Expanding the green network on rooftops: A Study of integrating green roofs as a part of urban green space planning

A thesis submitted by

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Abstract

This thesis explores the concept of green roofs and urban green space planning. Through a quantitative GIS analysis and various qualitative content analysis on most recent open space plans in Boston, this thesis aims to look at whether existing open space plans have considered applying spatial planning elements for green roofs, a prominent type of green infrastructure. Various green roofs programs and ordinances in the US recognized the multifunctionality of green roofs. But in the aspect of spatial planning, green roofs have not been integrated as a part of open space management. However, in the most recent Open Space and Recreation Plan 2015 – 2021, some green roofs key words could be found in the plan that indicates that the city is open to extend the functions of green roofs and explore ways to enhance urban green space network that includes green infrastructure.

Acknowledgement

I would like to offer my heartfelt thanks to my advisor, Justin Hollander and my reader, Sumeeta Srinivasan. They are both very encouraging, patient and helpful from the very beginning till the end of my thesis process. They took the time and effort to help me brainstorm ideas and provide me with insightful suggestions to better my research. Without their help at UEP, I would not have been able to complete this thesis.

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Introduction

This thesis is about incorporating green roofs into urban green space planning in a compact city development. There has been debate about what type of spatial development is sustainable in the long term (Jenks and Johns 2010). There are a lot of quantitative and qualitative research done to investigate whether increasing density in a city contributes to a society's economic, environmental and social benefits. The idea of 'compact city' emerged and gained popularity as studies have shown correlations between the attributes of a compact city (increased density, diverse land use, decreased time of travel) and economic, environmental and social sustainability of a city (Jabareen 2006). The compact city development improves environmental and social well-being by reducing travel time and promoting alternative travel. Diverse land use in compact city reduces average travel time by putting different services together. Alternative travel such as walking, and cycling could also be encouraged because of shorter travel distance. In long term, compact city development reduces carbon dioxide emissions and increases energy efficiency (Jenks and Johns 2010).

However, space is scarce and compact development would put a pressure on green space development. Therefore, in order to maintain sustainability in a compact city, some scholars and activists argue that careful urban green space planning is essential (Coolen and Meesters 2012) Green roofs should have an important role in urban green space planning as they do not occupy much space compared to conventional green spaces, yet are proven to be effective in reducing energy consumption of buildings, mitigating urban heat island effect, controlling stormwater overflow and increasing accessibility to green spaces (Vijayaraghavan 2016). Studies have also found that 40% of world-wide energy use is associated with the construction and maintenance of conventional buildings (Vijayaraghavan 2016). Buildings are also responsible for 33% of

greenhouse gas emission globally (Vijayaraghavan 2016). Cities in general have recognized the comprehensive benefits of green roofs and some cities have created regulatory and incentive programs to encourage implementation of green roofs. But there are not a lot of research on incorporating green roof development as a part of comprehensive planning.

In view of this, this thesis will try to bridge the gaps between green roofs regulatory and incentive programs and open space planning initiatives, hoping to inform planners/policy practitioners how green roofs could be a part of a city's open space network. This thesis will use Boston as a case study to explore the relationship between green roof initiatives and open space planning initiatives to understand how they may mutually reinforce one another.

Methodology

Before I conducted the research, I have set up a few research questions to guide my research. My research questions are:

1) How are green roofs integrated into green space planning?

2)) Is the multi-functionality of green roof being realized in open space planning?

3) Are there differences in interpretation of landscape connectivity between green roofs and open space management?

First, a literature review was conducted on sustainable development, green space planning and the economic and environmental conflicts in policy implementation. The literature review is compiled of academic journal articles and industry reports. The literature review will include a historical debate on sustainable development and the current advocate for sustainable development. The literature review on sustainable development will discuss the concept of compact city, the conflicts between economic and environmental policy and how it frames the policy implementation in a sustainable compact city. The keywords I used in literature search includes 'sustainable development', 'compact city', 'green space planning', 'green roof policies'. The database I used for my literature review includes peer-reviewed scholarly articles and planning reports. The first part will give the research a background on how and why compact city is important for sustainable city development and how it relates to urban green space planning and green roof developments in the city.

The second part of the literature review will be conducted to review green space planning in the compact city. The literature review will include the importance of urban green space planning (public and private spaces), existing green space planning practices and challenges, and people's perceptions on public and private green spaces.

The literature review will create a foundation for the research by looking at positive benefits of compact city development and existing green space planning policies. Most literatures have looked into the importance of green space planning in a compact city but not many have looked into the potentials of linking green roofs into open space planning system. This thesis will expand this knowledge by diving into the possibility of incorporating green roofs into urban green space planning. It will serve as a research to inform planners how green roof policies and open space planning initiatives could reinforce each other in the municipal level. The third part of the research will be focus on development on green roofs, including its economic, environmental and social benefits to a sustainable city and climate resiliency. The section will start by reviewing the historic development and evolvement of green roofs, followed by its relations with global and local climate change. In this section, policy initiatives at various level of government (federal, state and municipal) related to green roofs development will also be reviewed. The policy initiatives will also be broken down into different categories, including regulatory, incentive-based, and planning based. To accompany the research, policy case studies of various North American cities (Denver, San Francisco, Toronto, Chicago and Portland) will be conducted to compare and contrast the policy motivations, the nature and relations to green space planning.

The last part of the research will be divided into two main research, quantitative and qualitative. The quantitative part will look into accessing Boston's open space needs using GIS suitability analysis. The analysis will use environmental indicators (land temperature, impervious cover) and social indicators (population with low-to-no income, disabled population, children population, people of color etc.) to generate an opportunity layer that shows areas in need of green spaces and buildings suitable for green roof development.

With the knowledge of open space needs in the city, the qualitative research part will include content analysis of various existing open space plans in Boston. The plans I have chosen are the Open Space Plan 2008-2014, Open Space and Recreation Plan 2015-2021 and Imagine Boston 2030 Open Space chapter. Meta-analysis of the published reports will be conducted to identify any convergence and divergence in the research. Meta-analysis could also show the gaps in research which needs further analysis. Chapter 1 and 2 will be literature review for compact development and green space planning models. Chapter 3 and 4 will be an in-depth policy analysis of existing green roofs programs and open space planning.

Chapter 4 will include a quantitative analysis (GIS) of open space needs in Boston, a qualitative analysis (meta-analysis) of various chosen open space plans and reports and implications and recommendations for future studies in this topic for Boston. In this chapter, I will compare and contrast the results from the quantitative and qualitative analysis in order to investigate how the results of these two types of analysis complement each other. Both concepts of green roofs and open space planning will be operationalized and examined in reviewing most recent published open space planning reports. A manifest and latent analysis will be applied to examine all the chosen documents. A manifest analysis is a quantitative approach to measure text by the intensity of the number of times a word or phrase is used (Gaber and Gaber 2007). Latent analysis is described as a qualitative approach to interpreting the data to learn what they mean (Gaber and Gaber 2007). To conduct both content analysis, key words that are related to open space and green roofs are chosen to be examined. Key words chosen to be examined are based on existing content analysis and literatures on open space planning and existing green roof initiatives.

Three of the most recent open space in Boston will be examined, which is the Boston Open space plan 2008 – 2014, Open space and recreation plan 2015 – 2021 and Imagine Boston 2030 open space chapter, to determine the changes in perception of planning of and definition of open spaces. The changes in perception and definition of open spaces could inform us how planning models have changed overtime and whether the changes involve planning opportunities for green roofs as a type of open space.

In the last part of Chapter 4, the results of the quantitative analysis of open space need and the qualitative analysis of changes in perception of open space will be compared and contrasted in order to determine whether these two distinct analyses could complement each other in a way that answers my research question. The quantitative analysis of open space needs will offer insights about the places of opportunities to install green roofs, while the qualitative analysis of open space plans will complement the quantitative analysis by showing the bridges and hurdles of enacting policies and planning practices that integrate green roofs development in open space planning. Followed by that will be conclusion and recommendations of the thesis and limitations and recommendations for future research. Below is a flow chart showing how my methodology helps me answer my research questions.

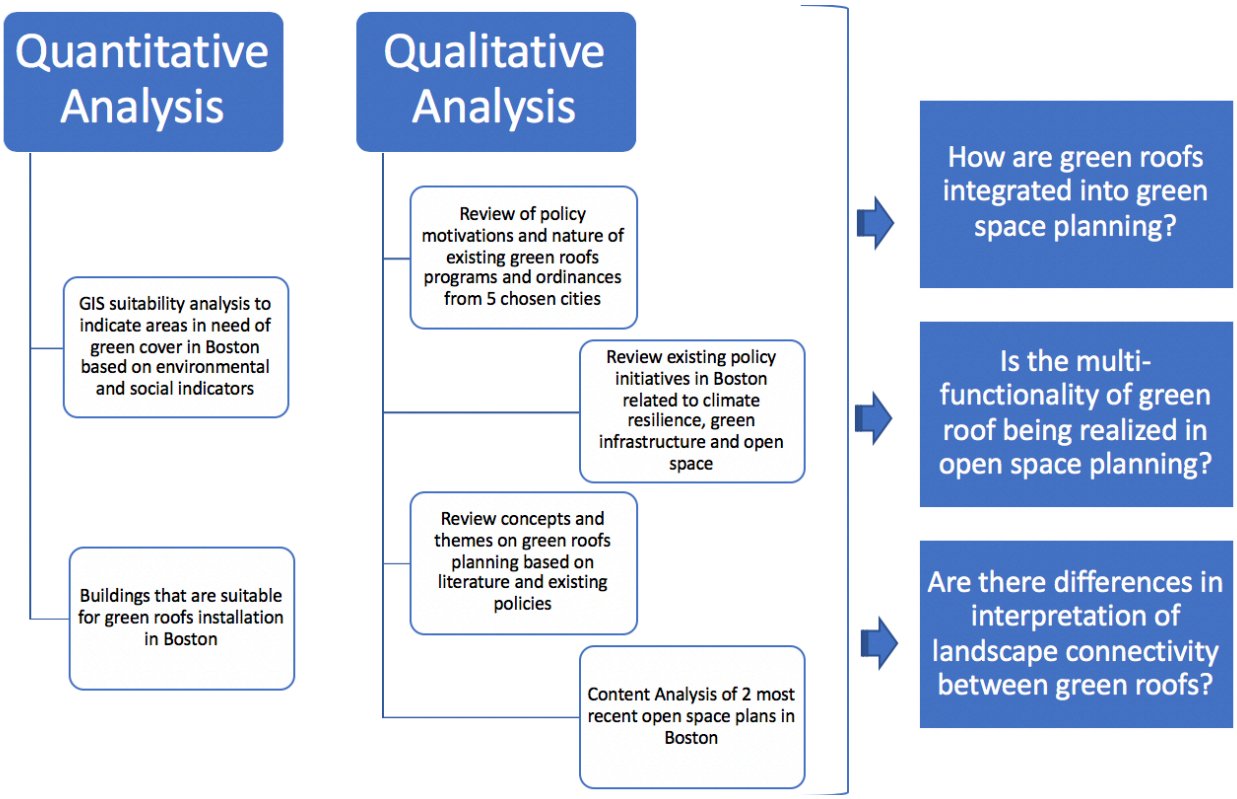

Figure 1 Methodology

Chapter 1 - Compact City Development

Sustainable development: A debate

Jabareen (2006) (Jabareen 2006) in Sustainable Urban Forms approaches sustainability in terms of different spatial levels. Unlike other literatures on compact city, Jabareen applied a more qualitative approach by creating a sustainable urban form matrix to analyze and assess sustainability of different urban forms. Though without the support of quantitative data, Jabareen's study provided a matrix that could assist planners and policy practitioners in different levels of government and geographical regions.

Jenks and Johns (2010) in Dimensions of the sustainable city view a sustainable city having its physical and social dimension. The debate on sustainable city circled around the density of development, diversity of uses, urban sprawl containment and social and environmental justice vitality. The above-mentioned concepts are often characterized as 'compact city', which is a concept introduced and advocated by the European Commission. The concept emerged based on the belief that compact urban forms could reduce sprawl, promote more efficient and effective use of land that protects agriculture and amenity. The compact city concept also promotes various alternative travel such as walking, cycling and public transport, which will in turn generate social, environmental and economic benefits in the long run.

