To do this most effectively, policymakers should use ample input from community members in defining the environmental issues which policies aim to address. This community-centric method of defining environmental issues is the most promising method of mitigating unforeseen consequences due to environmental policy.

In Easton, there are several environmental issues at the forefront of the public agenda. In the Easton Matters Report, residents and city officials identified flooding, water quality, air quality, access to food, crime and drugs, and trash and litter as their key environmental concerns, varying by neighborhood. While conducting research, the Nurture Nature Center also observed that residents of Easton care more about neighborhood pride and cohesion than is currently represented in city-wide planning. Although the Nurture Nature Center's report provides a general sense of individual neighborhoods' key concerns, more extensive research of individual neighborhoods is necessary before taking tangible steps toward defining environmental issues in a way which best represents the community's needs (Frankel & Goldman, 2017). However, given this preliminary research, we predict that the installation of green roofs throughout several neighborhoods in Easton may effectively address community-identified environmental concerns.

Public and Private Buildings

Green roofs can be installed on a diverse set of buildings, generally depending on specifications such as roof slope, maximum dead load, and maximum height. Although they can be installed on both public and private buildings, the political implications of each vary due to the proportion of public and private benefits experienced. Green roofs require a large upfront investment, while many of their benefits are granted externally to the public, such as air and water quality and stormwater management. This means that incentivizing green roof installation on public buildings depends mainly on the alignment of green roof benefits with community-defined environmental concerns and the liquidity of public funds. However, private green roof investors experience only some of the benefits due to green roofs, including lowered energy costs and extended roof life which are long-term benefits. Because the tangible benefits produced by green roofs are not experienced immediately by private investors, incentivization through policy would be necessary to encourage private investment in green roofs. The difference in economic benefits granted to the public and privately is addressed further in the economic section, located here.

To determine whether policy should be implemented in Easton to encourage private investment in green roofs, it is important to consider the equity of installing green roofs on only public buildings. Most of the public buildings in Easton are located downtown, meaning that if green roofs were only installed on public buildings, the West Ward, South Side and College Hill would not experience their benefits. Additionally, the overlap of floodplains and average household income below $30,000, demonstrated by *Figure 11* and *Figure 12* below, indicate that residential areas without the economic means to make a large investment are the areas which would benefit the most from a green roof system. This indicates that policy to economically incentivize individuals and organizations to install green roofs across Easton may be the best way to attain equity while still reaping the benefits from a green roof system.



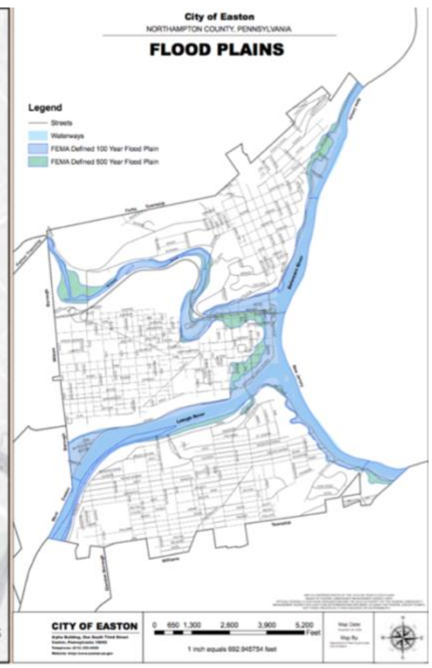


Figure 11. A map of the distribution of households with annual income below $30,000 in Easton, Pennsylvania. Adapted from *The Easton Matters: Evaluation Report* by the Nurture Nature Center for the City of Easton, 2018.

Figure 12. A map of the floodplains in the city of Easton, Pennsylvania. Adapted from *The Easton Matters Report* by Nurture Nature Center for the City of Easton, 2018.

Existing Green Roof Policy

We intend to explore the feasibility of implementing policy regulating green roofs in Easton by assessing different types of green roof policies which have been implemented in other communities. These policies will be evaluated based on the environmental issues they aim to address, if those issues align with Easton's as defined by the Easton Matters Report (Frankel & Goldman, 2017), and for their effectiveness in addressing those issues. Several countries with more extensive environmental policy than the United States have developed somewhat robust green roof initiatives. One common theme among these countries is the establishment of nation-wide guidelines and associations dedicated to green roof standards which protect users and investors from receiving sub-standard green roof systems (Ismail et al 2012). *Figure 13* below highlights several other countries which have developed national green roof associations and guidelines, as well as a brief summary of the content of their guidelines. If Easton were to implement city-wide guidelines, it would likely benefit policy-makers to review these guidelines more closely and model Easton's guidelines after those in countries with similar environmental issues.

Country	Association	Guideline	Content of guideline
Germany	1. German Roof Gardening Association 2. The Landscaping and Landscape Development and Research Society (FLL)	FLL guideline	FLL guidelines contain detail information on maintenance work of green roof and service information for the technical installations. FLL also valid for any of greening works on roofs and building covers.
Canada	Green Roofs for Healthy Cities	Design Guidelines for Green Roofs	This article is an introduction of green roof and describes the way to implement and market a green roof, cost consideration, and provided with three case studies.
		A Resource Manual for Municipal Policy Makers	This *Manual* provides the comparative studies on green roof policies and programs from International and Canada.
Japan	Urban Green Tech	Neo Green Space Design, Volumes 1 to 4	The Neo Green Space Design contains basic technique to create a green space. It has 4 volumes contain different information in each of it.
		Guide to Roof and Wall Green Technologies	This book provide summarization of green roof an wall technology development
Singapore	1. Singapore National Parks (NParks) 2. Urban Redevelopment Authority's (URA) 3. Landscaping for Urban Spaces and High Rises (LUSH) 4. Centre for Urban Greenery and Ecology (CUGE)	Introduction to Vertical Greeny	An introduction to vertical greenery systems, some basic principles for set-up, a quick look at classification of systems, and largely with details on the vertical green systems at Hortpark.
		Handbook of Skyrise Greening In Singapore	This handbook outlines the benefits and issues to consider in developing skyrise greenery and aims to be a handy guide and a source of information for parties interested in implementing skyrise greenery.
		Vertical Greenery for the Tropics	NParks, NUS and BCA collaborated to introduce and evaluate various vertical greenery systems, validating the benefits of urban greenery within our tropical urban environment. The results are presented in this joint publication that aims to promote vertical greenery within the city,through advancing the understanding of this new nature-architecture hybrid.
		Selection of Plants for Green Roofs in Singapore	This handbook presents a selection of over seventy plants that are suitable for green roofs in Singapore.
		Guidelines on Design Loads for Rooftop Greenery	This standard outlines basic loading considerations and issues when designing rooftop greenery - suggesting design loads of vegetation, substrate, recommended soil depths and the appropriate placement of rooftop landscape components in relation to common rooftop conditions.
		Guidelines on Design for Safety for Rooftop Greenery	This standard highlights safety considerations during the design, installation and maintenance phases. A useful reference for designers and installers of rooftop gardens.
		Guidelines on Substrate Layer for Rooftop Greenery	This standard outlines the basic physical and chemical properties for quality referencing in the composition and construction of the substrate layer for use on rooftop greenery.
		Guidelines on Filter, Drainage and Root Penetration Barrier Layers for Rooftop Greenery	This standard outlines the basic technical requirements for quality referencing in the construction of the filter, drainage and root penetration barrier layers of rooftop greenery.
Hong Kong	Architectural Services Department	Study on Green Roof Application in Hong Kong	Quick review of the green roof technology and concept and recommend technical guidelines to suit applications in Hong Kong in order to increase public awareness and understanding
Australia	Sydney City Council	Green Roof Design Resource Manual	Outlines the benefits of green roofs, the various types of green roofs, landscape and architectural design considerations, sustainable water and energy technologies, maintenance issues, and case studies
United Arab Emirates (UAE)	Dubai Municipality	Green Roof Manual	Guidelines for Planning, Execution & Maintenance of Green Roof & Green Wall
United Kingdom (UK)	1. Green Roof Organisation (GRO) 2. Livingroofs.org	Building Greener: Guidance on the Use of Green Roofs, Green Walls and Complementary Features on Buildings	The guidance is intended for use by those who require independent advice on the planning, design, construction and maintenance of green roofs, green walls and other biodiversity features. In particular the document aims to dispel myths for clients and designers and to enable planners to maximise the benefit of design options.
		Green Roof Code of Best Practice for the UK 2011	The GRO code is intended to be recognised as a code of best practice and as such it should be used to guide behaviour relating to green roof design, specification, installation and maintenance.
		The Green Roof Pocket Guide	This guide provides a brief introduction to green roofs, answers key questions, and gives sources of further information.

Figure 13. A list of countries with developed national green roof associations and guidelines, as well as a brief summary of the guidelines. Adapted from *Establishing Green Roof Infrastructure Through Environmental Policy Instruments,* T. Carter & L. Fowler, 2008.

In Japan, The Organization for Landscape and Urban Green Technology Development promotes urban greenery and green spaces with the main goal of mitigating the urban heat island effect. Although Easton does experience an urban heat island downtown, it has not been identified as a key concern by Easton's policymakers and residents. Therefore, although Japan has experienced benefits from promoting all buildings to have small green roofs, because Easton's concerns are more water related, this would likely not be a beneficial system for Easton to emulate. In Canada, however, the first green roof regulation was adopted in 2006 by Green Roofs for Healthy Cities, which required buildings of over 5000 square meters to have green roofs. The main purpose of this regulation is to decrease energy consumption, increase stormwater control, and increase thermal performance. Other benefits obtained were enhanced aesthetic views and biodiversity. These benefits align well with Easton's needs and were successful in Canada, but a standalone policy will not encourage enough investment in green roofs to develop a beneficial green roof infrastructure. In order to reap the intended environmental benefits from green roofs, the public must have a cohesive environmental agenda, as is pursued within green roof associations and guidelines in other countries (Ismail et al, 2012).

Beyond the development of nation-wide green roof associations and standards, four general types of policy which can be enacted at the state-wide and municipality-wide level to encourage the installation of green roofs are briefly explained *Figure 14,* below. There are two types of standard-based policies, which require certain buildings to adhere to a specified standard. A technology standard requires certain types of buildings to have a green roof proportional to the size of the building. A performance standard requires a certain level of sustainability for all buildings of a certain type; a common example of this is a required level of stormwater management. There are also direct and indirect economic incentive policies. Examples of direct economic incentives are grants and subsidies, which are credited to a green roof investor to aid in the costs of installation and maintenance. An indirect economic incentive policy is when money is credited back to a building owner for installing a green roof, such as in tax breaks and stormwater fee credits (Carter & Fowler, 2008).

