AMERICAN UNIVERSITY OF BEIRUT

URBAN GREEN INFRASTRUCTURE OPPORTUNITIES: SPATIAL SUITABILITY ANALYSIS AND MUNICIPAL GUIDELINES IN BEIRUT

by
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AN ABSTRACT OF THE THESIS OF

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Research on green infrastructure (GI) indicates that GI can provide multiple ecosystem services and benefits due to its nature based principles, multi-functionality, and no-regrets net benefit. These benefits are not evident in urban centers and densely built neighborhoods where natural open space is not abundant and alternative spaces are not readily available. GI requires space to develop and flourish to provide these benefits. Within the context of Beirut, where real estate and lack of planning for the public good drives land development and the urban landscape, the absence of planned and explicit open space and GI is evident. This research aims to identify opportunities of space where suitable GI typologies can be incorporated at the neighborhood scale to develop recommendations and guidelines at the municipal scale to mainstream GI as a municipal initiative.

Drawing on national and international data on urban greening, the research employs a spatial suitability and policy analysis to guide the methodology. To achieve the objective, an inventory of current conditions was conducted using extensive field surveys, GIS software, and aerial photographs, to determine the base line condition. After identifying suitable GI types for the neighborhood of Hamra (i.e. green roofs, street trees, green walls, planters and rain gardens) that matched needed ecosystems services, an assessment tool was developed to identify potential space available and suitability of locations for each GI type. Different metrics for each GI typology (i.e. number of street trees, area of roofs, and linear length of planters) were homogenized into a single metric with measures of high, medium and low opportunity. This metric provided the basis to combine the differing layers into a single map providing a measure of the extent of GI type applicability based on morphological conditions and location. In addition to the review of the regulatory context and municipal operations, the data from this research was used to develop a strategic vision and suggest adjustments to the municipal program by offering guidelines for GI implementation along with the required tools to realize them. The research proposes low, medium, and high spatial opportunities based on a set of criteria for each urban green infrastructure typology, and suggests specific municipal guidelines to facilitate their implementation.

The results serve as a stepping stone to introduce GI to Beirut and for future in-depth studies for applying the GI approach at the municipal scale in Lebanon, acting as a tool for decision makers and planners to improve the environment, community, and the economy in urban areas.

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CHAPTER I

INTRODUCTION

Today more than half of the world's population is concentrated in urban areas, and according to current studies, this figure is expected to double in the next few decades. The immense pressures on our current natural systems that are leading to environmental degradation and related social and economic problems, are also likely to double with the ascending rates of population growth and urbanization (Sandstrom, 2002).

In developed countries such as the United States, population growth and development have led to the transformation of more than thirty six thousand square kilometers of natural landscapes to urbanized areas between 1997 and 2001, causing fragmentation and loss of ecosystem services provided by nature (Benedict & McMahon, 2006). In developing countries this situation is even more problematic since land development and urbanization are haphazard and environmental impacts are almost completely neglected to achieve rapid economic growth (Jim, 2004).

In Lebanon, the situation in not very different, 87% of the Lebanese population dwells in urban areas, with most of the population concentrated in Greater Beirut and its surrounding suburbs in Mount Lebanon and coastal cities such as Sidon, Tyr, and Tripoli (UN-HABITAT, 2011). It is also expected that urban areas will increase in Lebanon from 649 Km^2 in 1998 to 884 Km^2 by 2030 (UN-HABITAT, 2011). The chaotic and unplanned urban sprawl occurring nowadays in Lebanon is spreading at the expense of open green spaces in urban centers and around urban fringes. This presents serious negative impacts on the provision of ecological services, environmental health, quality of life of urban residents, and the local economy.