In terms of discussing what benefits a compact city could bring to the society, the authors characterize the benefits in which increased density could bring into several topics:

- Environmental Sustainability – Energy savings, urban green space providing cooling service for buildings
- Transport – Reducing the need to travel and the length of journeys
- Social Benefits – Increase social interactions

- Economic Viability – More diverse local service provision

However, the authors argue that there is no single answer to what a city could benefit and how much it would cost for a city to adopt compact urban development. Both the costs and benefits are depended upon the social context and urban form of a city. The authors advocate the use of quantitative and qualitative analysis from the combinations of GIS, site analysis, environmental modelling to questionnaires and focus groups to define sustainable development for specific communities.

Boyko and Cooper (2001) in Clarifying and Re-conceptualizing density took a more quantitative approach in which the article analyzes the relationships of density among various variables. The results of the article suggest that the natural form, building form, material form, static form and people perception could pose an important impact in the design of a sustainable city. The authors also agree that policies related to density should be flexible, versatile and respond to specific physical and social context. The authors also introduce the concept of 'soft' and 'hard' density. The 'hard density refers to the quantitative measure of density (people, space and scale). When applying density policies to certain communities, the authors indicate that it is important to use 'hard' density data as a guidance in policy making. On top of that, looking at the needs and expectations and the current social contexts of spaces in a community would be helpful in deciding what types of density policies and design should be adopted. At the end of the paper, Boyko and Cooper made a similar point compared to Jenks and Johns in a way that compact development is a complex concept that any policies that are to be implemented should take local context into considerations.

The debate on compact city development have been going on for decades and policy planners' perception on the idea changes from strong opposition to gradually moving towards the compact city concept in a lot of European countries. The reason for such a change is due to the increase amount of empirical studies on the relationships between urban compactness and length of travel. (Holden and Norland 2005) Frames the debate on compact city development around two major arguments: Which urban forms afford the greater energy efficiency and which aspects of sustainable development are more important. The studies specifically looked at energy consumption in various residential neighborhoods in Greater Oslo region: low-density, medium density, and high density. The results show a correlation between high density and low energy consumption. In view of the results, the authors support developing decentralized compact cities, which are cities that compact developments should happen in towns in their own way instead of creating a mega monolithic city.

Economic and environmental conflicts in planning

Campbell (1991) Defines the ideal type of economic view as the traditional neoclassical economists in which the unit of analysis is the individual or the firm and transactions and values are measured in money. Their view in equilibrium is a balance of supply and demand in the context of a steadily growing economy. The needs of individuals are best served through enlightened self-interest as expressed through the marketplace. Natural resource is viewed as flexible and the supply and values of natural resource is determined by improving technologies of extraction and processing.

Campbell (1991) In Integrating Economic and Environmental Planning - The Regional Perspective explores the differing conceptions of economics and environmentalism in the

regional perspective dating back to the first establishment of the Regional Planning Association of America (RPAA) during 1920s, followed by the New Deal-era regional planning. Campbell highlighted the pragmatic shift in conceptions from viewing economy and the environment as a holistic, organic and balanced link in the RPAA era to viewing the link as a multi-use resource conservation, use and management with the ultimate goal of economic recovery and growth.

Campbell's critique on the RPAA was the inability of expanding their holistic view of achieving spatial balance of industrial urbanization and nature beyond a small group of people. Along with the push of the political arena of the Great Depression, regional planning shifts to be a pragmatic use of regional resource development for economic expansion and recovery.

Chapter 2 - Green Space Planning for the compact city

Density and greenspace interaction

(Coolen and Meesters 2012) mentioned in their research that there has been a strong advocacy for the compact-city concept because governments in the US as well as other parts of Europe have an active agenda for promoting sustainable urban areas. The motivations of developing compact cities resonates with the literatures reviewed on the previous paragraphs in the aspects of shortening work/travel time for people and making alternative travel possible for people. In long term, it could potentially reduce carbon dioxide emission. With a history of preference on suburban type of residential environment, there has been a tension between compact lifestyle and demand for space. Many people tend to not accept a residence without a garden. In order to make the compact-city concept more appealing to people, developers and planners have to incorporate dwelling concepts that respond to compact city and growing demand of urban green space. Coolen & Meesters explored people's perception and interaction on urban green space by dividing urban green spaces into two main categories, public and private green space.

Byrne and Sipe (2010) in their research mentioned that there has been ongoing debate about increased density and urban greenspace use. There is a notion that urban green space should be increase as density increases, which is always referred as 'compensation hypothesis'. Byrne and Sipe believe that there should be more to be considered when planning for increased urban greenspace. In the article, they criticized that we should not have an assumption that people living in denser neighborhoods with little access to private greenspace will tend to use neighborhood public parks and other greenspaces more frequently. City-dwellers may be stimulated to have more leisure-based travel to the countryside. The public green spaces in the

cities are not appealing to them. Apart from that, different typologies of public green spaces emerged and planned under different social and political context over time, planners have to consider on how to incorporate existing urban greenspaces into the needs of city dwellers. The authors also noted that there should be a need-based assessment when planning for urban public spaces as different typologies of parks could cater completely different groups of demographics. Along with the differences in demographic groups, cultural differences also determine the design and capacity of urban public spaces.

Both literatures have brought out the point that urban green space should not just be a 'compensatory' element in sustainable city planning. People's perception on the use and meaning of green spaces are essential in green space planning. The differences in perceptions could be explored under the lens people's cultures, the typologies and designs of the spaces and the ownership of the spaces. In addition, (Coolen and Meesters 2012) looked into similarities and differences in perception of public and private green spaces in Netherland concluded that people have different perceptions on public and private green spaces. The private green spaces such as private gardens are always considered as a place for enjoying life and freedom, while public parks are considered as a contributor to urban livability and social interactions.

Public and private green space and their relations to social identity and environmental sustainability

Bernardini and Irvine (2007) Further studies the psychological experience of place between public and private green space. When using public or private green spaces, people attached meanings and perceptions to different types of green spaces. In the study, the authors use the Place identity integrated model (PIIM) and environmental representation (ER) to address the meaningfulness and identity of people in relation to private gardens and public greenspaces.

The foundation of the PIIM includes the four principles: distinctiveness, continuity, self-esteem and self-efficacy.

Uzzell, Pol and Badenas (2002) Expands the discussion on place and identities into the relations among social identity and environmental sustainability.

Existing open space planning models

Definition of open space in land use planning

In modern planning terms, open spaces are closely related to land use planning. Land use planning deals with allocation of land for a variety of uses. The functions and values of open spaces are manifold, but in terms of land use, open spaces are most commonly defined either as provision of recreation and other services to society or conservation of natural values (Maruani and Amit-Cohen 2007).

Open Spaces as provision of recreational services are driven by people's increased leisure activities, which is driven by the rising standard of living and changing patterns on employment and lifestyle. Recreational demands such as sports and games could mostly be satisfied by open spaces. Defining open space as provision of services reflects a utilitarian approach. Open space is considered as beneficial to the society due to the recreational services it provides and the potential psychological and social purposes it serves. The existence of open spaces as services is justified by its benefits provided to the society.

Another commonly definition of open space is the conservation of natural values. This perception of open space reflects a moral and ethical approach. Open spaces are considered as a part of a complex ecosystems and are prone to continuous flow processes and external changes. The recognition of the natural values of open spaces as a part of an ecosystem motivates planners to conserve open spaces. Some scholars put a more economic view on the value of open spaces

by treating open spaces as natural assets, a resource of direct economic value (Maruani and Amit-Cohen 2007). This view resonates with the traditional neoclassical economic view that (Campbell 1991) mentioned when discussing economists' views on the value of the environment. Open spaces are sometimes vulnerable to interventions if treated as a good to attain economic benefits.

The economic and environmental conflicts discussed in chapter 2 can be reflected in the case of planning for open space conservation. In a capitalist society, open spaces are often given an economic value which quantifies the benefits of preserving open spaces. However, conflict between development and open space conservation arises as values of open spaces cannot be monetized and measured using monetary units. Therefore, the market and speculative value of a developed land are usually higher than the value of open spaces.

Open Spaces face market failures in a market economy. In economic terms, public open spaces are considered as public goods, which no one can maintain exclusive control over their use and no one has the motivation to finance such goods. Therefore, in a lot of cities, public open spaces are poorly maintained, full of crimes or ended up not entertaining the intended group of public. Open spaces also face market failure in terms of externalities. As mentioned in the previous paragraph, the benefits of open spaces to the society is hard to calculate and quantify. As the indirect environmental and social benefits of open spaces are not being captured, it is hard for open spaces to compete for land allocations in the market (Maruani and Amit-Cohen 2007).

The models of open space planning

Open space planning was a relatively new concept. The idea of open spaces emerged in the 18th and 19th century when public parks were planned to reduce the social stress and poor living conditions in the inner cities. Conservation of open spaces was not a part of land use

planning until rapid urbanization, increased motorization and urban sprawl threatened natural landscapes and heritage values in the 20th century.

The Garden City model was the earliest attempt to include open space into comprehensive urban planning. The model regards open spaces as an integral part of development (Maruani and Amit-Cohen 2007). Ebenizer Howard planned to address the overcrowding and uncontrolled growth in cities by creating open spaces as buffers to balance pollutions sources and development areas. The Garden City model has not only inspired planners around the world but also the origin of shape-related models such as greenbelts, green fingers, which will be discussed in later paragraphs.

The Park system model was first emerged at the end of 19th century, relatively newer than the garden city model. The park system model has taken into account the different sizes and ranges of services that park, and gardens provide. The model aims to connect various parks into an interconnected open space system that includes trails as well. Boston's Emerald Necklace is one of the examples of park system model. Boston has created an Open Space and Recreational Plan to reinforce the Emerald Necklace from 2015 – 2021.

Shape-related models originated from the garden city model when greenbelt became popular in the late 19th and early 20th century. Preserving a greenbelt is supposed to prevent cities' expansion and merging with small nearby settlements (Maruani and Amit-Cohen 2007). The greenbelt idea was developed and applied mostly in England but was being further adopted in other countries in Europe, America and Asia. Though greenbelt was not successful in preventing urban growth, it is useful in conserving accessibility of open spaces to the public (Maruani and Amit-Cohen 2007). Boston Greenbelt Walk could be one of the modern examples of greenbelt. The Boston Greenbelt Trail is a proposed 90-mile trail circling Boston and

connecting major parks and open spaces including the Blue Hills, Cutler Park, Middlesex Fells, Breakheart Reservation, Lynn Woods and a number of local conservation areas (Un 2015). From this example of greenbelt, it can be seen that the idea of greenbelt has gone beyond merely conserving accessibility of open spaces, but also improving conditions for walking along roadways and promoting a more connected regional trail system.

The remaining open space planning models are more focused on the conservation of open spaces. Ecological determinism planning model sets aside land for open space uses after analyzing data and values of the natural features of the plan area. While the rest of the plan will be used for development. This model of open space planning was more prominent in the 1960s when planners started to consider ecological values as a part of systematic planning. The first project related to ecological determinism was developed for the twin valleys in Baltimore. Ecological determinism planning devotes a lot of effort on sustainability analysis on water bodies, drainage basins, surface morphology, hydrology and agriculture. The analysis could be more expensive, complicated and differs projects by projects (Maruani and Amit-Cohen 2007).

Protected landscapes and biosphere reserves have similar functions and are less directly related to the planning system. Both models protect open spaces by designating them with a statutory status for protection. This model began with Yellowstone National Park in the US in the late 19th century and a lot of natural landscapes have proclaimed under similar title for protections (Maruani and Amit-Cohen 2007).

In this research, more emphasis will be focus on the open space planning approaches related to the urban areas as this research tries to explore urban open spaces planning. In the following parts which the research tries to explore possibilities to reinforce open space planning strategies and green roofs development together, the opportunistic model, the space standards

and park systems model will be analyzed with green roofs incentives. Table 1 below shows the characteristics of the three systems that are going to be analyzed in the later chapters.

Table 1: Characteristics of three main open space planning systems

Open space planning Model type	**Opportunistic model**	**Space standards model**	**Park system model**
Guiding principle	Focus on recreation Random Application	Focus on recreation Accommodating population size	Focus on recreation Interrelating between spaces physically or hierarchically
Relative costs	Low	Low	Low to Medium
Interrelations	None	None	High
Variety	High	High	High
Process duration	Short	Short	Short

Source: Maruani, Tseira, and Irit Amit-Cohen. 2007. "Open Space planning models: A review of approaches and methods." *Landscape and Urban Planning* 1-13.