Figure 14. Four general policy types which could be used to encourage green roof

Type of green roof policy	Example	Location	Key features
Technology standard	Mandatory green roofs on buildings of a particular type	Portland	All new city-owned facilities include green roof unless it is "impractical"
Performance standard	Require cool roof technology	Chicago	Use of green roof exempts building from reflectance and emittance requirements
Direct economic incentive	Subsidy or grants for construction	Chicago	$100,00 for 20 projects
Indirect economic incentive	Stormwater utility fee credit	Minneapolis	100% credit for green roofs that replace impervious surface

implementation, as well as a short explanation and example of each. Adapted from *Establishing Green Roof Infrastructure Through Environmental Policy Instruments,* T. Carter & L. Fowler, 2008.

Technology standard policy. A technology standard policy regarding green roofs would mandate in the building code of a jurisdiction that all buildings of a specific type must green all or part of their roof. For example, in Linz, Austria, all new buildings larger than 100 square meters with a slope lower than 20% are required to have green roofs. In the United States, Portland, Oregon has enacted a technology standard policy which requires all new city-owned facilities to include a green roof with at least 70% coverage, unless it is deemed impractical. This policy, specifically, is detrimentally vague, as the term 'impractical' is not defined within the guideline and can therefore be redefined by a building owner attempting to avoid green roof investment. A technology standard policy may be beneficial to a city attempting to implement city-wide green roofs and reap the maximum benefits possible from a robust green roof infrastructure. However, technology standard policies have an innate fault, as they assume that an entire jurisdiction will benefit from green roofs equally. This ignores other potential environmental solutions and can lead to a lower community benefit than is anticipated by policymakers. Specifically, in Easton, because different neighborhoods identified different key environmental concerns, a technology standard policy highlighting green roofs as the only environmental solution may not be ideal (Carter & Fowler, 2008).

Performance standard policy. Performance standard policies identify sections of cities or areas of new development to be held to tighter environmental controls. These policies often define environmental goals regarding stormwater management, urban greening, or the urban heat island effect, and require new buildings and developments to adhere to them. For example, in Berlin Germany, an inner-city area was redeveloped after decades of dilapidation, and a mandate was passed during its construction requiring the project to maintain 99% of its stormwater on-site. This was achieved using several stormwater management tactics, including the installation of several extensive green roofs. In the United States, several states, including Pennsylvania, New Jersey, and North Carolina have adopted manuals which define stormwater management standards and identify green roofs as a stormwater best management practice (BMP) which can be used to meet these standards. Performance standard policies such as these identify cohesive environmental issues which a jurisdiction aims to address while leaving the manner of addressing those issues up to the individual owner or investor (Carter & Fowler, 2008).

Another example of a performance standard regulation is Leadership in Energy and Environmental Design (LEED). LEED is a rating system created by the United States Green Building Council (USGBC) that certifies buildings with a classification based on their level of environmental performance or sustainability. Many cities are beginning to require newly constructed buildings to achieve a certain level of LEED classification in order to be erected. Notably, Washington D.C. has stringent LEED requirements for newly constructed buildings, and is also the jurisdiction with the largest abundance of green roofs in the country (Cities Requiring or Supporting LEED, 2018). Additionally, although Pennsylvania has not enacted state-wide LEED requirements, both Pittsburgh and Philadelphia have enacted city-wide requirements. A full list of jurisdictions with LEED requirements can be accessed here, and a map of states with city-wide LEED requirements can be found in *Figure 15* below. If a state is green, it means that there is some form of LEED certification required within that state. If a state is red, it means that they have some form of anti-LEED legislation, likely because they view the LEED certification system as flawed and believe another system should be used to assess sustainability. If a state is grey, it means that they do not currently have any form of legislation regarding LEED certification.

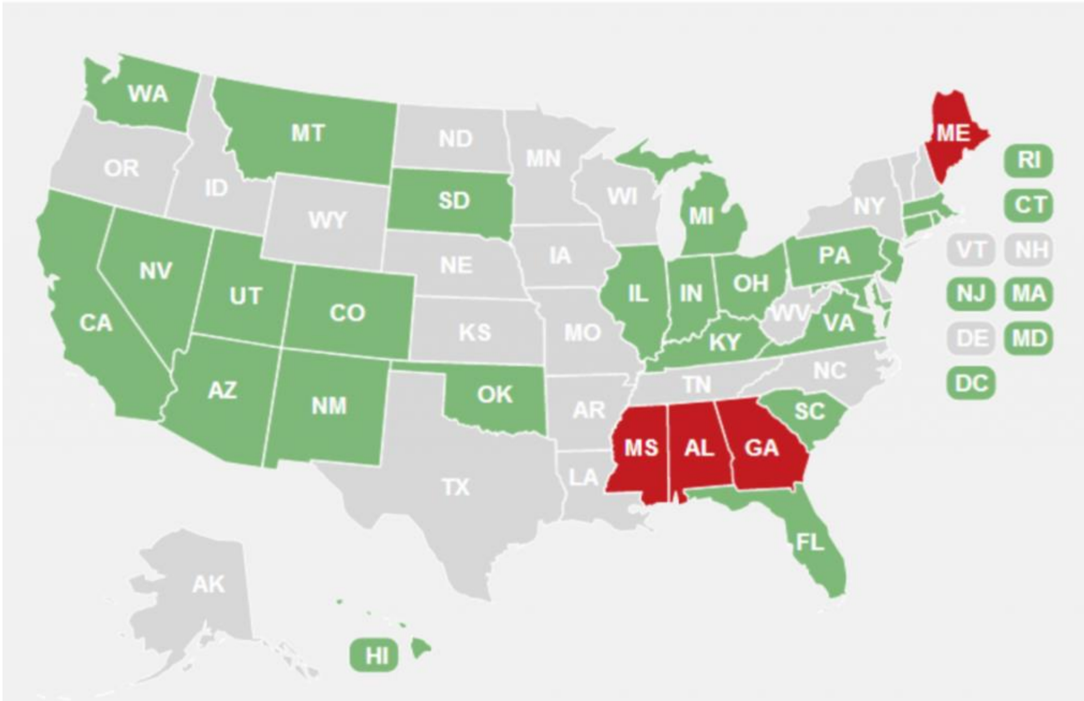


Figure 15. A map highlighting states which have jurisdictional policy in place that requires new buildings to be LEED certified. Adapted from *Cities Requiring or Supporting LEED, everblue Training,* 2018.

Buildings receive points based on a set of categories established by the USGBC; to receive general LEED certification, a building must receive a score of 40 or more points, a silver certification requires 50 points, gold requires 60, and a platinum certification requires 80 points. The addition of a green roof can earn a building up to 15 points, depending on how effectively the green roof is integrated with the building's other systems. A more extensive breakdown of how points can be achieved can be found here.

Direct economic incentive. Direct economic incentives to encourage green roof installation are realized in the form of subsidies and grants. Green roof projects can qualify for subsidies by meeting certain requirements such as stormwater retention or vegetation coverage. Two forms of subsidies that could encourage private investment in green roofs are general subsidies and targeted subsidies. General subsidies give money back to a building owner who adopts a green roof, proportional to the size of the green roof. A targeted subsidy is different, in that the building owner only receives the subsidy if the net private benefits of adoption are negative. This policy ensures that the green roofs are in fact benefiting the community (Mullen, Lamsal, & Colson, 2013). In Germany, approximately 50% of cities offer direct subsidies to building owners installing green roof systems which cover from 10% to 50% of installation costs. In North America, subsidies and grants are used sparingly to encourage green roof implementation. There are currently no jurisdictional programs within the United States which offer grants proportional to unit costs of green roofs. Instead, there are few highly competitive lump sum grants available. With this in mind, it may be difficult to employ a policy within Easton which provides direct economic incentives for installing green roofs (Carter & Fowler, 2008).

Indirect economic incentive. The most common type of green roof installation incentive is an indirect economic incentive policy. This type of policy provides indirect financial incentives to building owners who achieve a certain standard of sustainability or environmentalism. A common example of this is a stormwater utility fee credit, which involves a building owner receiving a reduction in their annual stormwater utility fee proportional to the amount of stormwater they manage on-site (Carter & Fowler, 2008). Another example of this type of policy is a tax break for building-owners who implement green roofs (Shiah, 2011). In 2007, to minimize upfront costs, Philadelphia began to offer 25% tax rebates of all costs incurred by green roof installation, up to a value of $100,000. In 2008, New York City began to offer buildings that cost over $2,000,000 a tax credit of

$4.50 per square foot if they construct a green roof. Policies in New York and Philadelphia cover approximately 1/4 of the fixed green roof costs while policy in Washington D.C. covers a majority of the costs (Wells, 2016). Although this type of policy is the most common in green roof incentivization, it is best suited for large corporations with the economic resources to realize the installation costs of green roofs and make a long investment in them. In Easton, because the areas which experience the most severe environmental issues such as flooding also often have lower average household incomes, this type of policy would likely not be the most beneficial for Easton's residents.

Easton's Government

To understand how a policy regarding green roofs can be passed in Easton, it is important to understand the way Easton's government works. Although Easton is a part of Northampton county, it regulates its own municipal government through enacting ordinances. The law that allows Pennsylvania municipalities to adopt these ordinances was created by the Pennsylvania General Assembly in 1933 through Act 69, article XVI. This act ruled that the board of supervisors for a township can adopt ordinances which they then defined as "a piece of legislation enacted by a municipal authority". Easton's citizens vote every four years on the officials that will represent them as a member of this council (City of Easton, 2009).

In general, the process of implementing an ordinance is simple, although it can differ between municipalities. Easton's council meets every other Wednesday at the Easton City Hall at 6 pm and is open to the public. Additionally, a private meeting is held the Tuesday before these Wednesday meetings for just council members. The meeting minutes are typically posted publicly on the town website to encourage transparency and community engagement in local issues (City of Easton, 2009).