As a solution that can address some of the impacts of urbanization such as loss of green spaces and biodiversity, generation of large volumes of stormwater runoff, urban heat island, and human health effects; green infrastructure has emerged as an ecosystem based planning approach that can be used to develop more sustainable cities by promoting urban livability and wellbeing, improving local economies, promoting ecosystem health, and increasing resilience (Vandermeulen, Verspecht, Vermeire, Van Huylenbroeck, & Gellynck, 2011). The concept is based on a strategically planned network of vegetated and non-vegetated features that promote ecosystem services (Dover, 2015). Green infrastructure concept emerged from temperate climate regions such as North America and some European countries where it was conceptualized and applied across multiple scales due to its services and benefits that it provides. However, when considering green infrastructure application in dense Lebanese cities, the research on developing a green infrastructure network in urban environments is not evident or absent.

The overall aim of this research is to explore the applicability of green infrastructure planning in the Lebanese context, specifically Beirut. The research will question the potential development of green infrastructure in a dense neighborhood in Beirut, and explore the possible municipal reforms required to realize it and promote its expansion. To achieve this, the following two research questions will guide the inquiry: How can different opportunities of integrating green infrastructure typologies be identified in a densely built neighborhood? How can municipal actions support implementation of green infrastructure typologies in Beirut?

The objectives of this research are to: 1) understand the green infrastructure concept and its components, 2) research policies implemented in other countries with green infrastructure programs, 3) identify applicable urban green infrastructure typologies, 4) establish an approach to develop green infrastructure in a neighborhood in Beirut, and 5) identify potential municipal guidelines that should be developed in Beirut in order to facilitate and promote the implementation of green infrastructure.

The structure of this research will be based on three main pillars that range from a general overview of green infrastructure to a specific implementation framework relevant to Beirut.

The first is based on defining and understanding the green infrastructure concept by reviewing the available literature from academic and practice journals, books, and websites to become familiar with the history and origins of the green infrastructure concept, as well as with its varying implementation modalities. Light will be shed on the different approaches behind utilizing green infrastructure in the United States and Europe, where most of the research on green infrastructure is concentrated. Additionally, a review of the strategic planning principles that dominate the green infrastructure concept and its implementation will be explored. The issue of scale and land use context are addressed by reviewing the different components and typologies that make up a green infrastructure network and their relative benefits on an ecological, environmental, and socio-economic level. International case studies of previously implemented projects, specifically from the United States and Europe, will also be portrayed.

Second, a revision of the urban green infrastructure planning policies implemented in other countries, along with international case studies of previously implemented projects, specifically from the United States and Europe. Moreover, existing urban planning and environmental policies in Lebanon that are relevant to the scope of the study will be explored.

The final pillar of this research is a case study in a neighborhood in the Hamra district of Beirut to identify potential opportunities for the development of green infrastructure. I will identify and analyze the available and suitable spaces in the neighborhood for different green infrastructure typologies based on specific criteria for each.

The research will present a novel concept in urban planning and urban ecosystem management in Lebanon, by introducing green infrastructure amongst a dense urban fabric. It exhibits the importance of introducing green infrastructure in Beirut amidst numerous environmental problems that already exist. Furthermore, the case study presented in this research can be considered as a prototype that could be adopted and further developed in order to propose a green infrastructure elsewhere with similar space constraints. Finally, the research proposes a set of guidelines, for the Municipality of Beirut, that can enhance the implementation of green infrastructure in the city. Such guidelines could also be adopted and applied by other municipalities in Lebanon.

CHAPTER II

LITERATURE REVIEW

A. Green Infrastructure Concept

As an approach that can mitigate the negative impacts of urbanization and land degradation, the concept of green infrastructure was developed as an essential multifunctional planning tool that can aid human societies to achieve sustainable development (Eisenman, 2013). As the term indicates, "infrastructure" which is often coupled with "gray infrastructure" as manmade elements and systems that are vital for the progression and development of today's communities (such as transportation, water supply networks, electricity, schools, etc.), green infrastructure is also considered as a crucial component that can affect the growth and progress of our communities (Benedict & McMahon, 2002). The green infrastructure concept is gaining increasing recognition internationally nowadays as a comprehensive planning framework that can result in sustainable community development by conserving the fundamental functions of natural systems and improve the societal and economic state of communities (Rouse & Bunster-Ossa, 2013). This is conceived by safeguarding the presence of an interconnected network of natural elements that are capable of generating the required ecosystem services crucial for environmental health and human wellbeing. (Eisenman, 2013)