Chapter 3 – Multifunctionality of green roofs and policy motivations

Green roofs are considered as a type of Green Infrastructure (GI). Green Infrastructure is defined differently in different countries and under different planning systems. In the UK, GI is developed around the idea of protected designation of green space. In Europe, GI is connected with the idea of the need to create integrated green space within high density landscape. However, the definition of GI from the US Environmental Protection Agency is relatively narrow compared to the UK and Europe. It defines GI as 'a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits…is designed to move urban stormwater away from built environment…'. From this definition, we can see that EPA perceive GI according to ecological benefits as opposed to economic and social ones. As a result, implementation of green infrastructure, including policies related to green roofs in the US are mostly translated from this definition. Consequently, policy initiatives related to green roofs, or GI in general, are mostly single-function. Details of the existing green roof policy drivers in federal, state and local level will be further discussed in the later part of this chapter.

In reality, studies have shown that vegetated green roofs are effective in reducing energy consumption of buildings, mitigating urban heat island effect and air pollution. Green covers also control stormwater overflow by increasing water retention with plants and reducing impervious cover. 40% of world-wide energy use is associated with the construction and maintenance of buildings. Buildings are also responsible for 33% of greenhouse gas emission globally (Berardi, GhaffaruabHoseini and GhaffarianHoseini 2014). A study on changes in tree cover and impervious cover in the City of Boston found that buildings account for higher percentage of

increase in impervious cover amongst all. In the City of Boston, buildings from 2003 and 2008 accounted for 16.7% increase in impervious cover.

Apart from environmental concerns, other studies have found that socially vulnerable people such as people with disability, limited English proficiency, medical illnesses etc. have a disproportionate risk and a decreased ability to avoid potential harm to climate change and environmental hazards. However, most literatures look into the effectiveness of green roofs with an environmental lens and neglects the importance of connecting the social needs of vulnerable population with the benefits of green roofs. Green roofs are proven to be effective in improving public health by mitigating air pollution. A study by Yang et al shows that 1675 kg of air pollutants was removed by 19.8 hectare of green roofs in one year. Various other studies have also shown that green roof could remove up to 4000kg of particle matter (Vijayaraghavan 2016).

Historic evolvement of green roofs

Green roofs have historically existed for many years. The earliest green roofs dates back to the hanging gardens in Babylon in the fifth century. The first generation of green roofs emerge when people started embracing the aesthetic values of roof gardens as well as the ability of roof gardens to improve human interactions. The aesthetic values of green roofs were popular among Roman Architecture. Green roofs are also popular for its ability to insulate. Northern European countries like Norway used green roofs to increase thermal insulation (Berardi, GhaffarianHoseini and GhaffarianHoseini 2014).

Green roofs were not being widely implemented in the modern age until Swiss architect Le Corbusier rediscovered it and re-apply it to modern architecture in the twentieth century (Berardi, GhaffarianHoseini and GhaffarianHoseini 2014). In the late 1970s, a more intensive

implementation of green roofs occurred in Germany. That also explains the reason why earlier research on green roofs are published in German. Green roof coverage in Germany alone increases by about 13.5 million m2 per year (Vijayaraghavan 2016). With Germany taking the initiative to implement green roofs on a wide scale, other neighboring European countries such as France and Switzerland followed through the trend.

North America initiated the first green roof application during the same time in the area of Portland. In 2005, the city of Portland requires all new city-owned buildings to be built with a green roof that covers at least 70% of the roof. Another North American city, Toronto, has a by-law that requires all newly developed buildings with a floor area of >= 2,000 m2 to include green roof on 20% - 60% of the roof area (Vijayaraghavan 2016). In Asia, Tokyo mandates all new publicly and privately constructed buildings to have green roofs, with private buildings larger than 1000 m2 and public building larger than 250 m2 to have 20% of the rooftop greened or an annual penalty of USD 2000 will be issued (Vijayaraghavan 2016).

Types of green roofs

To give a definition for green roofs in this research, the green roofs are divided into two main types, extensive green roof and intensive green roofs. These two types of green roofs include vegetation with different soil depth, weight, plant species, and maintenance and irrigation requirements.

Table 2: Types of Green roofs

	Extensive Green Roof	Intensive Green Roof
Soil Depth	3-6 inches	6 inches or more
Weight	15-50 lbs/sq.ft	Up to 150 libs/sq.ft

Organic Matter	10-20%	More plant options including trees and shrubs
Maintenance and Irrigation Requirement	Low	Require irrigation, fertilization and maintenance
Cost	Less	More
Roof Slopes	Up to 30 degrees	Low slopes or terraced slopes
Structural Carrying Capacity Requirement		

Environmental concerns – globally and locally

Greenhouse gases emission is widely perceived as a contributor to global climate change. The Intergovernmental Panel on Climate Change (IPCC) produced the fifth assessment report that summarized scientific, technical and socio-economic literatures and concluded that climate change impacts the natural systems in the strongest way (Metropolitan Area Planning Council 2015). Global mean temperatures have increased by 1.53 degrees Fahrenheit since the late 1800s. Other than that, IPCC also notes that other environmental trends including sea level rise, increases in precipitation levels, more intense precipitation patterns, decreases in sea ice cover and increases in flow off will also be prominent in the globally.

Geographic scale of climate change occurs unevenly around the globe. Unfortunately, Massachusetts has experienced higher impacts than other places. In terms of sea level change, Massachusetts has experienced sea level rises locally. The Massachusetts coastline have seen increase of 6-8 inches over the past 50 years, while other places like Alaska, experienced drop in sea level. Massachusetts is expected to have a sea level increase rate of 0.1 inches per year,

which is higher than global average of 0.07 inches per year. In terms of temperature change, Massachusetts has experienced a more severe temperature change of 1.8 degrees Fahrenheit compared to the global average of 1.53 degrees Fahrenheit since 1970. In terms of seasons, Massachusetts now experiences an average of 12 days per summer season above 90 degrees Fahrenheit and the number is expected to increase.

Green roofs adaptation to climate change

Recent trends for green roof development emerged with the increasing awareness of its ability to alleviate environmental impacts both globally and locally. Carbon dioxide is one of the by-product of combustion that contributes to global climate change. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), human activity related to the combustion of fossil fuels has increased carbon dioxide concentrations in the atmosphere 32% since 1750 (Rowe 2011). There is evidence showing that green roof can reduce CO2 in the atmosphere in several ways. Vegetated green roofs could reduce CO2 in the atmosphere as carbon is a major component of plant structures and is naturally sequestered in plant tissues through photosynthesis (Rowe 2011). On the other hand, green roofs could reduce CO2 indirectly by enhancing insulation of buildings.

In terms of temperature regulations and energy performance, green roofs can reduce overall building energy consumption and regulate temperature through mitigating urban heat island. Various research has shown that green roofs are highly efficient in reducing indoor temperature and level of building energy consumption both in warm and cold climate (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014).

Green roofs as passive open spaces

Apart from recognizing green roofs' environmental benefits, there are a range of literatures recognized green roofs potential to become passive open spaces, to provide space for urban livability (Mesimaki, et al. 2017). As the discussion on the benefits of green Infrastructure (GI) continues to include multiple ecological, social and economic benefits, (Mesimaki, et al. 2017) uses a passive roleplaying method to reveal the scope of meanings and values people attached to green roofs, the chosen GI for the study.

The study shows that GI such as green roofs should not be classified with standardized solution. Green roofs are proved to have environmental and social benefits that should be used as a multidimensional GI (Mesimaki, et al. 2017). To resonate with (Coolen and Meesters 2012)'s viewpoint on the differences in perception of public and private green spaces to prove that both types of spaces should co-exist, (Mesimaki, et al. 2017) believes that public, semi-public and private green roofs should be developed to accommodate the different open space needs.

Green roofs as a multi-functional green infrastructure

In addition to green roofs as open spaces, literatures have also emphasized the importance of the research on green roofs as a multi-functional GI. (Meerow and Newell 2017) developed a Green Infrastructure Spatial Planning (GISP) model analysis which considers of six ecological and social criteria: Stormwater management, social vulnerability, access to green space, air quality and urban heat island effect and landscape connectivity. (Meerow and Newell 2017) also noted that the model was developed to facilitate spatial planning at a city-wide scale by addressing the research gap of lack of planning models that investigate synergies and tradeoffs among the social and environmental benefits of GI. The quantitative GIS green roofs opportunity analysis for Boston in this thesis used this model as a reference and will be further elaborated in Chapter 4.

Existing green roof implementation drivers

Federal level

Existing Green roof incentive programs are all focused on the municipal level. However, most of the programs are driven by legal foundation at the federal level. Most of the programs are created based on the Clean Water Act (CWA). The National Pollution Discharge Elimination System (NPDES) was created in 1972 by the CWA which helps address the water quality problem by regulating point-sources that discharged pollutants to the water of the US. Later in 1987, the Water Quality Act expanded this permit requirements to apply to discharges of industrial stormwater and municipal separate storm sewers system (MS4). Section 402(q) of the CWA requires that communities serviced by combined storm sewer systems implement Best Management Practices (BMPs) as part of a pollution prevention program to reduce contaminants. Combined Sewers Systems are designed to collect rainwater runoff, domestic sewage and industrial waste water in the same pipe. When there's a heavy rainfall or snowmelt, the volume of waste water in a combined sewer system could overflow wastewater directly into nearby river streams. Green roof increases infiltration using vegetation and thus reduces overall stormwater runoff. As a result, some cities have included green roof as a one of the BMPs in controlling CSO.

Regarding non-point source pollution, such as stormwater management, section 319 of the CWA addresses non-point source pollution controls in which requires states to identify waterways that cannot meet water quality standards without control of non-point source pollution. To accommodate states in fulfilling this requirement, section 319 provides a grant program which allocate federal and state funds to local governments and other entities to fund non-point source pollution control. As of 2017, more than $160 million is granted. According to

a study by (Carter & Fowler, 2008), estimated that by 2006, twelve green roof projects were funded through this fund.

Municipal level

City of Philadelphia has a green roof incentive program that is tied to stormwater management. The Philadelphia Water Department (PWD) proposed the Green City, Clean Waters program for combined sewers overflow control in 2011. The plan was created in response to improving water quality and quantity in the long term. Green stormwater infrastructure was emphasized in this plan to reduce the demand on additional grey stormwater infrastructure and enhance the city's climate resilience as a whole. The plan recognized the importance of a watershed planning approach based on the fact that long-term sustainable improvement in water quality and control of water quantity could not be achieved without water-shed wide agency and support. The plan also emphasizes the effort to address overlapping regulatory requirements, which includes EPA's Combined Sewer Overflow Control Policy, Stormwater Regulations and management of the City as well as non-regulatory planning initiatives such as municipal and conservation planning efforts. In order to facilitate local and national integration with this plan, the Office of Sustainability and a Sustainability Advisory Board is created to increase public oversight and coordination among public, private and non-profit organization.

The Green City, Clean Waters program was prepared in light of the recent green storm water infrastructure guidance and policy documents developed by US EPA. The program supports EPA's initiatives especially on protecting America's water, improving air quality and reducing greenhouse gas emissions. In terms of green roofs and vegetated surface in particular, the City may first utilize public facilities as a demonstration and followed by an ordinance to

mandate a green buffer around all parking facilities that also function as a stormwater infiltration measure.

Apart from retrofitting parking spaces, PWD also introduces Green Roof Zoning Incentives that requires zoning application for parking lots to include a Parking Landscape Plan that provides for at least 10% of the interior of the parking lot to be landscaped. The Philadelphia Code also offers density bonuses to new developments or redevelopments that include a green roof that is at least 5,000 sq.ft and cover at least 60% of the rooftop (Philly zoning code: Section 14-602.7 of the Philadelphia Zoning Code ("Exception to Use Tables for Green Roofs").

Similar to the City of Philadelphia Green Roof Zoning Incentives, City of Chicago also adopted an incentive zoning to encourage the implementation of green roofs. Chicago Zoning Ordinance 17-4-1015 Green Roof Incentives awards a Floor-Area-Ratio (FAR) bonus for green roofs that cover more than 50% of the roof area. Apart from the incentive zoning, Chicago's Sustainable Development Policy mandates development projects that receive city's assistance to include sustainable elements including a green roof and LEED certification. PWD also works with the Department of Licenses and Inspections and the Planning Commission to streamline development review and permitting.

City of Chicago also recognizes green roof as one of the measures that could be adopted in a stormwater management plan according to the Chicago Stormwater Ordinance. The ordinance adopted in 2008 requires that any building with a footprint over 15,000 sq.ft or any parking lot over 7,500 sq.ft detain at least the first half inch of rainwater on-site. The Sustainable Development Policy reciprocates the Stormwater Ordinance by requiring the installation of green roofs and other sustainability measures such as meeting LEED standards or exceeding the requirements of the Stormwater Ordinance.