The process of bringing a potential ordinance into fruition is a community effort and grassroots movement by individuals looking to make a change. An ordinance starts as a proposal, created by any resident(s) of the city, who have identified a local issue and wish to propose a solution. This proposal could come from a multitude of sources, such as local politicians, private citizens (through public forums or petitions), as well as council, board, or committee meetings. Upon receiving the proposal, the city council discusses and evaluates the proposal. The council also has the ability to create a specialized committee to research, report, and make recommendations based on their findings. The proposed ordinance is read every time it is proposed to the city council, and the council is required to hold at least one public hearing. This gives the public a formal opportunity to provide input on the idea. Following all public hearings and their final discussions, the city council votes on the ordinance. Depending on legislature, the mayor may have the final say on whether it is passed. If it is passed, however, the ordinance is official and takes effect based on the agreed upon enactment process (City of Easton, 2009).

Conclusion

The composition of Easton's government allows a green roof policy to reasonably be passed. For this to happen, the town's citizens and council members would need to decide for themselves whether green roofs should be implemented. Our project avoids suggesting that we know what is best for another community, and instead lets the community decide if they would like to pursue green roofs based on our framework. The resources and time that go into adding green roofs could theoretically be expended towards other issues defined by Easton citizens, such as a new school or a food shelter. Bringing the idea to elected officials encourages them to make the best political decision for their residents.

It is up to the council to decide if a public work is fit for implementation based off of the evidence and framework presented. This council is a strong forum to gain public backing and is the likely channel for a green roof policy to be implemented. Through the ordinance system, and within a local municipality such as Easton, adding green roofs could reasonably become a reality. This policy would be driven by the city council, implemented through public works, and work toward benefitting Easton as a whole. However, before a policy can be used to implement green roofs, the technical aspects of the green roof itself and its intended building must be evaluated.

Technical Context

Green roofs are not an object, but a complicated and complex system. According to Green Roofs for Healthy Cities, "A green roof system is an extension of the existing roof which involves, at a minimum, high-quality waterproofing, root repellent system, drainage system, filter cloth, a lightweight growing medium, and plants" (Green Roofs for Healthy Cities). Simply stated, green roofs consist of vegetation placed on a roof, and infrastructure beneath the vegetation to support it and the roof/building below it.

Green Roof Components

There are six main layers of a green roof: the waterproofing membrane, the root protection layer, the drainage layer, the filter layer, the substrate layer, and the vegetation layer. Each layer of the green roof serves an important and unique purpose.

Vegetation. The vegetation layer is the most varying and customizable aspect of the system. It consists of either grasses, plants, shrubs, crops, or trees. Its components and layout depend on the purpose of the green roof, and the design parameters outlined by the roof's planner. A myriad of plant options exist within the vegetation layer, and are dependent on the roof's microclimate (media depth, solar levels, water availability, etc.) and its relation to the climate of the surrounding area. Ideally, green roof plants should be long-living, self-spreading, and should contain shallow root systems. Commonly used plants include sedums, moss, perennials, shrubs trees, and lawn. Generally speaking, succulents are a popular choice due to their ability to store excess water. *Figure 16* includes a table of recommended plants for green roofs in urban areas with similar climates to Easton.

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.

Figure 16. Ground covers appropriate for green roofs in the District of Columbia. Adapted from The Benefits and Challenges of Green Roofs on Public and Commercial Buildings by the United States General Service Administration, 2011.

Growing Medium. The growing medium is found above the filter layer and is responsible for supporting the layer of vegetation and its roots. Additionally, the growing medium is the source of water to sustain the vegetation as well as the main source of stormwater retention and detention, so its thickness has a direct reflection on the green roof's stormwater retention. The selection of specific material for growing medium varies abundantly, each material satisfying the following requirements: it satisfies the needs of the plants it supports, it must not pose excessive weight on the underlying structure, and it must provide an optimum balance between retention and drainage. Suggestions for the specific components of this medium are provided in ranges to account for differences in plant, roof and building needs. Roughly a 4:1 mixture of a mineral such as expanded clay and a lighter substance such as pearlite is used, and dried to contain about 20% aerated pore space, 40% water holding capacity, and 40% solid mixture of a mineral and a lighter substance. The ideal density for this mixture is five pounds per square foot per square inch. This will roughly retain 0.4 inches of rainfall per square inch of medium. One necessary consideration is the general lack of nutrients in such an inorganic material. To account for this, owners may need to use slow-release fertilizer which provides necessary minerals. Additionally, when constructing a green roof it is necessary to evaluate the surrounding climate and vegetation (Pérez, Vila, Rincón, Solé, & Cabeza, 2012).

Filter layer. Above the drainage layer is the filter layer in a green roof, which is responsible for allowing water to flow freely to the drainage layer while containing the growing medium and vegetation. Additionally, the filter layer prevents the drainage layer from getting clogged by trapping particles from the substrate layer (Vegetal i.D, n.d.). Polypropylene fabric is the most commonly used material because it is water-permeable, decay-resistant, inexpensive, tough, and durable. Variations within this layer are infrequent, however one gaining popularity is a system combining the filter layer and drainage layer. A failure within the filter layer could cause clogging of the drainage layer and roof drainage system which may cause irreparable damage to the building beneath (Vegetal i.D, n.d.).

Drainage layer. Above the protective layer of a green roof is its drainage layer, which is a porous material that allows water to flow from the green roof system to the roof's drainage system. The effectiveness of this layer is important to protect the roof from pooling and potential structural damage, but is also affected by the filter layer and growing medium chosen. There are two main types of drainage layer used. The first is a granular material such as pebbles, or plastic in a similar shape to account for weight. The second type of drainage layer used is a mat of spongy, webbed material which releases water once it becomes saturated. The robustness of this layer and the material used are dependent on the use of the roof and its orientation. For example, a nearly flat roof necessitates a thicker drainage layer to ensure water drains away from the roots of plants properly and does not drown them. Additionally, some drainage layers hold a certain amount of water to ensure the vegetation does not die. Drainage layers for some intensive green roofs are capable of incorporating irrigation systems to water more delicate vegetation. In Easton, due to the high frequency of flooding, a thicker drainage layer would be ideal to mitigate excess stormwater. This is especially true in floodplains where stormwater becomes flood water more quickly as the ground gets more saturated. Vegetation is much more effective at absorbing latent heat and therefore mitigating the urban heat island effect if it is not saturated in water. This is dependent on the effectiveness on the drainage layer (Center for Watershed Protection, 2013).

Protective layer. The layer after the waterproofing membrane is the protective layer (also known as the root barrier layer), which acts as a barrier between the roots of plants and the roof and waterproofing membrane below. One strategy for effectively separating these two layers is to provide a physical distance between the roots and the waterproofing, which is often done using layers of Polyvinyl chloride, welded PVC, or, more conservatively, plastic or metal trays elevated from the surface of the roof. This elevation can be invaluable in providing a physical distance which does not allow roots to reach the roof. Another, newer option within this layer is the use of a chemical root inhibitor which stops the growth of roots past a certain point. Although it has proven to be effective in several case studies, the existing presence of chemical pollutants in Easton's runoff suggests a physical barrier may be more suited for the city (Roof Protection, n.d.).

Existing roof membrane. The first distinction which must be made while initially considering the installation of a green roof is the condition of the existing roof membrane. Most roofs are designed to be weatherproofed, and are typically effective in protecting against the elements. However, for a roof to support consistent standing water, it must be waterproofed. This requires a higher standard of care and a thicker roof membrane. As green roofs become more common, some roofs are being built to be easily retrofitted for green roofs by including waterproofing and a more robust drainage system. However, due to the age of most buildings in Easton, it is likely that waterproofing and a more robust drainage system will be necessary to implement (Vegetal i.D, n.d.).

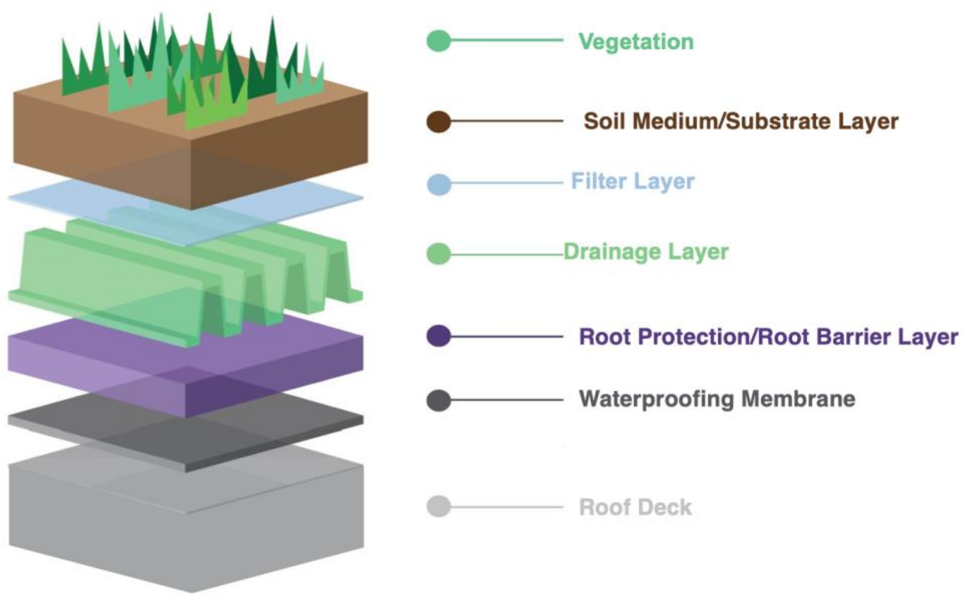


Figure 17. A description of the layers of Green Roofs. Adapted from *Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? - Edited by Authors,* Mentens, J., Raes, D., & Hermy, M. (2006).

Private Benefits of Green Roofs

For individual buildings or households where green roofs have been implemented, the main benefits include decreased energy use, increased roof membrane longevity, and improved acoustic insulation.

Energy reduction in heating and cooling. Green roofs reduce energy consumption in space heating in a multitude of ways: shading, evapotranspiration, insulation, increase in thermal mass, and reduction of heat loss through radiation. In the winter, green roofs can be more efficient in preventing heat loss than conventional roofs. An experiment in Ottawa found that a 6-inch extensive green roof reduced heat gains by 95% and reduced heat losses by 26% compared to a conventional roof. Another study conducted by Florida Solar Energy Center found that 18% of the energy that was used for space cooling was saved by a green roof compared to a conventional roof. That number increased to 44% when the plants were more established (Feng, 2018).