The concept that evolved over decades to become what is now known as green infrastructure, has initially emerged as a planning tool in response to increasing population growth and urban sprawl causing the degradation of the quality of life and the natural landscapes. One of the first projects that witnessed the integration of landscape planning amongst an urban settlement saw the light in the mid-1800s in

Philadelphia, United States through the establishment of Fairmont Park (Rouse & Bunster-Ossa, 2013). The realization of this park was motivated by acknowledging the importance of protecting the quality of the city's primary water source from the adjacent river, along with providing the public an open space for recreation. The idea of designing and planning urban landscapes was further enhanced by Frederick Law Olmsted, an American landscape architect, in the late 1800s, by designing numerous parks and green spaces as crucial elements in cities for the purpose of improving human wellbeing and ecological health, among which are Central Park in New York City and the Emerald Necklace in Boston (Rouse & Bunster-Ossa, 2013). On the other hand, the Emerald Necklace in Boston, a series of linked parks and green spaces, could be considered one of the first parks in the United States that presented the issue of connectivity among different green infrastructure components (Benedict & McMahon, 2006). Olmsted believed that single parks and green ways cannot deliver all the beneficial services if they were designed and built in a standalone context, whereby connecting different green spaces via greenways is essential. As such, the latter park now provides abundant ecosystem services that boost the residents' wellbeing as well as improving ecological health and quality (Benedict & McMahon, 2006).

Green infrastructure is a multifunctional system used to target certain objectives, which can be implemented at different scales and varying contexts. Such broad green infrastructure application scenarios have contributed to the fact that up to this date there is no standard universal definition for green infrastructure, rather the definitions available are influenced by the researchers' views, to the context in which green infrastructure is applied, and the scale of implementation. After reviewing the literature, Mark A. Benedict and Edward T. McMahon of the Conservation Fund, have shown to present in their book "Green Infrastructure: Linking Landscapes and Communities (2006) the most comprehensive definition of green infrastructure as *"…an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clear air and water, and provides a wide array of benefits to people and wildlife…the ecological framework for environmental, social, and economic health – in short, our natural life-support system"* (p. 1).

Other important green infrastructure working definitions identified from the available literature are listed in Table 1.

Table 1 Different definitions of green infrastructure

Source	GI Definition
EPA (Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs, 2013a, p.1)	*"…the natural and manmade landscapes and features that can be used to manage runoff"*
UNEP (Green Infrastructure Guide for Water Management, 2014, p.8)	*"Green Infrastructure refers to natural or seminatural ecosystems that provide water utility services that complement, augment or replace those provided by grey infrastructure."*
IUCN (Green Infrastructure a sustainable answer to Europe's challenges, 2014)	*"…a strategically planned network of natural and semi-natural areas, which deliver a wide range of ecosystem services in terrestrial and marine areas."*
Natural England (Green Infrastructure Guidance, 2009, p.7)	*"Green Infrastructure is a strategically planned and delivered network comprising the broadest range of high quality green spaces and other environmental features. It should be designed and managed as a multifunctional resource capable of delivering those ecological services and quality of life benefits required by the communities…"*
The Conservation Fund (Green Infrastructure Resources, 2015)	*"A strategically planned and managed network of natural lands, working landscapes, and other open spaces that conserves ecosystem values and functions and provides associated benefits to human populations."*
EU Commission (Building a Green Infrastructure for Europe, 2013, p.7)	*"…as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings."*

The varying definitions of green infrastructure are due to the fact that the concept of green infrastructure and its implementation is a relatively new field in ecosystem management and landscape planning which gained increased importance in the past few decades only. One can also comprehend that the definition of green infrastructure was tied in most cases to the purposes behind utilizing it and represents the priority of the agencies implementing it, whether it was conserving biodiversity, improving landscape planning, managing stormwater, or others as well. This issue is mainly visible when differentiating the purpose behind applying a green infrastructure network in the United States and Europe, where the bulk of research programs have been conducted.