Other than policy initiatives for green roofs, City of Chicago also developed the Green Alley Program which extends the retrofit effort from green roofs to green alleys and green streets. Since 2006, over 200 Green alleys have been installed and over 70,000 trees were planted which contributed into 17 million gallons of runoff reduction and citywide increase in green cover.

Evaluation of existing green roof programs

Regulatory Tools - Denver Green Roof Ordinance

Denver is built on high plains to the east of the Rocky Mountains and is one of the flattest of all American cities. It occupies a land area of 154 square mile. The total population in Denver is 704,621 in 2017. Denver is one of the cities with the highest populations of Hispanics or Latinos in the US, which is 31.2%.

Policy Motivation

In 2013, Denver Mayor Hancock signed an executive order creating the Denver Office of Sustainability. The office has set forth aggressive goals for the city to enhance climate resilience and provide sustainable solutions. However, the Denver Audit Office reported that there was no oversight on the process of meeting these goals. Denver ranks as eighth highest in ozone and/or particle pollution, third in urban heat islands and has multiple rivers containing unsafe levels of Arsenic, E. Coli and Selenium. Brandon Rietheimer, the founder of the Denver Green Roof Initiative, believes that green roofs would provide a viable solution to the problems (Murray 2017). In 2017, The Denver Green Roof Initiative started the green roof initiative as a grass root movement that seeks to increase trees and vegetable gardens on top of larger buildings across the city. The organization proposed Initiated Ordinance 300 and collected more than 10,000 signatures that successfully went into ballot. The City of Denver passed an ordinance on

November 2017 mandating green roofs for all new construction as well as many existing buildings be retrofitted. The mandate requires either rooftop gardens or solar panels.

The Ordinance requires that all buildings constructed after January 1 2018 with a gross floor area of 25,000 SF or greater must have at least 20% of available roof space covered with a green roof. The requirements increase with floor area up to 60% coverage for buildings with 200,000 SF of space or greater. Residential buildings that are equal to or less than 4 stories or 50 feet high are exempt from the requirements. Exemptions will be granted to buildings which meet two or more of the following criteria: buildings are used seasonally, building design cannot accommodate a green roof, the building collects at least 50% of annual rainfall or 0.25 inches of water per rainfall, or the structure has an Energy Star Rating of 80 or higher (City of Denver 2018).

Policy Discussion

Currently, the Denver Green Roof Ordinance is the most stringent green roof mandate in the US. This green roof mandate was driven by the willingness of mitigating carbon footprint urban heat island effect and improving stomwater quality. This ordinance is also driven by the public's realization of the city's neglected efforts towards combating climate change and improving the sustainability of the city. Before the ordinance was voted, it gained further support from a Toronto-based Green Roofs for Healthy Cities and the Green Infrastructure Foundation, which released a study showing that Denver will result in 57.5 million square feet of green roofs and generate 1.85 billion in savings by 2058 if the ordinance is passed. Although there are several oppositions toward the ordinance including the Mayor and business. Colorado Real Estate Alliance. All in all, the success of the ordinance was largely due to the public's realization of the need to tackle urban heat island effect and pollutions in the city, along with the

strong advocacy of a community organization and the support of a cost-benefit analysis for green roofs development in Denver.

After the ordinance was passed, the Green Roof Review Task Force was established to provide recommendations regarding modifications, clarifications and improvements of the program. The task force has proposed a recommendation with regard to existing building requirement that could explore opportunities to enhance green space allocations for the city. As certain existing buildings are exempted from the ordinance because of structural constraints of the buildings, the task force proposed that existing building owners should be allowed to choose on the ground green space within the property footprint to satisfy the requirement. Initially, the ordinance has nothing to do with green space planning as a whole at all, but the requirement proposed for existing buildings expanded the definition of green roofs to include on-the-ground green spaces as well. Although this ordinance was never part of the city's green space planning initiatives, the city perceives green roofs not only as a stormwater management best practice but also mediums for protecting biodiversity, reduces energy consumption, urban heat island effect and improving the quality of life in long term. The perception of green roofs as a multi-benefit asset could be a reason why the green roof mandate was passed with high level of support.

Regulatory Tools – San Francisco Better Roofs Ordinance

Policy motivation

The San Francisco Bay Area Planning and Urban Research Association (SPUR) Green Roof Task Force was set out in 2013 to develop ideas for more sustainable use of San Francisco's rooftops. The research that SPUR conducted shows that living roofs bring a lot of benefits beyond better stormwater management, reducing urban heat island, improving air quality, building energy efficiency. The research also highlights the importance of green roofs as

open space for passive recreation (San Francisco Bay Area Planning and Urban Research Association 2013). The policy motivation for the Better Roofs Ordinance was the collaboration between among city agencies. SPUR works collaboratively with the San Francisco Department of the Environment (SFE), the San Francisco Public Utilities Commission (SFPUC), and the San Francisco Planning Department. In October 2015, the Planning Department published The Living Roof Manual that emphasizes on best practices, guidelines, and recommendations for designing and implementing living roofs that cater the climate and needs to San Francisco.

Before the Denver Green Roof Zoning Ordinance, San Francisco is the first U.S. city to mandate solar and living roofs most new construction. The ordinance mandates that 15% - 30% of roof space on most new construction projects will incorporate solar, living roofs, or a combination of both. Buildings which are non-residential with a gross floor area of 2,000 SF or more, has 10 or fewer occupied floors are required to follow the above-mentioned mandates. However, compared to the Denver Ordinance, the San Francisco Ordinance is less robust.

Regulatory Tools – Toronto's green roof bylaw

Policy Motivation

Before the Green Roof bylaw was in place, the city has been taking a proactive role in encouraging city-wide implementation of green roofs. Back in 2006, the City of Toronto adopted Green Roof Strategy to encourage the green roof installations on both public and privately-owned buildings through incentives, public education and development approval process. The city partnered with Ryerson University to conduct a study which indicated city-wide implementation of green roofs would bring significant economic benefits to the city by improving stormwater management, reducing urban heat island and energy use for cooling. The

city then organized various stakeholder consultations to define criteria for green roofs, identify barriers and solutions and exploring options for green roofs implementations.

Though the major policy motivation came from the city, the city did not jump to adopting a mandate for green roofs right away. The city adopted the EcoRoof Incentive Program which offered a financial incentive of $10/m.sq that resulted in construction of 3,000 m.sq of green roofs. To accompany with this initiative, city agencies are also required to provide green roofs covering 50% of all available roof space. The Green Roof Strategy also established a website and held in-depth training sessions for city staff to educate them the benefits and design constructions for green roofs.

In 2006, the Province of Ontario made amendments which provides the city of Toronto to pass a by-law requiring and governing the construction of green roofs. The provincial government allows the city to provide municipal bylaws that exceed the requirement of the Ontario Building code only for green roofs. In 2010, Toronto became the first North American City to require installation of green roofs on new commercial, institutional, and multi-family residential developments across the city. The bylaw not only includes standards for when a green roof is required, but also elements that are required in the design. Smaller residential and commercial buildings that are less than six stories high are exempted from this requirement. Industrial buildings also have fewer demanding requirements compared to commercial buildings. The bylaw only requires new industrial buildings to vegetate only 10% of roof space. This green roof mandate has resulted in more than 1.2 million SF of new green space planned on commercial, institutional, and multifamily residential developments.

Planning Tools – Chicago's Sustainability Development Policy

The Chicago's Sustainability Development Policy was implemented since 2004 and has been updated several times to include green roof policies. The city started encouraging the installation of green roofs in 2003 with the green roof policy matrix. This policy is a mandate that requires green roofs to be put over certain types of buildings. The mandate applies to project that receives public financial assistance or is in a Planned Development or Lakefront Protection Ordinance Development. This policy alone has led to 95-98% of the developments that have green roofs. The City of Chicago Planning Department has a public Green Roof online interactive map that shows the overall count and locations of existing green roofs. There are total of 509 vegetated roofs within the city and the green roof coverage is 5,564,412 SF (Adaptation Clearing House 2011).

Incentive-based Tools – Chicago's incentive zoning

Apart from the regulatory tools and mandates, Chicago was one of the earliest cities which provides green roof incentives. Back in 2004, the city has created tax increment financing (TIF) and special zoning approvals to encourage green roof development. All projects that receive TIF or special zoning approvals must comply with the green roof requirement. The zoning code awards a Floor-Area Ratio (FAR) bonus for green roofs that cover more than 50% of the roof area. The FAR bonus is available for buildings in downtown mixed-use districts.

However, compared with the green roof policy mandate used in the Sustainability Development Policy, the incentive program was not as successful in increasing overall implementation of green roofs (Adaptation Clearing House 2011).

Incentive-based Tools – Portland, Oregon Ecoroof Incentive

The City of Portland, Oregon addresses the city's stormwater management problems by adopting an Ecoroof Incentive program in 2012. The motivation of the program is to provide an incentive for the installation of green roofs to better management stormwater runoff. The program offered property owners and developers an ecoroof construction incentive of $5 per square foot in the form of a subsidy. Projects that receive the subsidy have to be in the Portland city limit, designed to manage stormwater and feasible and buildable within two years of receiving funds. Though the program is not a mandate, it has a larger impact compared to other incentive program as it has received policy support from state and local jurisdictions. The Oregon Building Code has included ecoroofs as an elective measure of energy conservation. The Portland City Council has also passed the Green Building Policy that requires ecoroofs for all new city-owned facilities and roof replacements on buildings greater than 500 SF (Adaptation Clearing House 2011).

The ecoroof program has funded over 130 projects that created more than 8 acres of ecoroofs that manage an average of 4.4 million gallons of stormwater annually. However, the number of projects has been increasing since 2010 from 18 projects to 5 projects per year. This might be an indicator that the city should revise the incentive policy to encourage more green roof implementations (Adaptation Clearing House 2011).

Barriers for city-wide implementation of green roofs

As from the above examples of green roofs development initiatives from the municipal and federal level, there's a clear pattern of linking green roofs with stormwater management. In the Philadelphia case, green roofs have to combine with another stormwater management plan to

meet the flood control requirement. In the Chicago case, green roofs development also needs to comply with the municipality's stormwater ordinance. The tendency of creating strong correlation between stormwater control and green roof development was based largely on the Clean Water Act (CWA) and the NPDES. When the federal government encourages municipalities using green infrastructure to reduce non-point source pollution, green roofs were one of the green infrastructures effective in addressing non-point water pollution.

The developmental process of green roofs has limited the perception green roof's environmental benefits other than stormwater control. The limited purpose of municipal policy initiatives has led to a slow-paced and piece-meal development of green roofs. Other benefits of green roofs such as enhancing buildings energy performance, mitigating heat island effect and increasing open spaces receive limited attention because green roofs were only placed in policy initiatives related to stormwater control. As a result, policy initiatives that involve enhancing the city's urban heat island effect or climate resilience in general, fail to utilize green roofs. In cities like Philadelphia and Chicago, green roofs development is more rigorous as the municipal government either initiate incentive programs or listing green roofs as one of the Best Management Practice s (BMPs) in stormwater management ordinance. However, the benefits of green roofs have not been recognized as a measure to enhance energy efficiency and climate resilience.

Despite the homogenous depiction of green roof's environmental benefits in the federal and municipal level, regulatory systems are not updated to provide windows of opportunities for the respective development. Most of the local building codes do not exclude green roofs City of

Cambridge has recently amended its building code to allow the building of green roof to be exempted from the calculation of the building's floor area ratio (FAR). By changing the calculation of FAR, developers do not have to risk violating buildings codes just to include a green roof in the building.

Chapter 4 – Connecting the dots: Incorporating green roof into urban green space planning in Boston

Background of City of Boston

Boston is the capital city and most populous municipality of the Commonwealth of Massachusetts. The city proper covers 48 square miles with a population estimates of 685,094 as of 2017. According to Imagine Boston 2030, population in Boston is expected to reach 724,000 by 2030 and 801,000 by 2050. Boston's population is becoming more diverse over the years as well. Since 2000, Boston has become a 'majority-minority' city in which non-white population is over 50% partly due to the growth of the foreign-born population from Latin America, the Caribbean, and Asia.

In terms of climate, like most urban cities, Boston suffers from urban heat island effect in the city area. According to a research report by Climate Central, summer heat in Boston proper could be up to 15 degrees hotter than in nearby rural areas. There are also on average 5 more days above 90 degrees Fahrenheit each year than rural areas (Climate Central 2014).