Membrane longevity. There are three ways in which green roof technology increases the lifespan of a building's roof: by protecting it against diurnal fluctuations, UV radiation, and thermal stress. Studies have shown that green roofs can lengthen the lifetime of a roofing membrane between 40 and 50 years. On the other hand, conventional roof's have lifespans that range between 10 and 30 years (Feng, 2018).

Acoustic insulation. By increasing absorption, green roofs improve the soundproofing of a building and reduce the sound reflection. For buildings located near very strong sources of noise, such as Route 22 which crosses Easton's downtown, green roofs can be extremely helpful. One of the most common methods used to improve noise insulation is applying an extra layer of plasterboard into the ceiling. The benefits from green roofs are similar and often times exceed those of the extra layer of plasterboard since there are multiple layers in a green roof (Feng, 2018).

Public Benefits of Green Roofs

In addition to the individual benefits, there are many public benefits, such as the reduction of stormwater runoff, the improvement of air quality, and the mitigation of the urban heat island effect.

Reduction of stormwater runoff. Green roofs can have a significant impact on the stormwater retention capacity of buildings. Traditionally, rainwater flows off of a building's roof and into the sewers quickly, but with the implementation of green roofs, it slows down significantly since they can retain some of the water. Sewer systems capacity requirement can be lowered by using green roofs since they can hold as much as 50% - 95% of the annual precipitation depending on the regional climate (Feng, 2018).

Improvement of air quality. The vegetation plays a very crucial role for the green roof. It actively absorbs many pollutants and passively filters and directs airflow, thus reducing air pollution. A study conducted in Toronto, Canada found that by implementing 109 hectares of green roofs, eight metric tons of unclarified air pollutants can be removed per year. Additionally, a study conducted in Chicago, Illinois estimated that 1,645 kilograms of air pollutants can be removed by 19.8 hectares of green roofs (Feng, 2018).

Mitigation of the urban heat island effect. As mentioned earlier, in urban areas, much of the natural vegetation and landscape has been replaced by impervious surfaces. The dark surfaces, such as roads, reflect less solar radiation and absorb more energy. A simulation study in New York found that if 50% of the roof area is covered with vegetation, the average roof temperature can be reduced by as much as 0.8 degrees Celsius. In Toronto, Canada, it was estimated that the urban heat island effect can be reduced by 12 degrees Celsius if only 6% of the city was covered with green vegetation. In the Mediterranean region, green roofs can save between 10% and 14% of the electrical energy consumed in cooling residential buildings. However, it is important to realize that green roof performance in reducing the urban heat island effect is different depending on the location due to factors such as climate (Feng, 2018).

Intensive and Extensive Green Roofs

There are some universal requirements for green roof plants. First, the plants cannot have invasive roots because these could puncture the system. Additionally, they cannot be too heavy in order to satisfy the maximum load bearing capability of the roof (Grant & Jones, 2008).

Generally speaking, there are two main classifications of green roofs: intensive green roofs and extensive green roofs. While not all green roofs fit perfectly into this categorization, the two work to satisfy differing wants and needs and work to improve different aspects of the natural environment. Both intensive and extensive green roofs have significant environmental benefits. They both help improve stormwater runoff, improve air quality, and reduce the urban heat island effect.

Intensive green roofs are often intended for human interaction. Therefore, they are more in the form of a garden with pathways and thus are often times a source of food. Additionally, they serve as space for people to gather, similar to a park. With this additional human interaction, intensive green roofs must be designed to sustain the additional weight from human foot traffic as well as the plants and trees. Therefore, these green roofs are almost exclusively installed on concrete roof frames. Similarly, intensive green roofs can only be installed on flat roofs. Since intensive green roofs are meant for interaction, they require frequent maintenance. Routine work includes watering the plants, cutting the shrubs, or even harvesting the crops. The complete intensive green roof system can weight between 102 and 410 pounds per square foot. Additionally, the substrate layer is typically at least 12 inches thick (Vegetal i.D, n.d.). Overall, although intensive green roofs are heavy and typically expensive, some of the unique features are the wide variety of wildlife, a community gathering spot, a source of food, and their visual appeal. *Figure 18* shows an example of an extensive green roof and *Figure 19* shows an example of an intensive green roof.

Figure 18. An Example of an Intensive Green Roof with Specific Areas for Community Members to Gather. Adapted from *Baltimore Convention Center,* Greenroofs.com, 2018

Figure 19. An Example of an Extensive Green Roof. Adapted from *Extensive versus Intensive - Which Would You Choose?*, by Yurek, 2013.

Extensive green roofs are vastly different than intensive green roofs. They are not intended for human interaction and take the form of a mostly self-maintained system. Extensive green roofs typically do not include plants that require maintenance, but rather opt for species that are drought resistant and self-sufficient (Grant & Jones, 2008). Some of the common choices are sedums, moss, and perennials (Vegetal i.D, n.d.). Since extensive green roofs are not intended for people to interact with, they are much more versatile than intensive green roofs. They can be installed on roofs with slopes in addition to flat roofs. Extensive green roofs are significantly lighter than intensive green roofs, weighing between 15 and 37 pounds per square foot (Vegetal i.D, n.d.). This makes it much more feasible to retrofit an existing building with an extensive green roof than an intensive green roof. In addition to the lightweight system, there is very little, possibly even no, maintenance required. Furthermore, extensive green roofs do not require as thick of a substrate, typically between 2 and 6 inches (Vegetal i.D, n.d.). Overall, some of the unique features are the low maintenance requirements, versatility to retrofit existing roofs, and relative lightweight. The table below, *Figure 20*, further explains the differences between extensive and intensive green roofs.

EXTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
• Thin growing medium; little or no irrigation; stressful conditions for plants; low plant diversity.	• Deep soil; irrigation system; more favorable conditions for plants; high plant diversity; often accessible.
Advantages: • Lightweight; roof generally does not require reinforcement. • Suitable for large areas. • Duitable for roofs with 0 - 30° (slope). • Low maintenance and long life. • Often no need for irrigation and specialized drainage systems. • Less technical expertise needed. • Often suitable for retrofit projects. • Can leave vegetation to grow spontaneously. • Relatively inexpensive. • Looks more natural. • Easier for planning authority to demand as a condition of planning approvals.	**Advantages:** • Greater diversity of plants and habitats. • Good insulation properties. • Can simulate a wildlife garden on the ground. • Can be made very attractive visually. • Often accessible, with more diverse utilization of the roof. i.e. for recreation, growing food, as open space. • More energy efficiency and storm water retention capability. • Longer membrane life.
Disadvantages: • Less energy efficiency and storm water retention benefits. • More limited choice of plants. • Usually no access for recreation or other uses. • Unattractive to some, especially in winter.	**Disadvantages:** • Greater weight loading on roof. • Need for irrigation and drainage systems requiring energy, water, materials. • Higher capital & maintenance costs. • More complex systems and expertise.

Figure 20. Comparison of the advantages and disadvantages of extensive and intensive green roofs. *Adapted from Design Guidelines for Green Roofs., S.* Peck, S., & M. Kuhn, M., 2016.

Overall, most of the differentiation between intensive and extensive green roofs stem from their different purposes, and thus the vegetation choice. Since extensive green roofs are almost strictly for environmental benefits, the most common choices are sedums, moss, and perennials because they are able to flourish in harsh environments (Vegetal i.D, n.d.). On the other hand, since intensive green roofs are intended for human interaction and are therefore maintained, there is a much wider choice of vegetation options. Choices range from shrubs, grasses, large perennials, and even small trees (Step Digital, 2016).

In addition to having physical differences in size, weight, and material, intensive and extensive green roofs can also address a variety of different community concerns. These concerns include flooding, water quality, stormwater runoff, access to food and air quality, but vary by district because of the distinctly heterogeneous nature of Easton. This indicates that the best decision making framework would take into account the different needs of different communities within Easton, and how those needs might best be satisfied by green roofs of different styles (Frankel & Goldman, 2017).

Conclusion

Green roofs are a complex system and, at a minimum, are made of the following components: the vegetation, the growing medium, the filter layer, the drainage layer, the protection layer, waterproofing. There are benefits for both the individual building owner as well as the general public. Some of the private benefits include: decreased energy use, increased roof longevity, and increased acoustic insulation. In contrast, the public benefits include the reduction of stormwater runoff, improvement of air quality, and the mitigation of the urban heat island effect. The two main classifications of green roofs are intensive and extensive. Intensive green roofs differ from extensive green roofs in that they are designed for human interaction. Intensive green roofs often include gardens, pathways, and can be used as a source of food. Extensive green roofs are considered a self-maintained system but still yield significant benefits due to its versatility. These benefits include its low maintenance, ability to be installed on sloped roofs, and relatively small weight. Each green roof is unique and the specific layers of the green roof must be catered to each building's differing context and specifications. This element of green roofs adds significant variability to their costs, which will be further explained in the economic context of this report. *Figure 21*, below, demonstrates the variability of factors that should be considered during green roof design.

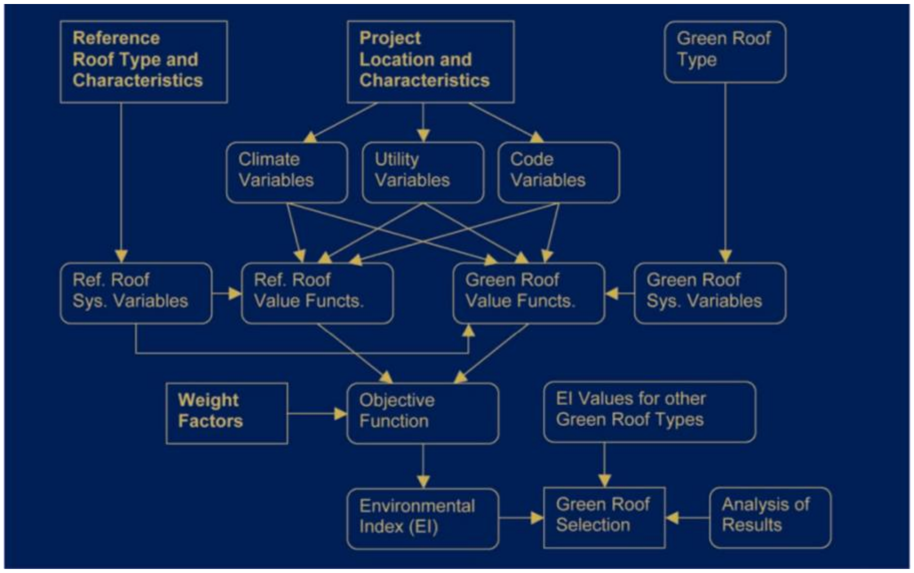


Figure 21. A flowchart showing the sequence of variables that need to be considered for green roof design. Adapted from *A decision-making framework for vegetated roofing system selection, by* Grant, E. J., & Jones, J. R., 2008.