In the United States, the approach used to define and implement a green infrastructure network is dominantly eco-centric, and aims to conserve undeveloped lands and ecological biodiversity from future human expansion (Kambites & Owen, 2006). Most of the literature and projects conducted in the US have considered the concept of green infrastructure to improve the ecological functions of the landscape (Mell, 2009). One example is the state of Maryland which initiated a state-wide green infrastructure assessment project that identifies ecologically significant areas based on a landscape ecology and conservation biology perspective, in order to protect such areas from future urbanization (Weber, Sloan & Wolf, 2006). Conversely, other researchers in the United States did not solely emphasize the ecological importance of green infrastructure. For instance, Benedict and McMahon (2006) considered green infrastructure as a land use planning tool that can balance between ecological conservation and human development, so that to achieve an optimal use of the landscape in a manner that preserves the needs for environmental health as well as human wellbeing and economic progress (Benedict & McMahon, 2006). On the other hand, countries in Europe mainly the United Kingdom have initially focused on incorporating and protecting green features for aesthetic and recreational purposes (Jongman, Kulvik & Kristiansen, 2004) through practices that can affect their communities on a social level by connecting people to nature (Mell, 2009). Although there is a difference regarding the ultimate benefit of green infrastructure, Kambites &

Owen (2006) consider these differences to be minor and complementary to each other, since both concepts will provide multifunctional benefits that support sustainable development.

Furthermore, a key word that is prevalent in green infrastructure definitions is “strategic planning”, which implies the proactive management of the causes behind landscape degradation in an interdisciplinary manner. The use of strategic planning integrated within the green infrastructure approach can help communities and ecosystems achieve resiliency to future changes, serving the development of sustainable communities (Novotny & Ahern, 2010). Based on Novotny and Ahern (2010), five design and planning elements are embedded in the green infrastructure approach are crucial to develop a resilient strategic plan these include: multifunctionality; connectivity; diversity; redundancy and modularization; and adaptive capacity.

While Novotny and Ahern (2010) focus these principles on communities in general, these aforementioned elements can be directly linked to green infrastructure to be considered as a strategic planning tool. To elaborate on this subject, it is accepted that green infrastructure is a multifunctional system, whereby a single green infrastructure typology can by itself provide various ecosystem services that benefit both humans and ecosystems alike (Novotny & Ahern, 2010). As an example, parks can provide shelter and habitats for wildlife and at the same time serve as a recreational destination for people improving their wellbeing. The issue of connectivity and building a network on the other hand, is a vital component for a successful green infrastructure plan, whereby a connected landscape promotes ecological stability and creates corridors between habitats facilitating species migration and flow of energy across a geographical area (Jongman, Kulvik & Kristiansen, 2004). A connected network can reduce habitat fragmentation and loss of biodiversity and at the same time enhance natural processes that improve ecosystems' health and the generated ecosystem services enjoyed by human communities (Novotny & Ahern, 2010). Likewise, a connected network of greenery in an urban context is also important as it creates a more walkable environment and creates open spaces for social interaction (Condon & Isaac, 2003) in addition to the aforementioned ecological benefits.

The presence of a connected green infrastructure network composed of multifunctional different components assures in a way the presence of a diverse, as well as a redundant and modular system, two important elements of strategic planning. A green infrastructure system that is composed of a set of different connected components spread across an area increases the benefits and is less vulnerable to disturbances. Hence, it is more efficient to have several green infrastructure components having similar and different functions in delivering the desired outcomes. (Novotny & Ahern, 2010)

The last element in developing a green infrastructure strategic plan is adaptive capacity. In this case Novotny and Ahern (2010) stress on the importance of monitoring the results of the applied green infrastructure project in a transdisciplinary manner in order to build precise empirical knowledge on the project amidst continuously changing factors that can affect the implemented project.