Initiative related to open spaces and green roof in Boston

City of Boston defines Green Infrastructure as a way to increase the city's overall resilience. Green Infrastructure could better manage stormwater, mitigate urban heat island effect and and provide other benefits like purifying air and creating a more attractive environment.

City of Boston have started to realize the importance of enhancing climate resiliency and protecting open spaces. The city has initiated several initiatives and plans for both purposes separately. Boston is famous for its open-space legacy. The Emerald Necklace began in the late 19th century when the Olmsted Corporation was there has made Boston becomes a city with a extensive park network system.

Opens Space Plan 2008

The City of Boston initiated an Open Space Plan 2008 to assess Boston's open space system. The plan aims to improve the integrated open space system by addressing the open space need. The plan explores the existing inventory of open spaces in terms of protection of natural resource and environmental base of the open space system. Chapters in the open space plan are therefore more focused on preservation of existing natural resources along the harbor and greenways.

The plan highlighted a few substantive goals that it was planning to achieve. By assessing the existing inventory of open spaces, public comments and collected efforts in the Parks Department, the plan aimed to improve coordination and fiscal stability to help restore the existing system and expand it in a way that protects the environment (City of Boston 2008).

Open Space and Recreation Plan, 2015 – 2021

The City of Boston initiated an Open Space and Recreation Plan 2015-2021('The Plan') to assess Boston's current open space management system. The plan explores the existing inventory of open spaces in terms of access, quantity and quality to understand the current open space system. Along with constant population growth and climate change, the plan also mentioned the importance of exploring ways to create new public spaces and connections to existing public spaces.

The Plan broadly defined open space as lands that are not developed for building purposes, which includes parks, natural areas, athletic fields, courts, plazas, waterfront areas, community gardens and cemeteries. The Plan considers public open spaces that owned by the City of Boston Parks and Recreation Department, the Commonwealth of Massachusetts' Department of Conservation and Recreation (DCR), Massachusetts Port Authority, the State

Department of Transportation and a few privately-owned public spaces that are publicly accessible.

The Plan also recognized the value of parks as places where contribute to people's sense of place in the city that express cultures, history and engage the community by providing a shared space. The Plan also recognizes benefits of open spaces in terms of the overall health, economic, environment and social benefits to the city.

The Plan takes special acknowledgement on open space and the relations with the public right of way and the idea of 'complete streets' as part of the open space plan. But, the plan has also noted the difference between right of way and open spaces. Though right-of-way has the potentials to transform traditional streets into green connections, the right-of-way should not be considered as the same open space system as the existing park lands and open spaces.

Apart from public right-of-way, the plan also acknowledges the relations between climate change and resilience and open spaces management. However, the plan does not provide any details on how to connect the plan with climate change and resilience initiatives.

One of the ideas that the plan has advocated that would be useful for guiding this research in terms of connecting green roofs into urban green space planning in Boston is to create 'a stronger relationship between building development and open space development. It shows that the city acknowledges the growth of the development in the city may potentially widen disparities in open space distribution in the long term so that open space development should be aligned with building development.

The plan acknowledges the existence of public and private open spaces as an important inventory for the city and further expansion of green space network. However, the plan fails to

acknowledge the interrelations between public and private green spaces, which could be further explored in terms of enhancing green space connections.

Imagine Boston 2030 and budget for open space

Most of the funding for open space planning in Boston comes from Winthrop Square proceeds, City capital dollars and leveraging external funds. Imagine Boston 2030 calls for the city to enhance existing park system and invest in new open spaces. Most of the open space efforts are being put into renovating existing large public parks and neighborhood playgrounds. Franklin Park renovations are one of the most prominent initiatives with investments on improving the pathways and tree canopy. The Mayor has committed $28 million from the Winthrop garage sale to renovate Boston Common.

In the Imagine Boston 2030 plan, the open space section acknowledges the fact that Boston is home to some of the country's most historic and iconic parkland. About 97% of Bostonion lives within a five-minute walk of a park or open space. As parks and open spaces varies in sizes, quality and functions, the plan acknowledges that the high accessibility does not necessarily mean the parks and open spaces are accessible to the diverse population with different needs.

The plan divided open spaces into different categories, which are:

- Parks, Playgrounds & Athletic Fields
- Parkways, Reservations & Beaches
- Urban Wilds & Natural Areas
- Cemeteries & Burying Grounds
- Malls, Squares & Plazas

Figure 1 below shows the distribution of existing open spaces based on the categorization.

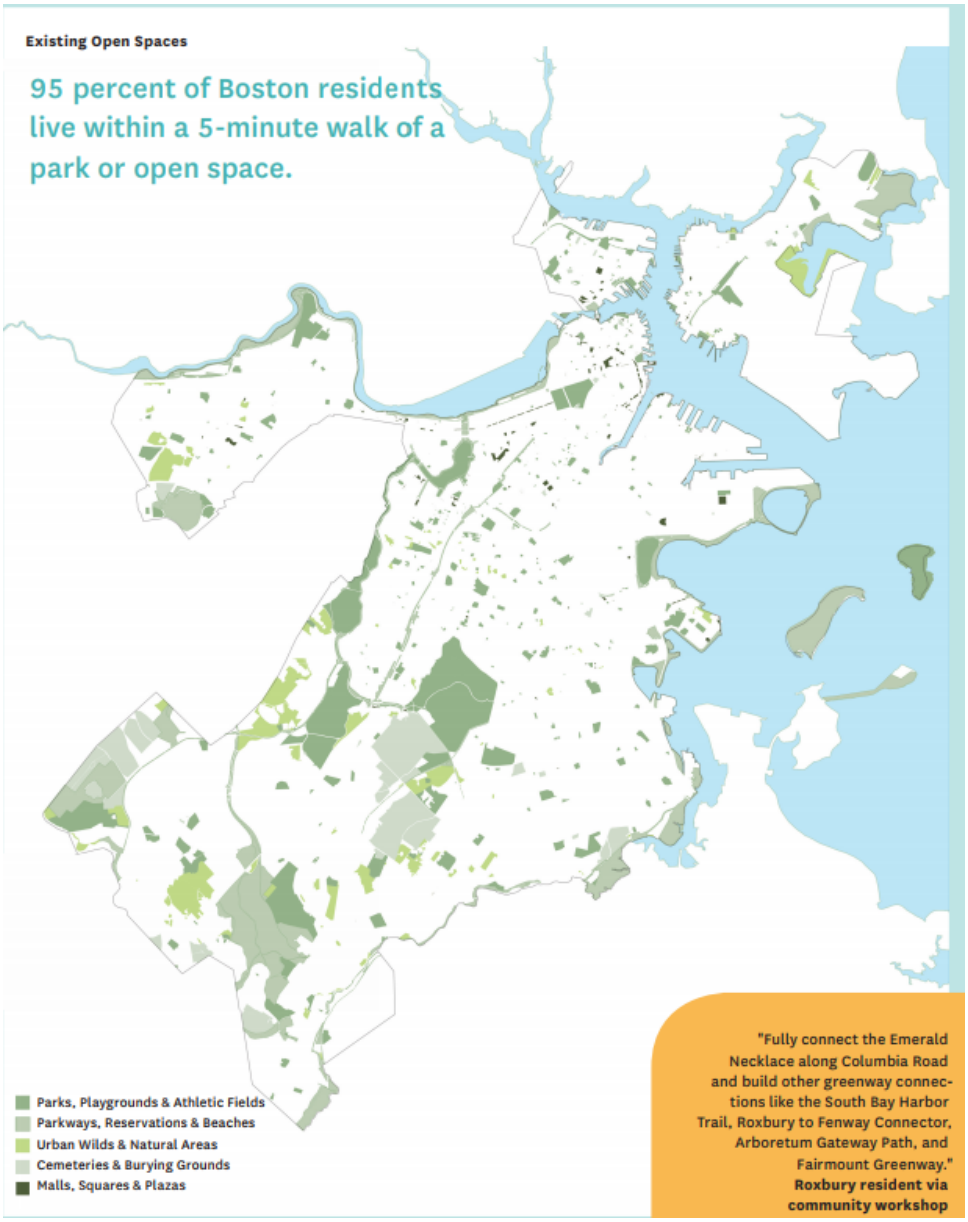

Figure 2 Existing open spaces in Boston
(Source: City of Boston, Imagine Boston 2030 (2007))

Policy implications and discussion

The plan does not provide a detailed explanation on how this categorization will benefit future open space planning nor how it could inform future policy measures. In general terms, the plan acknowledges the importance of investing in Boston's existing largest park, including Franklin Park, Boston Common and creating new connections from the largest park to the

waterfront as well as creating a network of green spaces. It is important for the city to protect and utilize existing green space inventory. Content analysis of this plan will be conducted in the later part of this chapter to evaluate it connection with green roof planning.

Green Roof Development in Boston

Looking into the locations of existing green roofs in Boston, most of them are clustered in the downtown Boston area. In neighborhoods such as Dorchester, Roxbury and Mattapan, where population of low-to-no income, population of disabled, population of medical illnesses are higher than the downtown area, there's only one existing green roof located in East Mattapan. It's clear that there's a disproportional distribution of green roofs in Boston. Studies have shown that social vulnerability factors are always accumulated to produce negative consequences before, during and after emergences and reduce social resilience to environmental hazards. As a result, it is valuable to develop an opportunity overlay based on social vulnerability to find out areas with potential to use green roofs as a mean to enhance climate resilience.

Existing green roof are developed in a piece-meal manner. Most of the developments are driven to be developed based on aesthetic reasons. Developers build green roofs to increase property values of apartments. This phenomenon is particularly prominent in Boston.

Other initiatives related to climate resilience and green building

Climate Ready Boston

City of Boston has adopted several citywide planning initiatives enhancing climate resilience and stormwater management. According to Climate Ready Boston, the city has identified areas with stormwater challenge, urban heat island, risk of coastal flooding and social vulnerability respectively. The results are as follow,

- Stormwater challenge: South Boston, Boston
- Urban Heat island: Allston, Brighton, South End
- Risk of coastal flooding: South Boston, Mid-Dorchester
- Social Vulnerability: Roxbury, Dorchester

The main purpose of the Climate Resiliency Plan is to Connect, Cool, Absorb, Protect. It aims to provide climate resilience initiatives on neighborhood scales. The plan has distinguished neighborhoods including Charlestown, Charles River, Dorchester, Downtown, East Boston, Roxbury, South Boston and South End. The plan has anticipated that there will be more extreme climatic events, sea-level rise, stormwater flooding and heat. The city also recommends strategies that create layers or protections by working multiple scales. The plan prioritizes in tackling extreme heat impact and stormwater flooding as Boston has been experiencing increasing average temperatures and increasing frequency, duration and intensity of heat waves. Increase in frequency of heat waves will further lead to loss of canopies and green spaces and intensify urban heat island effect and stormwater runoff in the long run. In light of this, this city recommends district-wide flood protection system and land use planning. Potential measures mentioned include changes to the building codes and explore measures that increase climate-ready retrofits in existing buildings, which could be a window of opportunity to incorporate green roof development.

Article 37 Green Building and Climate Resiliency Guidelines

The Article 37 Zoning Code is developed with reference to the US Green Building Council Leadership in Environmental and Energy Design (LEED) Rating Systems. The code requires all projects achieve at minimum ‘certifiable’ level. Apart from the LEED certifiable

requirement, the resiliency policy also requires that all projects consider present and future climate conditions in accessing project environmental impacts, including carbon emissions, extreme precipitation, extreme heat and sea-level rise.

Boston's open space needs assessment using GIS

As mentioned in Chapter 2, various scholars have both applied quantitative and qualitative analysis to address people's needs and perceptions on green roofs. (Meerow and Newell 2017) developed the GISP model that includes six environmental and social indicators (refer to Chapter 2). The GIS analysis developed in this thesis was inspired by that GISP model. For this GIS analysis, I have chosen to apply a fuzzy suitability analysis. Fuzzy overlay suitability analysis addresses the inaccuracies between class boundaries. As different attribute data in the model have different definitions of class and measurement of the phenomenon that could cause imprecision. Fuzzy overlay could help address these imprecisions by focusing on modeling the inaccuracies of class boundaries and thus providing a more clear and accurate result.

The differences between this GIS analysis and the GISP model is that this analysis only considers two environmental indicators and social vulnerability due to data availability. But in addition to that, this analysis will consider building capability, which was not being considered in the GISP model.

1) Land temperature (i.e. urban heat island) and

2) % of Impervious cover (i.e. Areas with high % of impervious cover indicates stormwater management need)

3) Social Vulnerability

4) Criteria for buildings suitable for green roofs is based on a Green Roof Planning Study for the City of Boston published in 2009.