Economic Context

General Costs:

The tabulated costs associated with green roof design and construction are driven by the type of green roof, the scope of each component, and the aspects of the roof. Macroeconomic factors will likewise affect the cost of green roof construction. Generally speaking, green roofs cost between $10.00 and $30.00 per square foot to install, with annual maintenance costs ranging from $0.75 to $1.50 per square foot (Baker, n.d.).

Intensive green roofs are limited in that they can only be installed on buildings with a flat roof. Traditional flat roofs typically cost anywhere between $7.00 to $12.00 per square foot to install (Learn How Much It Costs to Install a Flat Roof, 2018). There are three common types of flat roofing. All of which have slightly different perks but overall similar costs. One type is called a "built-up roof" which is composed mostly of tar and gravel. Another is modified bitumen, which is made of various compounds and can be rolled or "peeled and stuck" conveniently. Lastly, a flat roof can be made of a rubber membrane which is lightweight, durable, resists sun damage, and is easy to repair (Learn How Much It Costs to Install a Flat Roof, 2018). The biggest benefit of flat roofs is that, when treated properly, they are capable of being walking on safely. Furthermore, this allows them to hold entities such as intensive green roofs and gardens (Green Roofs for Healthy Cities, n.d.).

Green Roof Service Life:

An additional benefit of green roofs is that they extend the lifespan of the building's roof by protecting against diurnal fluctuations, UV radiation, and thermal stress (Feng, 2018). Green roofs have a service life of 30 to 50 years, but must be maintained in order to remain safe and functional (Feng, 2018). When a green roof is created, its first years of existence are called the "establishment period" (General Service Administration, 2011). This period requires additional attention to the young plants as they acclimate, including additional watering and removing weeds to ensure the vegetation develops properly. Maintenance is critical to the long-term success of the roof; costs are highest for both for extensive and intensive roofs during the establishment period, however, intensive green roofs require more frequent and longer visits than extensive green roofs due to their components especially following this period (General Service Administration, 2011).

If an intensive green roof is installed with crops, they have to be tended to and the garden has to be maintained as well. This inherently creates a market for jobs in the green roof business. The process involves installation, gardeners, repairmen, and others, which in turn, creates jobs as well as a new domain in the construction and agricultural industry. Maintenance includes weeding, harvesting, and distributing grass to improve coverage as well as checking the growth medium and inspecting for other potential problems. Following the establishment period, maintenance requirements will decrease (General Service Administration, 2011).

Effects on Green Roof Costs:

Broadly speaking, green roof costs are determined based off of type (extensive and intensive). Because extensive green roofs work to abate environmental issues like stormwater runoff, air quality, and the urban heat island effect with minimal human interaction, they generally run a lower cost than intensive green roofs. Intensive green roofs work to do all of the above while providing a space for the community, which requires reinforcements for additional load bearing capacities. Extensive green roofs cost between $10.00 to $20.00 per square foot while intensive green roofs cost between $20.00 to $40.00 (Peck and Kuhn, 2016). Macroeconomic elements can greatly affect the cost of these green roofs. The people that dictate these costs are the green roofs companies that work in the business. Factors that could influence costs are listed below:

- Project location
- Size and slope of the roof
- Height of roof above grade
- Availability of labor
- Accessibility by crane
- The structural capacity of the roof deck
- Location and type of roof drainage and waterproofing
- Use and specific features desired (i.e. deck, pavers, trees, turf, other)

These factors affect specific costs associated with green roof installation and maintenance. In order to determine the costs associated with each of these aspects, green roof installation companies have created several planning guides. These either craft specific green roof systems for an individual roof's specifications and owner's wants and needs, or they determine which predesigned system they created best fits those wants and needs. However, for those determining if a green roof is the right option to be implemented at all, the following guides serve as a starting point for determining green roof costs. (See Appendix). The tables shown highlight which components of green roof construction are more costly than others. As indicated, much of the costs stem from re-roofing the existing roof and initial construction of the green roof system. Both of these costs can be adjusted greatly in conjunction with scope to fix the project to better meet the needs of the green roof. The other costs are either relatively negligible, involved with the initial design or necessary construction phase of the project, or optional.

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

	Component	Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, growing medium, decking and walkways)	$160.00 - $320.00 per sm. ($15.00 - $30.00 per sf.)	Cost factors include type and depth of growing medium, type and height of curbing, type of decking, and size of project. (cost does not include freestanding planter boxes.)
e)	Plants	$54.00 - $2,150.00 per sm. ($5.00 - $200.00 per sf.)	Cost is completely dependent on the type and size of plant chosen, since virtually any type of plant suitable to the local climate can be accommodated (one tree may cost between $200.00 - $500.00.
f)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf.)	Cost factors include type of system used and size of project.
g)	Guardrail / Fencing	$65.00 - $130.00 per lin.m. ($20.00 - $40.00 per lin. ft.)	Cost factors include type of fencing, attachment to roof, and size of project / length required.
h)	Installation / Labor	$85.00 - $195.00 per sm. ($8.00 - $18.00 per sf.)	Cost factors include equipment rental to move materials to and on roof, size of project, complexity of design, and planting techniques used.
i)	Maintenance	$13.50 - $21.50 per sm ($1.25 - $2.00 per sf) annually.	Costs factors include size of project, irrigation system, and size and type of plants used.

Figure 22. Cost ranges of the different components of extensive green roofs with the determining variables associated with each price range. *Adapted from Design Guidelines for Green Roofs., S.* Peck, S., & M. Kuhn, M., 2016
Source: Peck and Kuhn, 2016

4.2 ACCESSIBLE INTENSIVE GREEN ROOF

(Costs assume an existing building with sufficient loading capacity; roof hatch and ladder access only. The larger the green roof, the cheaper the cost on a square metre basis.)

Component		Cost	Notes & Variables
a)	Design & Specifications	5% - 10% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
b)	Project Administration & Site Review	2.5% - 5% of total roofing project cost.	The number and type of consultants required depends on the size and complexity of the project.
c)	Re-roofing with root-repelling membrane	$100.00 - $160.00 per sm. ($10.00 - $15.00 per sf.)	Cost factors include type of existing roofing to be removed, type of new roofing system to be installed, ease of roof access, and nature of flashing required.
d)	Green Roof System (curbing, drainage layer, filter cloth, growing medium, decking and walkways)	$160.00 - $320.00 per sm. ($15.00 - $30.00 per sf.)	Cost factors include type and depth of growing medium, type and height of curbing, type of decking, and size of project. (cost does not include freestanding planter boxes.)
e)	Plants	$54.00 - $2,150.00 per sm. ($5.00 - $200.00 per sf.)	Cost is completely dependent on the type and size of plant chosen, since virtually any type of plant suitable to the local climate can be accommodated (one tree may cost between $200.00 - $500.00.
f)	Irrigation System	$21.00 - $43.00 per sm. ($2.00 - $4.00 per sf.)	Cost factors include type of system used and size of project.
g)	Guardrail / Fencing	$65.00 - $130.00 per lin.m. ($20.00 - $40.00 per lin. ft.)	Cost factors include type of fencing, attachment to roof, and size of project / length required.
h)	Installation / Labor	$85.00 - $195.00 per sm. ($8.00 - $18.00 per sf.)	Cost factors include equipment rental to move materials to and on roof, size of project, complexity of design, and planting techniques used.
i)	Maintenance	$13.50 - $21.50 per sm ($1.25 - $2.00 per sf) annually.	Costs factors include size of project, irrigation system, and size and type of plants used.

Figure 23. Cost ranges of the different components of intensive green roofs with the determining variables associated with each price range. Adapted from *Design Guidelines for Green Roofs*., S. Peck, & M. Kuhn, 2016.

Green Roof Scope:

As the scope of the green roof increases, the benefits granted to the community increase as well. Similarly, the larger a green roof is, the less costly the installation cost premium will be. Maintenance costs are high for a large green roof, however, the maintenance cost per square foot decreases the larger a green roof is. Therefore, the most effective green roof in terms of its cost to its benefit is one that is as large as feasibly possible, this effect is shown in *Figure 24*.

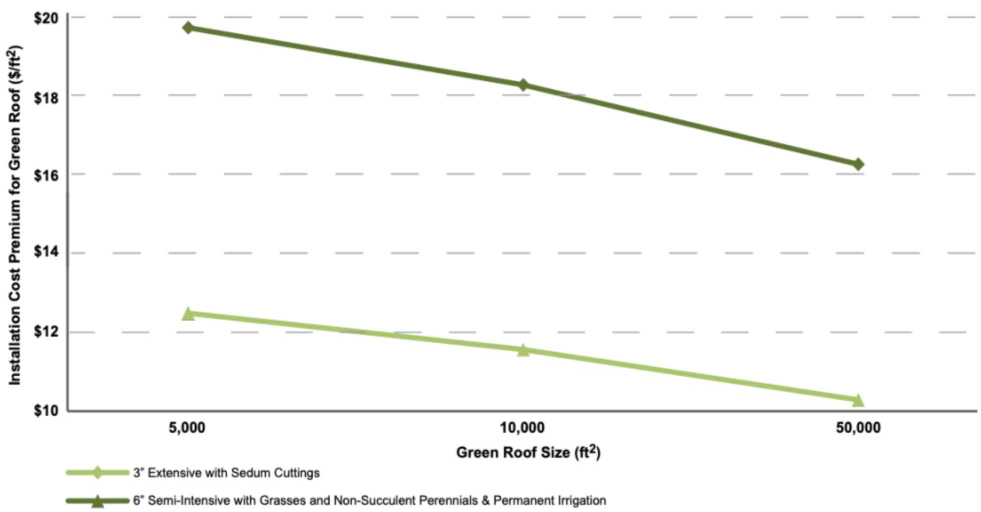


Figure 24. The correlation between green roof size and installation costs per square foot. Adapted from *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings,* by the United States General Service Administration, 2011.