The elements of the strategic planning approach on which the concept of green infrastructure is based on are in harmony with the principles of green infrastructure presented by Benedict and McMahon. The principles elaborated below, are regarded as critical factors that can determine the success of a green infrastructure initiative since they promote sustainable development once incorporated within a planning and policy framework for establishing a green infrastructure network. (Benedict & McMahon, 2006)

The ten principles of green infrastructure as stipulated by Benedict and McMahon (2006) are as follows:

1. *Connectivity is Key*

Connectivity is a primary characteristic of green infrastructure, since linking natural habitats together is vital for maintaining healthy ecosystems and preserving the natural services they provide. Connectivity among different agencies, whether governmental or not, is also important so that they all work collaboratively to implement a comprehensive green infrastructure plan.

2. *Context Matters*

Before planning to develop or conserve a green infrastructure network the context into which this plan is implemented should be considered to identify the factors that can affect it.

3. *Green Infrastructure Should Be Grounded in Sound Science and Land Use Planning Theory and Practice*

Planning for a green infrastructure network should be based on an interdisciplinary approach whereby professionals from different fields of expertise should share the knowledge and work together in a manner that adequately reflects the ecological, cultural, social, and economic aspects of the plan based on scientific evidence.

4. *Green Infrastructure Can and Should Function as the Framework for Conservation and Development*

Green infrastructure is an approach that aims to develop sustainable communities by conserving natural resources and planning where should future development take place.

5. Green Infrastructure Should Be Planned and Protected before Development

Green infrastructure is a framework that can be used to identify ecologically important areas so as to protect them from future development and reduce their vulnerability to degradation. Previously developed areas could be improved by green infrastructure through restoration initiatives linking habitats together.

6. Green Infrastructure Is a Critical Public Investment that Should Be Funded Up Front

Just as governments nowadays formulate funding plans in order to invest in new grey infrastructure projects, the same should be followed to invest in a comprehensive green infrastructure network to ensure its continual development.

7. Green Infrastructure Affords Benefits to Nature and People

Green infrastructure practices can provide a multitude of ecological, social, and economic benefits. A strategically planned green infrastructure network can also reduce the vulnerability of ecological systems and human communities to natural risks such as flooding by directing development away from flood-prone areas.

8. Green Infrastructure Respects the Needs and Desires of Landowners and Other Stakeholders

Green infrastructure is not antidevelopment, on the contrary it respects the needs of private landowners. As part of strategic planning, involving the stakeholders in developing green infrastructure networks is important so that they understand the value of it and how can it help plan and regulate future development.

9. Green Infrastructure Requires Making Connections to Activities within and beyond the Community

Green infrastructure planning is not bound by juridical boundaries, whereby a successful green network is established via collaborative efforts between adjacent communities in an aim to conserve the landscapes from ecological degradation and ensure planned development.

10. Green Infrastructure Requires Long-Term Commitment

A green infrastructure plan should be well planned and continuously modified when needed, as communities evolve. Planning shall also consider future funding sources that will allow a green infrastructure network to persist through regular maintenance and restoration activities.

Based on the ideas presented above, the concept of green infrastructure and its integration among human settlements which emerged decades ago, is a strategically planned approach that relies on a connected network of diverse, redundant, and multifunctional natural typologies that can preserve ecosystem functions and deliver essential ecological services.

B. Green Infrastructure Components

Green infrastructure includes numerous components which could be implemented in different contexts and on varying scales making it a flexible planning approach. Through a landscape transect (Figure 1) of a certain area that ranges from natural lands to urban cores, it is possible to implement green infrastructure in all transect zones. However, the difference between each zone lies in the components of green infrastructure due to the physical characteristics of each (Rouse & Bunster-Ossa, 2013).