Table 3: Criteria for green roof installation

Roof Slope	Less than 30 degrees
Building stories	Less than 15 stories
Roof size	Greater than 2,000 SF

The social vulnerability index (SoVI) used was based on Climate Ready Boston, a report published by the City of Boston on enhancing climate resilience. The index was developed by a quantitative analysis of the relationship between social factors and vulnerability. The Social Vulnerability Index (SoVI) is the susceptibility of social groups to the impacts of hazards as well as their resiliency, or ability to adequately recover from impacts (Martin, 2015). The index is developed by the Hazards and Vulnerability Research Institute at the University of South Carolina (University of South Carolina 2014).

- Criteria for areas with high social vulnerability
    - High population of Low to No Income
    - High population of Disabled
    - High population of Old Adults
    - High population of Children
    - High population of People of Color
    - High population of Low English Proficiency

The first part of the GIS analysis will be devoted to documenting the existing locations of green roofs in Boston in order to see if there is any spatial pattern. As there is no official tracking

of green roofs development in Boston, database of existing green roofs is compiled based on various sources. Greenroof.com is an unofficial tracker of green roofs development that includes details on size and types of roofs, locations and purpose. Other sources include database from various green roof contractors in Boston such as LiveRoof, Apex etc.

The second part of the analysis will focus on comparison between existing green roofs locations and places with high environmental and social vulnerability. Based on the literature review, current green roof incentive programs lack comprehensive initiative. It also acts as a barrier to fully realize the environmental benefits of green roofs and incorporate them in a climate resilience policy program. Therefore, green roofs were always adopted solely for aesthetic purpose. In view of this, a GIS-based suitability analysis will be adopted to determine if there is a mismatch of green roof development and areas with high environmental and social vulnerability. In order to reassure that the analysis fit the local context of Boston, the environmental and social vulnerability criteria will be based on recent policy report published by the City of Boston. The environmental vulnerability index used in this analysis was developed based on the research from the Climate-Smart Cities program. The program has chosen indicators to identify areas with high vulnerability to climate change. The indicators I chose are more directly related to land temperature and stormwater as green roofs are proved to be effective in tackling these two environmental concerns.

The result showing areas with high environmental and social vulnerability would also be an indicator for areas that should be prioritized for green roof development. The GIS-based analysis will indicate the mismatch and act as a guide for policy planning.

The final part of the research will look into specific policy programs, zoning and building codes that the City of Boston has in place that could either be a policy window or a hurdle to promote green roof development. The analysis will also identify opportunities for coordination among each existing planning initiatives and provide recommendations on how to incorporate green roof development in climate resilience plan in a citywide scale.

Social vulnerability index

The Social Vulnerability Index (SoVI) examined the spatial patterns of social vulnerability to natural hazards in order to describe and understand the social burdens of risk. In a broader context, there are two main conceptualizations of social vulnerability index. The first conceptualization focuses on treating vulnerability as a pre-existing condition and potential exposure to hazards. The second conceptualization is built on the assumption that not all individuals and groups exposed to a hazard are equally vulnerable. People who are affected by hazards display patterns of differential loss.

(Cutter 1996) approaches social vulnerability by combining the two conceptualizations and that emerges as the third theme of social vulnerability assessment. He sees the concept of vulnerability as a "hazard of place" which assess biophysical risk and social response within a specific geographic domain. Researchers such as (Yarnal 1994), (Clark, et al. 1998) and (Wu et al., 2002) have adopted this approach.

In comparison to the definition the City of Boston has adopted when developing the social vulnerability index, the definition suits the second conceptualization of the social vulnerability index. The index was developed by a quantitative analysis of the relationship between social factors and vulnerability. It was set to inform the susceptibility of social groups to

the impacts of hazards as well as their resiliency, or ability to adequately recover from impacts. Comparing the vulnerability index City of Boston adopted with the Cutter's approach, the index is able to identify geographies with high social vulnerability but lacks the ability to address social response.

The drawbacks of social vulnerability index are also being addressed in most literatures. As there is not clear definition of vulnerability and guidelines as to how social vulnerability indicators are addressed, the multi-dimensional nature of the index is hard to put in validation. (Schmidtlein, et al. 2008) Suggests that one way to assess social vulnerability assessment is to identify how changes in the construction may lead to changes in the outcome.