Green roofs have a large initial cost, as design, site assessment, and material costs must be paid before the green roof is even put in place. Therefore, green roofs are a large investment where most of the benefits will come at a later point in time (General Service Administration, 2011). Following construction and installation costs, the long term costs of the roof are relatively low. Extensive green roofs require minimal maintenance following installation, so long term costs are low, if not nonexistent. Intensive green roofs require more maintenance costs than extensive green roofs as the plants and components of the roof endure human interaction and may need frequent attention (such as walkways and crops). However, these costs can be mitigated at the designer or owner's discretion (Dvorack, 2010). The following figure displays how costs decrease as a green roof gets larger. Therefore, owners who want to completely capitalize on green roof benefits will get a better value if they implement a larger green roof.

Cost-Benefit Analysis:

Cost-benefit analysis weighs the costs of various green roof components to their benefit in a relative manner through standardization such as putting all of the costs into the net present value. A study conducted by the General Services Administration (General Service Administration, 2011) found that the overall costs and benefits of green roofs are net positive in the long-term. A table of these results is located below. The analysis compares the results nationally to the results found in Washington D.C., further emphasizing the fact that the costs and benefits will change based on geography and context. The high upfront cost due to installation and the frequent maintenance during the establishment period is what deters individuals from implementing them on their own buildings. The benefit is measured in NPV, or net present value, which is a dollar amount in the net present. It is a measure of the potential profit from an investment. It measures the expected value of the future costs and benefits (with inflation considered) and turns it into the net present. A positive net present value means an investment will produce positive returns over the time frame while a negative net present value means that an investment will return losses over the time frame. This cost-benefit analysis demonstrates that much of the benefits of green roofs are granted to the public, while the building owners are the ones who suffer financially.

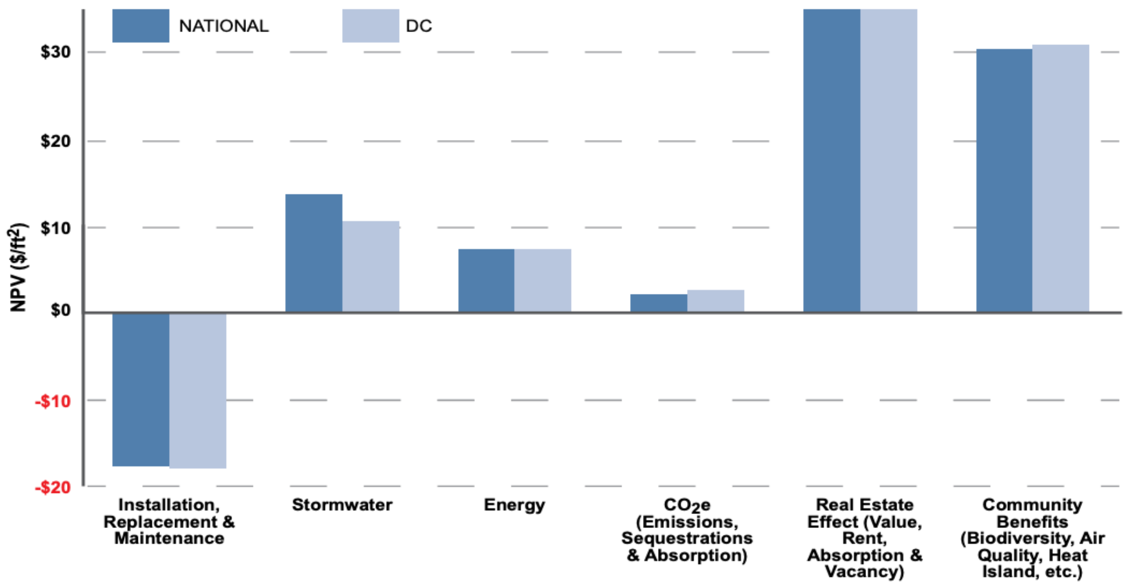


Figure 25. A Cost Benefit Analysis of Green Roofs –The positive net present value (NPV) mostly lies within a green roof's benefits to the community and the pure existence of a green roof on a building's real estate. Adapted from *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings,* by the United States General Service Administration, 2011.

HARD COST VARIABLES	CHANGE IN TOTAL NPV PER 1% CHANGE IN VARIABLE
Roof Longevity (1-year change)	13.24%
Installation Costs	11.32%
Discount Rate	4.89%
Maintenance Costs	3.38%
Energy Savings	2.51%
Stormwater Equipment Cost	1.44%
Stormwater Surcharge	1.35%
Green Roof Risk Contingency	1.21%

Figure 26. Sensitivity Analysis of Green Roofs highlighting which variables most impact a green roof's value and cost. Roof longevity and installation costs are the highest variables. Adapted from *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings,* by the United States General Service Administration, 2011.

Sensitivity Analysis:

The authors of this General Service Administration study also conducted a sensitivity analysis to analyze which factors have the highest effect on benefits relative to their costs. In other words, it identifies which variables are more important based on their ability to impact the total NPV. As illustrated, roof longevity and installation costs are the most sensitive variables. A 1% change in a green roof's lifespan increases the total net present value by 13.24% while a 1% change in initial costs increases the net present value by 11.32%. Installation costs are also the most significant cost incurred by owners, further highlighting the importance of this part of the process. Roof longevity is also an important variable in that each additional year that a green roof exists allows its benefits to exist as well. As mentioned earlier, green roofs roughly double the lifespan of a traditional roof. Sensitivity analysis is important in that it highlights the tradeoff between quality and cost. Building owners should keep this tradeoff in mind when considering what purpose they want their green roofs to serve.

Public vs. Private Benefits:

A major factor in determining the financial feasibility of implementing a green roof is the public and private benefits. These benefits differ greatly and therefore have a major impact concerning one's decision to implement a green roof. In general, the largest individual benefit of green roofs are the reduction in energy use and cost for heating and cooling. Although, other individual benefits include sound insulation, roof longevity, as well as aesthetic benefits. Public benefits include reduced stormwater runoff, improved air quality, mitigation of urban heat island effect, and the promotion of urban biodiversity. Civic planners should work to encourage individuals to add green roofs so that the benefits to the community can come into existence and provide long-term sustainability of the community. The following table shows the how the NPV changes based on one's relationship to the green roof. The community has a much higher national average benefit of $29.80 per square foot of green roof compared to the owner which is near-zero Those who live in the buildings are intermediary between these two values at around $5.00 or $6.00 per square foot of green roof. The driving forces behind these differences is how owners have to pay for the installation and maintenance of their buildings while the community benefits from factors such as the mitigation of the urban heat island effect, reduced flooding risk, stormwater management, and biodiversity.

	OWNER	OWNER/ OCCUPANT	TENANT	COMMUNITY	MARKET EXPECTATION (YEAR 1)
NATIONAL	$0.06	$6.0	$5.4	$29.8	$12.9
WASHINGTON DC	-$1.0	$3.1	$4.1	$30.3	$10.0
TOP 2 DRIVERS	Maintenance Costs & Avoided Stormwater Infrastructure	Maintenance Costs & Avoided Stormwater Infrastructure	Maintenance Costs & Energy Savings	Biodiversity & Urban Heat Island	Longer leases & Rent

Figure 27. How NPV differs for community members depending on one's relation to the green roof. Adapted from *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings,* by the United States General Service Administration, 2011.

Therefore, the question arises of who will pay for green roofs? Our research indicates that the public sector will have to implement them into society, not the private. Therefore, in conjunction with policy, taxpayers will ultimately be paying for their implementation. To help combat high overhead costs, many municipalities have enacted incentive programs. These programs subsidize the costs to individuals so that the overarching benefits of green roofs can be realized to the community. Examples of these are further explained in the policy analysis section of the report. Green roofs also help buildings achieve LEED certification. LEED certified buildings are effective in that they promote eco-friendly practices, have lower operating costs, improve public relations and health standards, as well as other benefits to the community. Some areas require newly constructed buildings to have a certain level of LEED certification, thus providing further incentive to construct a green roof.

Conclusion:

To summarize, green roofs occupy space which is considered an opportunity cost; the space and resources could be ultimately used elsewhere or for other purposes. Taxpayers fund the incentivations that the green roof policy would have. It is highly possible that the Easton citizens could choose to use these resources elsewhere, effectively choosing a do-nothing option. The differences between the benefits of green roofs for the public and private sector make their feasibility a challenge. The scale of time for the benefits to come to fruition differ between public and private. Public sectors prioritize civic planning and sustainability which could take multiple decades to occur, where the private sector focuses on individual benefits like increasing the profitability on their building, typically in a shorter time frame. In any event, a policy would be required to bring these benefits to the public; although it is up to the citizens to decide if that is how they would like to allocate their tax money.

Conclusion

To recap, a green roof is a sociotechnical system that has a multitude of environmental benefits, particularly for urban areas such as Easton. These benefits include improved air and water quality, stormwater management, and mitigating the urban heat island effect. Furthermore, building owners have the opportunity to significantly decrease their energy use, saving money and benefiting the environment. In this project, our group created a framework to address whether or not green roofs are viable option for solving Easton's specific environmental problems. We did this by considering the social, political, technical, and economic contexts of Easton's four major neighborhoods to provide a custom recommendation while keeping the community members ultimate decision makers. This allows the Easton community to decide themselves whether they think green roofs are worth it or if the resources should go elsewhere.

Challenges

One of the main issues that we faced during this project dealt with determining what the citizens of Easton viewed as the most important environmental concerns. We had originally speculated that flooding, stormwater management, and air quality would be major concerns, but had no evidence. We initially planned to survey members of the Easton community to find out what environmental concerns they had, but we realized that in order to conduct our own survey, we would need to receive approval from the Institutional Review Board (IRB). Not only would it take the entire semester to receive the appropriate approval, we realized that our survey would likely yield biased results stemming from response and convenience biases. To overcome this challenge, we reached out to Ms. Kathryn Semmens of Easton's Nurture Nature Center. We asked Ms. Semmens if she had any data regarding the environmental concerns of Easton's citizens and she sent us the Easton Matters Report that was conducted in 2016. Contained in that report were 311 responses from community members regarding their environmental concerns, organized into the four major neighborhoods: College Hill, West Ward, Downtown, and South Side. Additionally, the report consisted of responses from 16 city officials and 18 representatives from 10 community based organizations. All of these responses allowed us to understand what environmental concerns were most important for each neighborhood and for Easton as a whole. However, it is extremely important to understand that none of the samples contained more than 95 responses, so it is possible that the concerns identified in the Easton Matters Report are not undoubtedly significant.