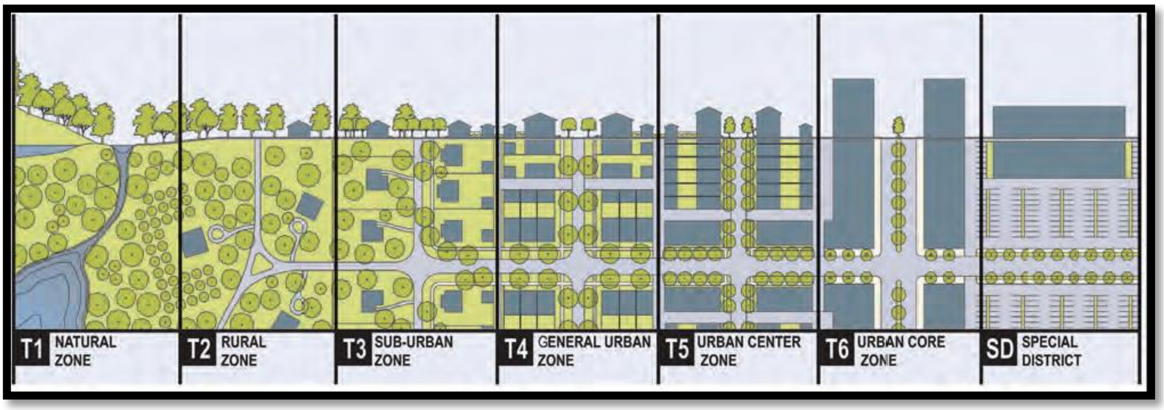

Figure 1 The landscape transect (Rouse & Bunster-Ossa, 2013)

The scale of implementing green infrastructure falls, according to William L. Allen III (2012), into three overlapping categories, landscape, region, and site scale. Implementation at the landscape and regional scale are somewhat very similar, yet at the regional scale the juridical boundaries of the province or district are considered as the limit, whereas at the landscape scale political boundaries are not recognized. Nevertheless, no matter of the difference of scale as well as the context, one aspect remains constant, which is connectivity. As discussed before, the issue of having a connected network between the green infrastructure components is crucial to maintain healthy ecosystems and the efficient provision of ecosystem services.

On a broad spatial scale, green infrastructure components forming an ecological network are composed of cores, hubs and corridors (Benedict & McMahon,

2006) (Figure 2). Green infrastructure cores are seen as the nucleus of natural habitats which foster high quality ecological processes and habitats for flora and fauna. Hubs are in turn larger natural areas which include core areas and others as well. Such hubs have high ecological integrity with high rates of biodiversity, especially of native species (Allen III, 2012).

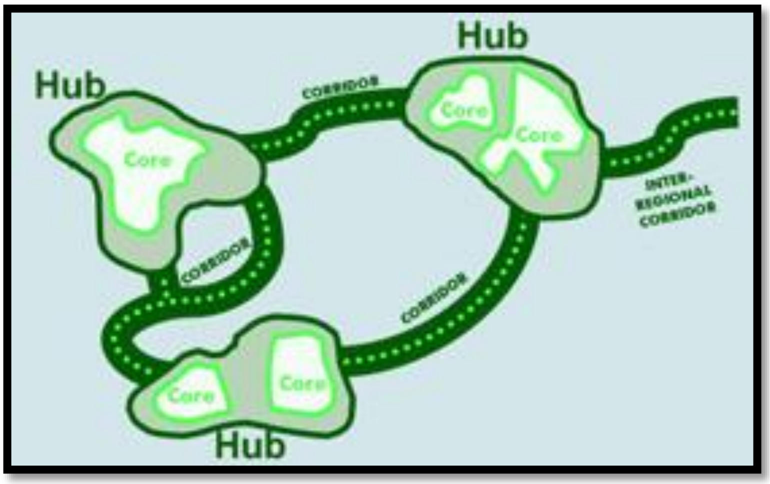

Figure 2 Schematic diagram of cores, hubs, and corridors (EPA, 2015)