Figure 3 Locations of existing green roofs in Boston

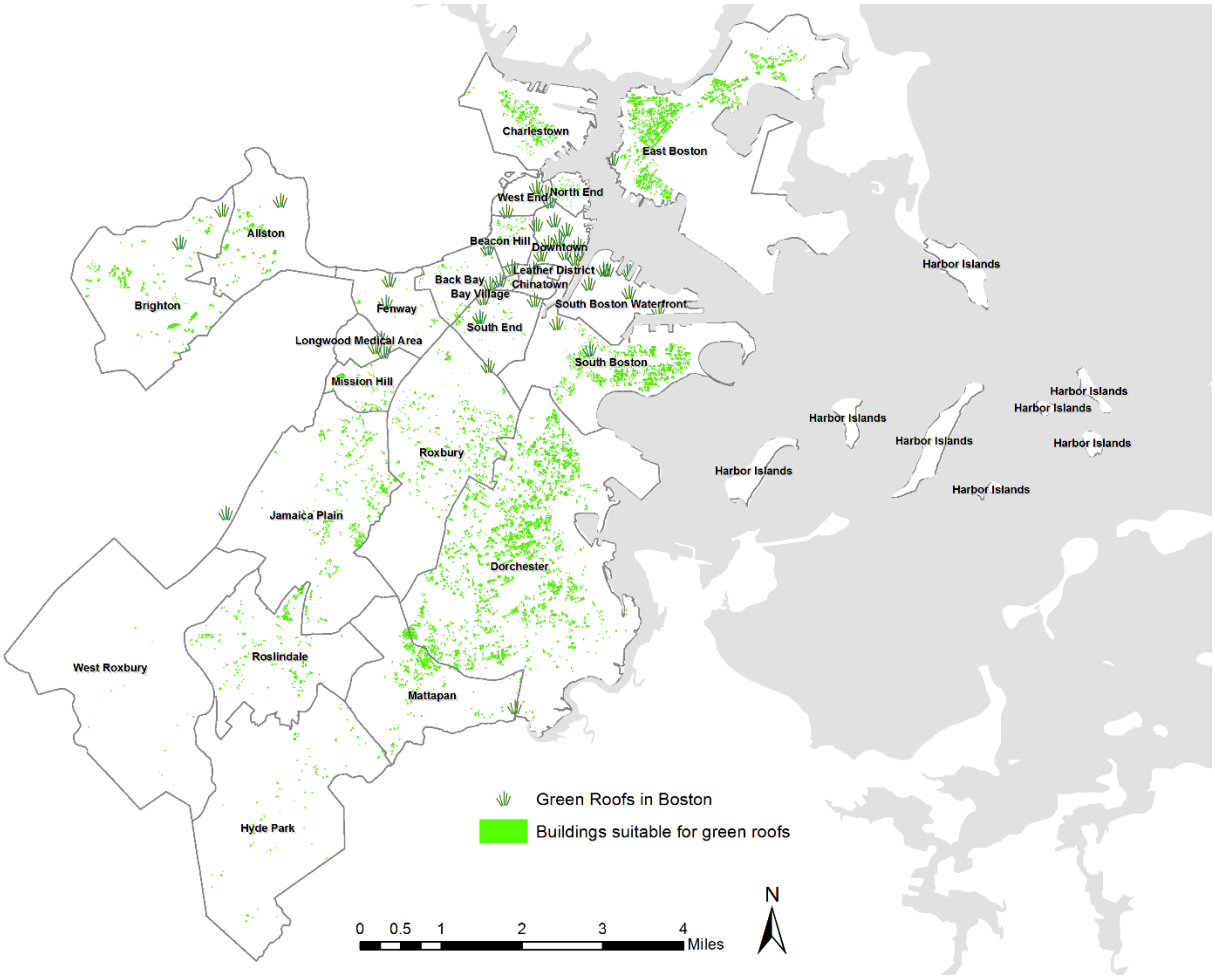

Figure 4 Buildings suitable for green roofs

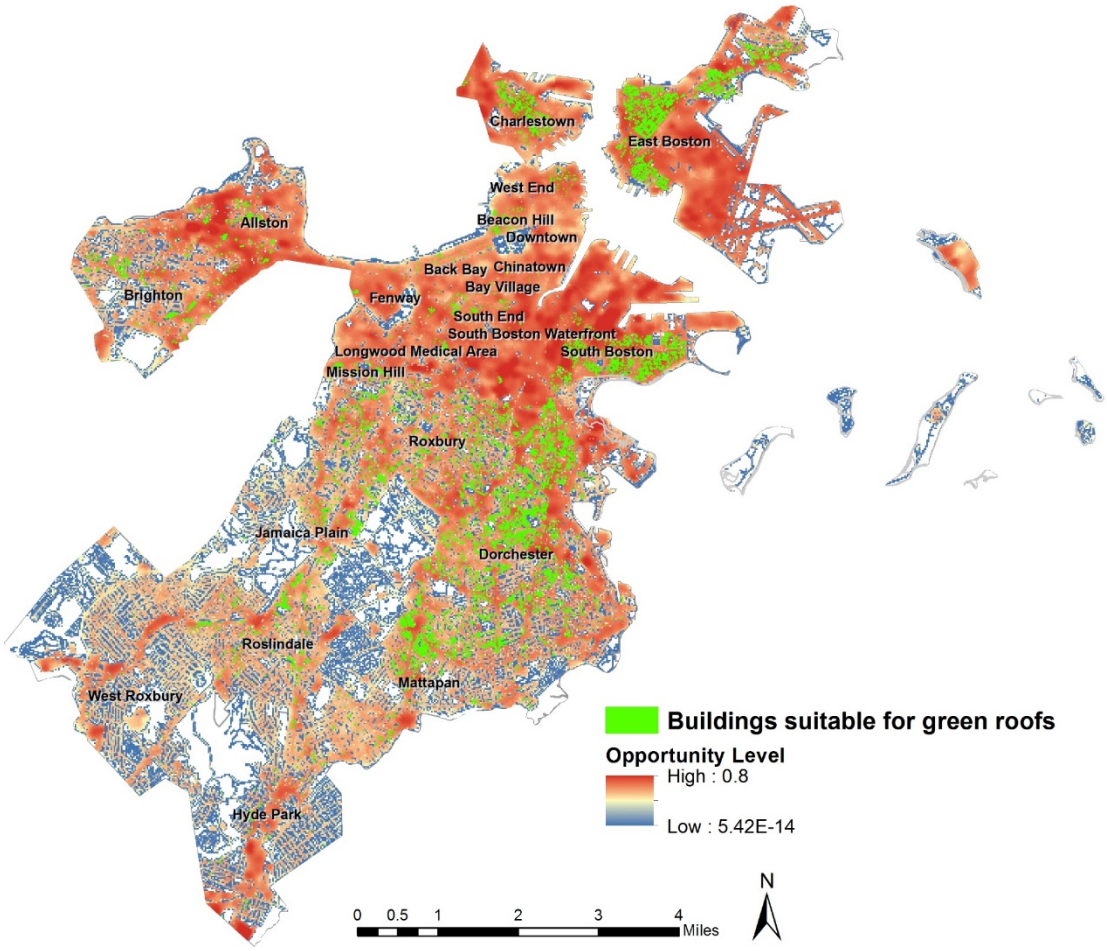

Figure 5 Opportunity index based on environmental indicators

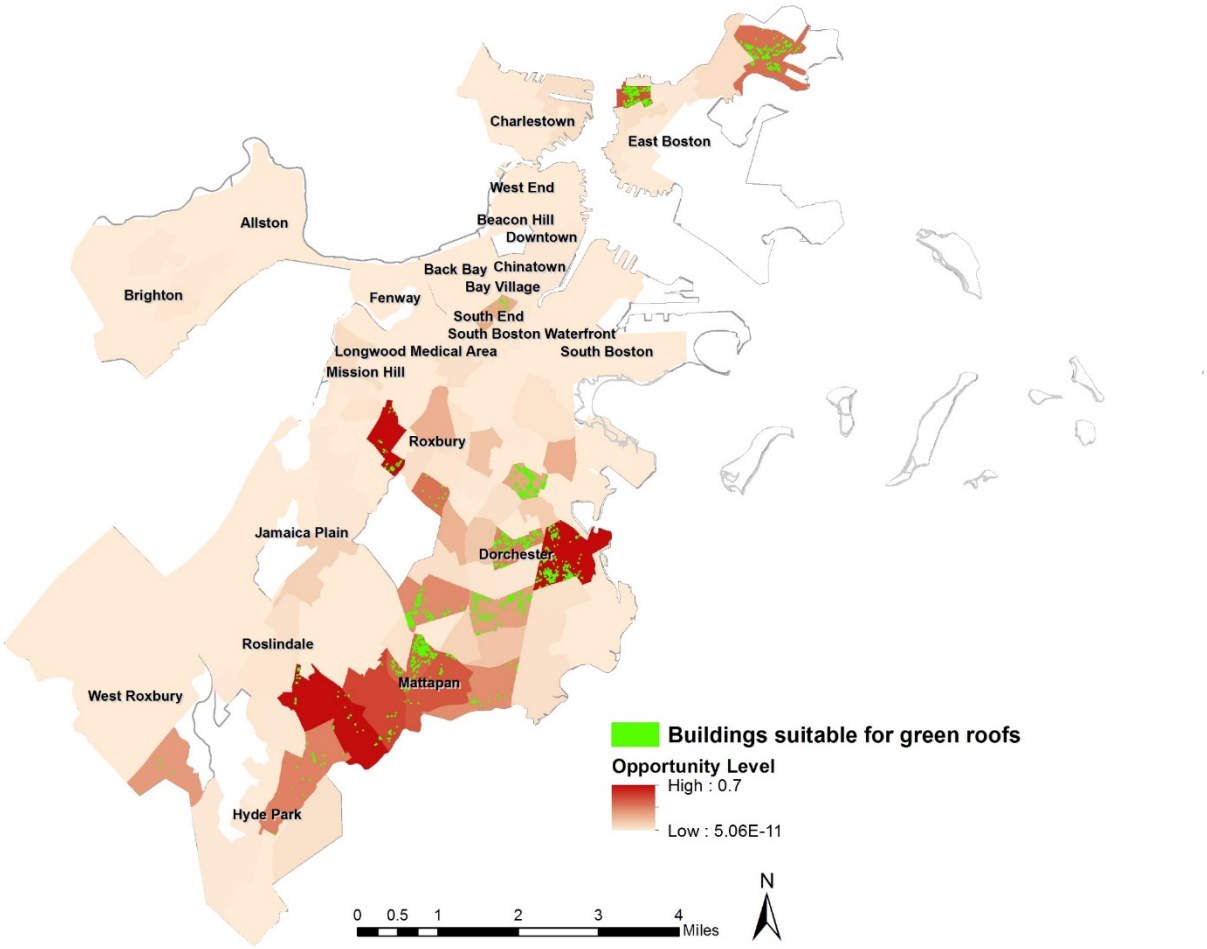

Figure 6 Opportunity index based on social indicators

Discussion of the results

We can see a distinction between areas with high social and environmental vulnerability with a few overlapping. According to the social vulnerability map (Figure 6), areas with the highest social vulnerability are located in Roxbury, Dorchester and Mattapan. Areas with the second highest level of social vulnerability is East Boston and the areas bordering Roxbury and Dorchester.

According to both fuzzy maps (Figure 5 & 6), **East Boston** turns out to be socially and environmentally vulnerable. Unfortunately, if we refer back to Figure 1, there is only one green

roof in the area. In terms of social vulnerability, **Dorchester** is the most vulnerable neighborhood.

For environmental vulnerability, area with the highest vulnerability is located in the downtown area and East Boston, meaning that areas with highest land temperature and percentage of impervious surface are located in downtown, Allston and East Boston. This result is not surprising as the downtown area is the most urbanized. Other areas of high environmental vulnerability are scattered around Dorchester.

Regarding priority areas, **East Boston, Dorchester and Mattapan should be prioritized** for green roofs implementation. East Boston and Dorchester are high in both social and environmental vulnerability. Mattapan should be prioritized over South Boston because it is one of the areas with high social vulnerability but currently there is no green roofs around the area.

According to the statistics results, **the total number of buildings suitable for green roofs is 14,515**. The total number of suitable buildings in environmentally sensitive areas is 12,514 while the total number of suitable buildings in socially vulnerable areas is 2,001. In Dorchester, there are a total of 3,165 buildings eligible to implement green roofs. In East Boston, there are total of 1,980 suitable buildings. In Mattapan, there are a total of 331 suitable buildings.

Most of the suitable buildings are multi-family residential buildings. In spite of enhancing resilience on a neighborhood scale, prioritizing multi-family residential buildings could be beneficial to a community in a way that households could reduce overall energy consumption and enhance the longevity of rooftops in the long run as well.

To conclude, this analysis shows us a mismatch of places needed green roofs and places where existing green roofs are located. Also, the total number of suitable buildings suggested that there are plenty of opportunities to implement green roofs in an area-wide or neighborhood scale. The City of Boston should consider using green roof technology to tackle environmental concerns and enhance climate resilience. Different green roof neighborhood plans could be developed according to respective neighborhood characteristics and resources. Incentive programs could also be incorporated to incentivize private implementation of green roofs.

Limitation

In terms of data availability, this analysis does not consider all the possible ecological indicators mentioned in the GISP model. Indicators such as air quality and access to green space were indicators being left out of the analysis. Also, because stormwater management and land temperature regulation are the prominent functions of green roofs according to various literatures, % of impervious surface and land temperature were chosen as the environmental indicators. To accompany the data access to green space, the overall access to open space data showed on Boston Open Space and Recreation Plan 2015 - 2021 will be used as a reference.

Also, buildings being selected as suitable for green roofs installation do not include roof decks and balconies, which might be suitable for green roofs installations in reality. Structural capability of a building often needs assessment of engineers to determine whether it is suitable for green roofs installation. This GIS analysis does not consider that and only generated the results based on basic criteria.

Manifest and latent content analysis of open space plans

Boston Open Space Plan 2008 – 2014, Boston Open Space and Recreation Plan 2015-2021 and open space chapter in Imagine Boston 2030

In light of the above quantitative GIS analysis using environmental indicators and social indicators to determine open space needs in Boston, the results showed that there are specific areas that in need of more green cover and should be prioritized for green roof installations. To complement this result, this research will then apply manifest and latent content analysis on three recent Open Space Plans in Boston to determine if any green roof keywords were presented in the document and to discover whether the open space plans emphasized more keywords or concepts over the others.

As mentioned in the methodology chapter, content analysis describes a research technique where a planner makes observations by systematically analyzing written or spoken communication, including planning commission meeting transcripts and research reports (Gaber and Gaber 2007). Content analysis consists of manifest and latent content analysis. Manifest content analysis is quantitative while latent analysis is qualitative. This thesis will apply content analysis as an inductive analysis as currently there has not been previous research done in looking at integrating green roofs and open space planning in an American city. Content analysis consists of three main phases: Preparation, Organizing and Reporting.

1) Preparation: Determine the main concepts for analysis based on green roofs literature
2) Organizing: Organize key words into the concepts
3) Reporting: Word frequency count and key-word-in-context (kwic) to see how the words are used for contextual meaning (latent analysis)

Keywords are chosen based on various literatures on green space planning and existing green roofs policies. According to the literatures, the key concepts related to green roofs could be divided into three main concepts, Restorative, Resilience and Access. As mentioned in the

methodology chapter, three plans: Open Space Plan 2008, Open Space and Recreation Plan 2015- 2021 and Imagine Boston 2030 open space chapter will be analyzed in this part.

Table 4: Manifest analysis of Boston Open Space Plan 2008 ('Plan 2008')

Green Roof Concept	Key search term or phrase	Total times key term used in text (Boston Open Space Plan 2008)	As a percentage of all key terms in the text	Number of mentions relevant to green roofs	As a percentage of all key terms relevant to green roofs
Restorative					
	Existing buildings	0	0%	0	0%
	Retrofit	1	2%	1	5%
	Reuse	2	3%	2	12%
	Restore	19	**29%**	0	0%
	Biodiversity	3	5%	0	0%
	Expand	20	**31%**	0	0%
	Nature	20	**31%**	0	0%
Total		**65**	100%	3	**17%**
Resilience					
	Stormwater	4	10%	0	0%
	Urban heat island	0	0%	0	0%
	Air quality	1	3%	0	0%
	Landscape	33	**85%**	0	0%
	Social Vulnerability	0	0%	0	0%
	Environmental Justice	1	3%	0	0%
Total		**39**	100%	0	**0%**
Access					
	Urban Farm	2	1%	1	5%
	Livability	1	0.3%	0	0%
	Roof Garden	0	0%	0	0%

	Vegetated Roof	0	0%	0	0%
	Meadow	6	2%	0	0%
	Oasis	2	1%	0	0%
	Loose	0	0%	0	0%
	Passive	19	6%	3	18%
	Connection	25	8%	0	0%
	Linkage	13	4%	0	0%
	System	81	**26%**	0	0%
	Network	43	**14%**	0	0%
	Existing	24	8%	0	0%
	Recreation	99	**31%**	10	59%
Total		**315**	100%	14	**82%**

Table 5: Manifest analysis of Open Space and Recreation Plan 2015 – 2021 ('Plan 2015')

Green Roof Concept	Key search term or phrase	Total times key term used in text (Boston Open Space and Recreation Plan 2015-2021)	As a percentage of all key terms in the text	Number of mentions relevant to green roofs	As a percentage of all key terms relevant to green roofs
Restorative					
	Existing buildings	1	1%	1	2%
	Retrofit	1	1%	0	0%
	Reuse	1	1%	0	0%
	Restore	20	**25%**	2	4%
	Biodiversity	2	2.5%	0	0%
	Expand	35	**43%**	0	0%
	Nature	21	**26%**	0	0%
Total		**81**	100%	**3**	**6%**
Resilience					
	Stormwater	3	2%	0	0%
	Urban heat island	0	0%	0	0%
	Air quality	2	2%	0	0%

	Landscape	65	**47%**	0	0%
	Social Vulnerability	0	0%	0	0%
	Environmental Justice	68	**49%**	34	74%
Total		**138**	100%	**34**	**74%**
Access					
	Urban Farm	13	1.7%	3	7%
	Livability	29	3.8%	0	0%
	Roof Garden	1 (South End)	0.1%	1	2%
	Vegetated Roof	0	0%	0	0%
	Meadow	15	2%	0	0%
	Oasis	3	0.4%	0	0%
	Loose	0	0%	0	0%
	Passive	34	4.4%	0	0%
	Connection	18	2.4%	0	0%
	Linkage	4	0.5%	0	0%
	System	142	**19%**	0	0%
	Network	37	4.8%	0	0%
	Existing	60	7.8%	0	0%
	Recreation	409	**53%**	5	11%
Total		**765**	100%	**9**	**20%**

Table 6: Manifest analysis of Imagine Boston 2030 open space chapter

Green Roof Concept	Key search term or phrase	Total times key term used in text (Imagine Boston 2030)	As a percentage of all key terms in the text	Number of mentions relevant to green roofs	As a percentage of all key terms relevant to green roofs
Restorative					
	Existing buildings	0	0%	0	0%
	Retrofit	0	0%	0	0%
	Reuse	0	0%	0	0%
	Restore	4	**40%**	0	0%

	Biodiversity	0	0%	0	0%
	Expand	2	**20%**	0	0%
	Nature	4	**40%**	0	0%
Total		**10**	100%	0	0%
Resilience					
	Stormwater	1	6%	0	0%
	Urban heat island	0	0%	0	0%
	Air quality	1	0%	0	0%
	Landscape	13	86%	0	0%
	Social Vulnerability	0	0%	0	0%
	Environmental Justice	0	0%	0	0%
Total		**15**	100%	0	0%
Access					
	Urban Farm	0	0%	0	0%
	Livability	0	0%	0	0%
	Roof Garden	0	0%	0	0%
	Vegetated Roof	0	0%	0	0%
	Meadow	2	4.5%	0	0%
	Oasis	0	0%	0	0%
	Loose	0	0%	0	0%
	Passive	0	0%	0	0%
	Connection	15	34%	0	0%
	Linkage	1	2%	0	0%
	System	1	2%	0	0%
	Network	6	**13.6%**	0	0%
	Existing	9	20%	0	0%
	Recreation	10	**22%**	0	0%
Total		**44**	100%	0	0%

Discussion of content analysis results

The initial word frequency count of keywords of the two plans: Open Space Plan 2008 and Open Space and Recreation Plan 2015-2021 are shown in Table 4 and Table 5 above.