A second major challenge of this report is the complex relationship between building ownership, maintenance, and funding. Private buildings have a less complicated path towards implementing green roofs because they are funding the project themselves. Public buildings would require funding through policy and taxpayers, where citizens might disagree on where this money should be allocated. It is important to note that while the majority of green roof benefits are granted to the greater public, the private sector suffers a majority of the costs. Even though policy would allow for green roof implementation on public buildings, we faced the challenging question regarding who "owns" the public building and who decides whether or not to implement a green roof? This is crucial to understand because the size of the investment and the lifespan of the green roof significantly influences current and future tax allocation.

Lastly, we faced a significant challenge in the form of time. With the way that the Engineering Studies 451 capstone was structured this semester, the scope of our project has changed significantly. Originally, we planned on implementing green roofs on governmental buildings in downtown Easton. However, the combination of limited time and a lack of data regarding the specifications of the buildings led us to refocus our scope. Next, we considered using one public and one private building within Easton as a case study which could then be applied to other situations. We planned to collect the building specification data in order to determine whether or not green roofs are a feasible solution in Easton. This would also allow for other urban areas similar to Easton to use our case study as a model for their community. Once again, we quickly realized that we lacked an adequate amount of time to gather such data. Thus, we eventually had to broaden the scope of our project and ultimately created a specific framework for each of the four major neighborhoods in Easton.

Next Steps and Recommendations for Future Work

In order to continue building off of our findings, we recommend future initiatives begin by reading our report and framework to gain an understanding of the four contexts that are associated with green roofs. We have a three-step suggestion for those looking to continue this research with the purpose of improving Easton's environment. Due to the limitations of the Easton Matters Report, our first recommendation is to gather more data from Easton's citizens regarding their concerns. One potential way to do so is to collaborate with Easton's Nurture Nature Center to create a new survey that allows the citizens to respond more freely about their concerns of the city as a whole. A more open-ended question, such as, "What could be done to improve Easton?" would allow citizens to identify any concern, not just environmental concerns. This is important because, for instance, if most of Easton's citizens view education as the biggest concern, it would not make sense to pursue green roof implementation in Easton.

With this data, if Easton citizens identify environmental concerns as their foremost issue, we recommend reaching out to community members, city officials, and the city's Public Works Department. By doing so, they could work with these groups to gather data regarding building specifications, such as the building's dimensions, how much weight it can support, its energy usage, and the existing roof membrane. Gathering all of this data would allow future researchers to determine the technical feasibility of green roofs in Easton with more certainty.

If green roofs are determined to be technically feasible, our final step of recommendation includes hosting a presentation at the Easton City Council. This presentation would include the framework that we developed, the results from the refined survey, and the technical feasibility of green roofs in Easton. This provides an initial reception from citizens and city representatives to assess community support towards green roofs. By presenting this information to the citizens, they are kept at the center of the entire process and are the ultimate decision makers in determining whether or not green roofs are the best solution to their specific concerns.

A Framework for Understanding Green Roof Feasibility
Easton, PA

Brynn Fuller-Becker
Gaby Greenfield
Daniel Figler
David Alpert

EGRS 451 - Engineering in Society
Professor Ben Cohen

Types of green roofs: Intensive (shown left), and extensie (shown right).

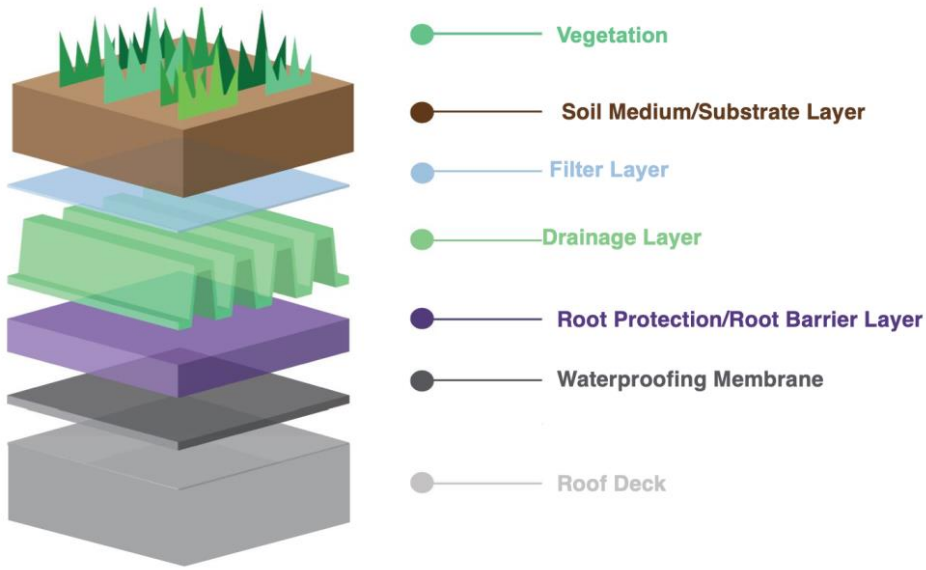
Intensive: Intended for Human Interaction

- More in the form of a garden with pathways and thus are often times a source of food
- Serve as space for people to gather, similar to a park
- Must be designed to sustain the additional weight from
    - Human foot traffic
    - Plants & Trees
- Almost exclusively installed on
    - Concrete roof frames
    - Flat roofs
- High maintenance requirements
    - Watering the plants
    - Cutting the shrubs
    - Harvesting the crops
- High weight: 102 and 410 pounds per square foot
- Thick substrate layer: typically at least 12 inches thick

Extensive: Intended for environmental benefit

- Self-maintained system
    - Do not include plants that require maintenance
    - Do include drought resistant and self-sufficient plants
        - Sedums, moss, and perennials
- More versatile than intensive green roofs
- Can be installed on roofs with slopes in addition to flat roofs
- Low weight: 15 and 37 pounds per square foot
    - More feasible to retrofit on an existing building
- Little to no maintenance required
- Thin of a substrate: between 2 and 6 inches

Green Roof Components:



- Vegetation Layer
  - Most variable
    - Dependent on :
      - Measures of hardiness, wind resistance, and drought tolerance
      - Weight data
      - Availability and price data
      - Evapotranspiration rates
      - Data on thermal effects of evapotranspiration
      - Leaf area indices
      - Foliage heights
  - Commonly used plants for extensive roofs - sedums, moss, perennials
  - Commonly used plants for intensive roofs - shrubs, trees, lawn
  - Determining factor for all other aspects of roof
- Growing Medium/Substrate Layer
  - Supports vegetation and its roots, and provides water for vegetation
  - Main source of stormwater retention/detention
    - The thickness of this layer has a direct correlation with the amount of stormwater a green roof can retain
  - Inorganic material
    - May be mixed with a slow-release fertilizer to sustain vegetation
  - Specific materials within the substrate layer vary frequently based on the necessary minerals for intended vegetation
  - General guidelines

        - Begins with roughly a 4:1 mixture of a mineral (such as clay) and a lighter substance (such as pearlite)
            - roughly 20% aerated pore space, 40% water holding capacity, and 40% solid mineral mixture
- Filter Layer
    - Prevents drainage layer from getting clogged by trapping particles from substrate layer
    - The most commonly used fabric is Polypropylene Fabric:
        - Water permeable
        - Decay resistant
        - Tough
    - Can be combined with the drainage layer in order to make the installation process easier

- Drainage Layer
    - Allows water to flow away from the green roof system and toward the roof's drainage system
        - Important on completely flat roofs because if drainage doesn't happen properly, water could pool on the roof causing potential structural damage, as well as drowning the roots of the vegetation.
    - Prevents plants from being consistently saturated with water, which may cause them to drown, and dampens their ability to absorb latent heat and mitigate the urban heat island effect.
    - Two types for different environmental benefits:
        - Granular material made of plastic (similar shape to pebbles, but lighter)
            - Releases water slowly, but does not have stormwater retention, and does not hold water in instances of drought.
            - Best suited for intensive green roofs - ability to include irrigation for higher maintenance plants
        - Mat of spongy, webbed material
            - Heavier because it holds water
            - Stormwater retention
            - Can provide plants with water during drought
            - Not well suited for irrigation
            - Better suited for Extensive green roofs
- Protective Layer
    - Provides a barrier between plants' roots and the waterproofing membrane beneath.
    - Invaluable to a successful green roof
        - Failure at this layer could cause severe water damage to the existing building.
    - Two types of protective layers
        - A physical barrier typically consists of strong metal or plastic trays welded together and elevated from the waterproofing membrane.

        - A chemical root inhibitor stops the growth of roots once they've reached it.
- Existing roof membrane and drainage system
    - Implemented to withstand consistent standing water
        - Green roofs can be most readily implemented on buildings whose roofs are already waterproofed and flat.
    - Two main types:
        - Polyurethane-based liquid applied treatments
        - Asphalt-based sheets.

‘

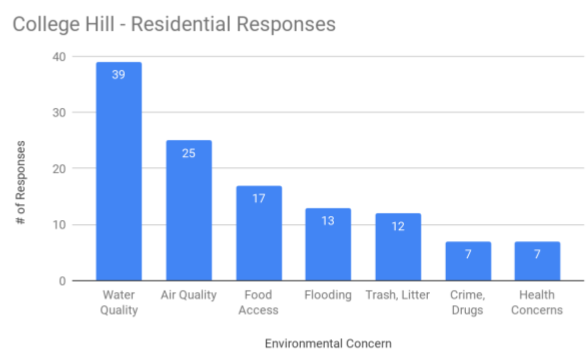
Note: Information and images compiled in this framework is drawn from the sources referenced in the full Green Roof Feasibility Assessment, found here.

Additional Resources for green roof design and implementation may be found in the appendix.

Neighborhood:
College Hill

Main Identified Concerns (88 responses)
(Source - Easton Matters Report)

1. Water Quality (44%)
2. Air Quality (28%)
3. Food Access (19%)



Other factors:
(Source - Vulnerability Assessment)

- Presence of Lafayette College
- Relatively few impervious surfaces
- Relatively high tree canopy cover
- Relatively high socioeconomic-status
- High prevalence of parcels at possible risk of flooding

Assessment: A green roof best suited to solve College Hill's environmental issues could either be extensive or intensive, depending on the community members' prioritization of concerns. An extensive green roof works to solve air and water quality, while a intensive green roof works to improve food access, in addition to improving air and water quality. However, since the intensive green roof provides the additional access to food, it does come at a higher cost. Generally speaking, an intensive green roof costs $20-$40 per square foot and an extensive green roof costs $10-$20 per square foot. The higher general socioeconomic status of the residents of College Hill increases the likelihood of private implementation of green roofs, either on residential homes or on the Lafayette College campus. We speculate that green roofs will be a viable tool to help College Hill solve their environmental issues, given the wide range of implementation options and ample financial resources.

If College Hill were to decide to implement a green roof, our design recommendations for the roof are as follows:

Vegetation
- Shrubs to improve air and water quality if community decides to do an extensive green roof
- Fruit and vegetable crops for food access if community decides to do an intensive green roof

Substrate Layer
- Dependant on intensive or extensive

    Extensive - Ideally growing medium with high proportion of sand for sedum growth, can also grow in mediums with high prevalence of loam and clay

    Intensive - Slow releasing fertilized growing medium to promote produce growth, with high proportion of loam and organic material

Filter Layer - Polypropylene fabric (most common)
Holds nutrients in the system and prevents substrate from going into the drainage layer

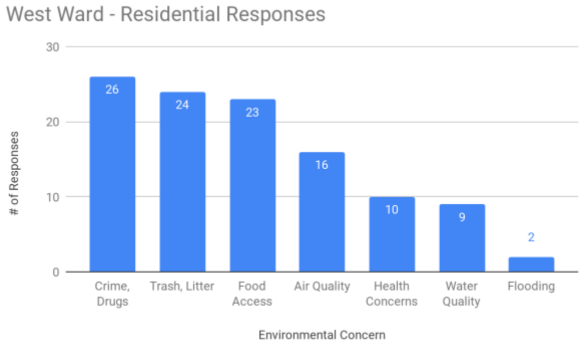
Drainage Layer - Granular material made of plastic (as flooding and stormwater management are not major concerns)

    Releases water slowly
    Does not store very much stormwater
    Tends to be the lighter of the two drainage layer options
        More versatile for different buildings.

Protective Layer - Physical protective layer (as water quality is a main concern)
Mitigate the possibility of the chemical root inhibitor polluting stormwater/watershed

Roof Membrane - Cannot make a sufficient recommendation - dependent on the uplift resistance of included soils and the expected roof life.

Neighborhood:
West Ward



Main Identified Concerns (95 responses)
(Source - Easton Matters Report)

1. Crime, Drugs (27%)
2. Trash, Litter (25%)
3. Food Access (24%)

Other factors:
(Source - Vulnerability Assessment)

- Relatively high prevalence of impervious surfaces
- Relatively low tree canopy cover
- Relatively high percentage of household in poverty
- Low prevalence of parcels at possible risk of flooding

Assessment: Green roof implementation which successfully alleviates the environmental issues of the West Ward consists of a highly interactive intensive green roof, costing around $20-$40 per square foot, likely on the upper range of $30-$40 per square foot. While the West Ward has a high percentage population with low household income, policy could help the neighborhood subsidize green roofs high initial costs. Additionally, the main issues identified by community members and city officials differed, so government assistance and policy may help to align concerns. Ultimately, we are skeptical that green roofs are a viable solution to the West Ward's environmental issues, given their main identified concerns and financial constraints.

If West Ward were to decide to implement a green roof, our design recommendations for the roof are as follows:

Vegetation - Trees and grasses, fruit and vegetable crops
Provide space for community gathering
Fruit and vegetable crops help to improve food access

Substrate Layer - Growing medium with slow-release fertilizer, higher content of organic material
Loam, clay will promote growth of produce and other delicate vegetation
Soil may be tended to and fortified with consistent maintenance

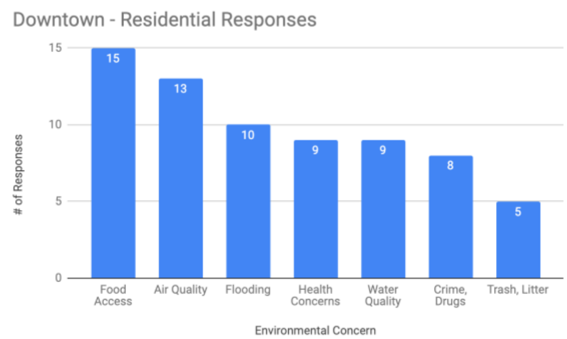
Filter Layer - Polypropylene fabric (most common)
Holds nutrients in the system and prevents substrate from going into the drainage layer

Drainage Layer - Granular material made of plastic (as flooding and stormwater management are not major concerns)
Releases water slowly
Does not store very much stormwater
Tends to be the lighter of the two drainage layer options
More versatile for different buildings.

Protective Layer - Physical barrier
Less expensive (more manageable for areas with lower socioeconomic status)

Roof Membrane - Cannot make a sufficient recommendation because it is dependent on the uplift resistance of included soils and the expected roof life.

Neighborhood:
Downtown



Main Identified Concerns (68 responses)
(Source - Easton Matters Report)

1. Food Access (22%)
2. Air Quality (19%)
3. Flooding (15%)

Other factors:
(Source - Vulnerability Assessment)

- High prevalence of parcels in 100 year, 500 year flood plain
- High impervious surface coverage - majority of impervious surfaces are structures
- Low tree canopy cover
- Relatively high percentage of household in poverty
- High prevalence of parcels at possible risk of flooding

Assessment: Downtown has a high prevalence of impervious surfaces and lies in a flood plain. It has a relatively low socioeconomic status, but with proper policy in place, intensive green
roofs could be a feasible solution to their environmental concerns. Intensive green roofs provide food access to the urban area and mitigate issues with air quality and flooding in the area. Therefore, intensive green roofs are a viable solution to address the concerns raised by the citizens of Downtown Easton.

If Downtown were to decide to implement a green roof, our design recommendations for the roof are as follows:

Vegetation
- Shrubs to improve air and water quality
- Fruit and vegetable crops for food access
- Plants with high water retention capabilities (e.g. succulents) to help with stormwater management.

Substrate Layer - Growing medium with slow-release fertilizer, higher content of organic material

Loam, clay will promote growth of produce and other delicate vegetation
Soil may be tended to and fortified with consistent maintenance
High proportion of sand for sedum and succulent growth

Filter Layer - Polypropylene fabric (most common)

Holds nutrients in the system and prevents substrate from going into the drainage layer

Drainage Layer - Granular material that is made of plastic

Allows for installation of an irrigation system
Lighter of the two drainage layer options

More versatile for buildings with different weight capacities and
Allows more flexibility in vegetation options.

Protective Layer - Physical protective layer (as water quality is a main concern)

Mitigate the possibility of the chemical root inhibitor polluting stormwater/watershed

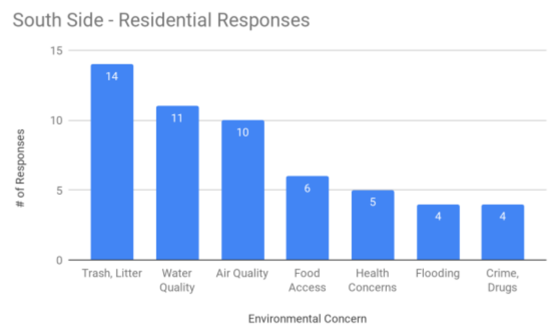
Roof Membrane - Cannot make a sufficient recommendation because it is dependent on the uplift resistance of included soils and the expected roof life.

Assessment: Downtown has a high prevalence of impervious surfaces and lies in a flood plain. It has a relatively low socioeconomic status, but with proper policy in place, intensive green
roofs could be a feasible solution to their environmental concerns. Intensive green roofs provide food access to the urban area and mitigate issues with air quality and flooding in the area. Therefore, intensive green roofs are a viable solution to address the concerns raised by the citizens of Downtown Easton.

Neighborhood:
South Side

Main Identified Concerns (60 responses)
(Source - Easton Matters Report)

1. Trash, Litter (23%)
2. Water Quality (18%)
3. Air Quality (17%)



Other factors:
(Source - Vulnerability Assessment)

- Relatively few impervious surfaces
- Moderate amount of tree canopy
- Low prevalence of parcels at possible risk of flooding
- Relatively low percentage of households in poverty (<$30,000)

Assessment: South Side has a generally low prevalence of impervious surfaces, with generally high tree canopy cover and relatively low percentage of households in poverty. An extensive green roof implemented would help solve the environmental issues identified by the South Side. Relatively high household income increases the feasibility of private implementation of green roofs. Ultimately, we believe green roof implementation in South Side helps to solve the environmental issues identified by community members.

If South Side were to decide to implement a green roof, our design recommendations for the roof are as follows:

<u>Vegetation -</u> Grasses, shrubs, and sedums for an extensive green roof
Species from different taxonomic groups increases biodiversity and survivability

<u>Substrate Layer</u> - Higher ratio of inorganic material for an extensive green roof
Slow-release fertilizer may be necessary depending on specific plant needs - not necessarily required.

<u>Filter Layer</u> - Polypropylene fabric (most common)

Holds nutrients in the system and prevents substrate from going into the drainage layer

Drainage Layer - Spongy, webbed material is best suited for extensive green roof

Retain stormwater during instances of high precipitation

Retaining water for plants to use in instances of drought

Mitigates any need for outside irrigation to maintain vegetation

Protective Layer - Physical protective layer (common and less expensive option)

Prevents chemicals (and pollutants from trash and litter) from entering water supply

Mitigate the possibility of the chemical root inhibitor polluting stormwater/watershed

Roof Membrane - Cannot make a sufficient recommendation because it is dependent on the uplift resistance of included soils and the expected roof life.

Appendix (GR)

Bauder Green Roof Design Considerations:

https://www.bauder.co.uk/technical-centre/downloads/design-guides/green-roof-design-guide.pdf

Zinco Planning Guide – System Solutions for Intensive Green Roofs:

https://www.zinco-usa.com/downloads/pdfs/ZinCo_Intensive_Green_Roofs.pdf

Zinco Planning Guide – System Solutions for Extensive Green Roofs:

https://zinco-usa.com/downloads/pdfs/ZinCo_Extensive_Green_Roofs.pdf

Design Guidelines for Green Roofs:

https://www.eugene-or.gov/DocumentView.aspx?DID=1049

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