According to the results, it was clear that two plans do not exhibit a strong correlation with green roof concepts. It can be seen that the percentage of words mentioned relevant to green roof concepts are low in both plans, with 4.4% for Open Space Plan 2008 and 6.0% for Open Space and Recreation Plan 2015 – 2021. However, it is worth to evaluate the count among the three concepts: Restorative, Resilience and Access to generate a better understand of the focus of the two plans.

First, both plans have the strongest emphasis on the Access concept. Plan 2008 has a percentage of 76% related to the access concept while Plan 2015 has a percentage of 77% related to the access concept. In view of this result, we can conclude that both plans have a central theme of increasing accessibility to open spaces. This result can be accompanied by analyzing the contextual meaning of certain paragraphs in the plans with the access keywords. Below is an excerpt regarding linkages of harbor open spaces from Plan 2008.

"While each district will have its unique attractions derived from the above mix of activities, critical to waterfront open space development will be a system of linkages which ensure pedestrian, bicycle, automobile, public transportation, and water shuttle access to the harbor." (City of Boston 2008, 7.1.1-2)

Another excerpt from the chapter: Greenways, trails and bikeways emphasized the importance of creating linkages that connect existing open spaces to beautify the urban public realm.

"In urban areas, these linear facilities could be used to link existing parklands and natural areas. This open space linkage could help generate a feeling of connectedness and continuity ("connectivity") that would, like an Olmsted park, provide relief from the confined,

maze-like spatial experience of city streets that are typical of the urban public realm." (City of Boston 2008, 7.1.1-3)

It could be seen from both excerpts that creating linkages connecting existing open spaces assets could be effective in enhancing public accessibility to open spaces. In addition to that, Plan 2015 has an even higher emphasis on open space access as in each subchapter, there are a paragraph titled 'Open Space Access and Equity', which does not exist in Plan 2008.

After looking at the similar emphasis of the two plans, we could turn to look at the differences. In terms of Resilience, the Plan 2015 has a stark increase in focus on environmental justice compared to Plan 2008. According to Table 1 and 2, we can see that the word count of environmental justice grows from 1 to 68. This informs us that Plan 2015 considers Environmental Justice as an important factor in planning for open space compared to Plan 2008. On the contrary, Plan 2008 was more focused on Landscape. In terms of Resilience, the percentage of the word 'Landscape' appearing on Plan 2008 is slightly higher than Plan 2015, which is 84 % compared to that of Plan 2015, 47%. This result could also be explained by the organization of the chapters in Plan 2008. Plan 2008 has dedicated chapters to Greenways, trails and bikeways, and urban wild natural areas in which it explored the landscape characteristics of existing open spaces. Below is one of the excerpts from the Chapter: Urban Wild Natural Areas talking about the importance of protection and maintenance of existing natural lands.

'City and county court community service programs, as well as neighborhood and local community groups have been enlisted to conduct clean-ups, plantings, and special landscape restoration projects in the urban wilds, with some limited support from the Parks Department Maintenance Division.' (City of Boston 2008, 7.1.3-3)

Even though both plans do not have strong correlation to green roof concept, Plan 2015 at least has some mentions of key words that could be interpreted as related to green roofs based on the analysis result. In the chapter which evaluates the open space access in the South End, the evaluation shows that South End is the neighborhood with the least amount of protected open space. With development pressure going on in the neighborhood, open space needs will escalate and increase pressure on overcrowded existing open spaces. In light of this future projection, the plan suggests that,

'*Small scale private open spaces can be provided within these new developments with roof decks, balconies or courtyards. These are meaningful private amenities, but the pressure on shared, active, public facilities will continue to be an issue until a large (1 acre +) space is designated for public open space needs.'* (City of Boston 2015, 342)

According to this paragraph, it could be seen that the plan does consider using roof decks, balconies to develop additional green spaces and realize the importance of private open spaces as well when existing open spaces were oversubscribed and space in the area is limited. These two perceptions of open spaces neither exist in Plan 2008 nor other chapters of Plan 2015. However, as mentioned by (Coolen and Meesters 2012), public and private spaces possess different meanings to people and should be valued equally. In both Plan 2008 and Plan 2015, emphasis were put entirely on publicly-owned open spaces as for a city, publicly-owned land is easier to manage and control as opposed privately-owned land. Also, with access and equity being the main theme of both plans, it is easy to understand why public open spaces are valued higher.

All in all, Plan 2015 has a stronger direction towards realization of the co-existence of public and private spaces as well as a more open attitude towards incorporating green roofs as

part of open spaces. However, both plans do not exhibit a strong indication of willingness to discover the multi-functionality of green roofs and incorporate green roofs into future open space and landscape management.

According to the manifest content analysis of Imagine Boston 2030 open space chapter (Table 6), no keywords that are correlated to green roofs are found. The Chapter consists of 9 pages of the entire report and most of the open space suggestions are evaluating the existing open space inventory and network with a strong focus on enhancing the park network in Franklin Park. Therefore, it is not surprising to see that there are not many keywords related to utilizing building rooftops for green cover. The central theme of the Imagine Boston 2030 open space chapter was outlining long-term visions on open space planning and restoring the livelihood of existing legacy open spaces like Boston Common and Franklin Park. However, the plan does acknowledge the need to invest in new open spaces to accommodate the growing residential community in Boston (City of Boston 2017).

Chapter 5 – Bridging the gap between green infrastructure and open space planning: What's the next step?

Responding to my research questions

Regarding my research questions, this section is going to review whether my research has helped me answer my research questions I mentioned at the beginning of the thesis. To recap, below are the research questions I have set for this research.

1) **How are green roofs integrated into green space planning?**

City of Denver has the most stringent green roofs ordinance and by looking at the recommendations that the Green Roof Review Task Force, it has been trying to explore more ways to increase green covers instead of building roofs, like encouraging the city to provide more options for properties where roofs are not capable to construct a green roof. One of the suggestions was considering on-the-ground green spaces. Among all the other ordinances reviewed, green roof ordinance of the city of Denver is the only ordinance that intending to expand the definition of green roofs. Even though we still could not consider that as a part of open space planning, it could open doors to future opportunities for spatial planning for green infrastructure.

2) **Is the multi-functionality of green roof being realized in open space planning?**

By looking at various policy motivations of green roofs incentives and ordinances in Chicago, Portland, Denver, San Francisco and Toronto, it can be seen that the green roofs policies in Denver, San Francisco and Toronto recognized the multi-functionality of green roofs, but there is no evidence that cities have tried to apply spatial planning strategies for green roofs,

let alone being a part of green space planning. Overall, the green roofs initiatives and ordinances still act as a policy initiative by its own as opposed to a component of a larger comprehensive plan.

3) Are there differences in interpretation of landscape connectivity between green roofs and open space management?

The GIS suitability analysis results indicate that there is a mismatch of existing green roofs and areas that are in need to more green covers. The piece-meal installations of green roofs also indicate that there have not been any spatial planning elements assigned to planning of green roofs. Landscape connectivity is a concept that cannot be found in green roofs development but appeared to be a more prominent concept in open space management.

In terms of the difference in interpretation in landscape connectivity between green roofs policies and open space planning, by reviewing the various climate related initiatives, green building initiatives and open spaces plans of Boston, landscape connectivity was not an important theme being brought out in discussion about green infrastructure nor open space planning. Though in open space planning, landscape connectivity comes into play when the city tries to leverage existing resources such as trails, greenways to enhance overall open space accessibility of the neighborhood.

According to the content analysis results, it was clear that three plans do not exhibit a strong correlation with green roof concepts. It can be seen that the percentage of words mentioned relevant to green roof concepts are low in both plans, with 4.4% for Open Space Plan 2008, 6.0% for Open Space and Recreation Plan 2015 – 2021 and 0% for Imagine Boston 2030

open space chapter. Open Space and Recreation Plan 2015 – 2021 has a stronger direction towards realization of the co-existence of public and private spaces as well as a more open attitude towards incorporating green roofs as part of open spaces. However, both plans do not exhibit a strong indication of willingness to discover the multi-functionality of green roofs and incorporate green roofs into future open space and landscape management.

Conclusion and recommendations

The GIS Open Space needs study indicate areas that are in need of green cover as well as buildings that might be suitable for installing green roofs. I called the results of the suitability analysis an opportunity index because the results highlighted areas and buildings that could be prioritized for green roofs in future planning. East Boston turns out to be socially and environmentally vulnerable. In terms of social vulnerability, Dorchester is the most vulnerable neighborhood.

For environmental vulnerability, area with the highest vulnerability is located in the downtown area and East Boston, meaning that areas with highest land temperature and percentage of impervious surface are located in downtown, Allston and East Boston. This result is not surprising as the downtown area is the most urbanized. Other areas of high environmental vulnerability are scattered around Dorchester.

Regarding priority areas, East Boston, Dorchester and Mattapan should be prioritized for green roofs implementation. East Boston and Dorchester are high in both social and environmental vulnerability. Mattapan should be prioritized over South Boston because it is one of the areas with high social vulnerability but currently there is no green roofs around the area. The total number

of buildings suitable for green roofs is 14,515, which indicates that there are a lot of opportunities for green roofs.

The combination of the quantitative GIS opportunity analysis and qualitative content analysis of published plans allows me to address the limitations and research gaps between the two and complement each other. The GIS assessment informs me the mismatch of green roofs developments in comparison to places where needed as well as areas that should be prioritized for green roofs. The content analysis allows me to look at whether the city has realized the multifunctional benefits of green roofs and opportunities to integrate green roofs into open space management. The combination results of the two analysis inform me that there are opportunities to develop green roofs in a larger neighborhood-wide/city-wide scale yet the city has not realized.

Contributing to this could partly because of the way EPA and the City of Boston define green infrastructure. Referring back to the beginning of Chapter 4, both EPA and the City of Boston define green infrastructure as single-function, which is the ability to better manage stormwater. According to (Mell 2010), North America has its foundation in green infrastructure mainly focus on landscape conservation. As compared to the UK and Europe, the development of green infrastructure in America historically focuses on ecological than economic and social benefits. The narrow definition of green infrastructure hindered the realization of the multifunctionality of green infrastructure, also leading to single-functional development of green infrastructure. Below is one of the examples of green infrastructure definitions from the UK, which is more broadly defined.

Green Infrastructure is the physical environment within and between our cities, towns and villages. The network of open spaces, waterways, gardens, woodlands, green corridors,

street trees and open countryside that brings many social, economic and environmental benefits to local people and communities. (TEP 2005, 1)

From this definition, it could be seen that network of open spaces is being considered as a part of green infrastructure development. By including open space network in the definition, it provides opportunities for planners to include green infrastructure as part of open space planning. This lack of connection between green infrastructure and open space planning could also be seen in current climate resilience plan and open space plans. When reviewing existing planning initiatives in Boston related to green infrastructure and open spaces in Chapter 4, Plan 2015 did mention the importance of planning open spaces with references to climate resilience. However, it failed to provide any visions that could connect with current climate resilience plan: Climate Ready Boston, which underlines the importance of developing green infrastructure. Apart from Boston, most green roof initiatives adopted in other cities like Chicago and Portland are also single-functioned and detached from a broader planning initiative.

Moreover, the fragmented planning system in America increases difficulties in realizing the multi-functionality of green infrastructure. As federal, state and local authorities could have different planning agendas, perceptions and regulations towards green infrastructure development, it will be more challenging for American cities to adopt a spatial planning approach for green infrastructure planning. Even the diversity of planning control, funding among cities could hinder green infrastructure development in an area-wide scale. Federal policies lack the framework of translating policies at the county and city level (Mell 2010).

As it is impossible to amend the entire planning system to create opportunities to integrate green infrastructure into broader open space planning, it might be helpful if EPA could start by adopting a broader definition of green infrastructure. It could also start by providing

guidance on how to enhance the multi-functionality of green infrastructure and allocate specific funding for corresponding developments.

Limitations and future research

Due to data availability and time constraints, this research has some limitations that could be addressed in future research. Regarding the GIS analysis, more environmental vulnerability indicators such as air quality, stormwater flow could be considered. Also, interviews and focus groups could also be conducted to accompany the analysis to acknowledge stakeholders' priorities. In addition to that, the method to choose buildings that are suitable for green roofs could also be improved by finding a layer that includes various roof decks, courtyard as well so that the results will be more inclusive.

Regarding the content analysis, I have categorized green roof related key words into three main themes, Restorative, Resilience and Access. I applied content analysis for this research in an inductive way because not much former research has done to address the integration of green roofs and urban green space. The concepts I generated might be too general so that certain keywords appear more than the others. In addition to that, more plans with a wider time frame should be reviewed if time allows in order to see if there are evolutions over time.

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