In some studies conducted, natural areas have to meet certain criteria in order to be scientifically classified as a hub. The state of Maryland in the United States for example (Weber *et al*., 2006), has established a list of criteria in order to consider an area as a hub in its attempt to assess its green infrastructure (Table 2). Common areas which are classified as cores and hubs namely include natural reserves, large publically owned lands, regional parks, and ranch lands among others. (Benedict & McMahon, 2006)

Table 2 Criteria used to classify hubs in Maryland, USA (Weber *et al*., 2006)

Maryland Hub Criteria
Habitats for sensitive flora and fauna
A minimum of 100 hectares of connected forests, with a 100 meters transition zone
A minimum of 100 hectares of unmodified wetlands
Riparian forests and wetlands along rivers and streams which include important species
Protected lands by governments or other organizations

Corridors, on the other hand are the links that connect different hubs together. They are linear features which play a significant role in allowing species movement across different hubs ensuring their survival (Allen III, 2012). Ryan, Fabos, and Allan (2006) suggest that green corridors have also been considered in preserving the cultural and historic heritage of an area, as is the case of New England, USA. In New England several strategies have been proposed in order to increase the area of ecological corridors for the sake of conserving nature's integrity as well as the cultural heritage of the region (Ryan, Fabos, & Allan, 2006). In order to function satisfactorily, corridors should be physically long and wide enough to allow the wildlife species to thrive. Rivers, streams, greenways, and green belts are all elements of ecological corridors which can preserve ecosystems and serve as a recreational destination to humans too. (Benedict & McMahon, 2006)

Those green infrastructure components present in natural areas, rural areas, and around urban fringes provide the majority of the ecosystem services in our natural system (Weber *et al*., 2006). Thus land conservation to safeguard the services provided (EPA, 2014) is crucial to protect the health and integrity of the biotic and abiotic resources of the landscape. (Abunnasr, 2013)

The types of green infrastructure mentioned above which create cores, hubs, and corridors are suitable on a spatially large scale and in a landscape context which is predominantly natural and rural to a certain extent. As the scale of implementing a green infrastructure network diminishes, and as the context of the dominant landscape becomes increasingly urbanized, the concept behind the function and importance of these components remains unchanged, however their typologies change. The typologies of these components are modified to include a wide range of finer green infrastructure components, since other typologies must be designed to fit the surrounding urbanized context, in a manner that fulfills human needs and benefits them. (Abunnasr, 2013).

Through reviewing the literature various types of green infrastructure have been identified at varying contexts and scales. These typologies are elaborated below.

1. Green Roofs

Green roofs are vegetated roof tops designed to reduce the impervious surfaces of buildings and promote the provision of ecosystem services in developed areas. They are classified into two types, intensive and extensive green roofs (Dover, 2015). This designation is based on their characteristics. Intensive green roofs (Figure 3) mimic ground-level gardens with deep soil membranes (more than 20 cm), and are usually planted with trees and shrubs. They are mainly constructed for aesthetic and recreational purposes and require high investment and maintenance costs. On the other hand, extensive green roofs (Figure 4) are shallow in depth (less the 20 cm), planted with small-sized plants such as moss or sedum plants, and require minimal maintenance (Hazim, 2012). Extensive green roofs are not designed for human use or aesthetic purposes, whereas their significance is in the functional benefits they provide such as reducing stormwater runoff and building insulation. Extensive green roofs consist of a drainage layer to remove excess water and maintain aeration; a filtrate membrane, a substrate layer for plant growth, and low-growing communities of vegetation (Hazim, 2012).

Figure 3 Intensive green roof (Source: www.greenroofs.com)

Figure 4 Extensive green roof (Source: www.greenroofs.com)

Green roofs can provide multiple ecosystem services, often deficient in urban environments, which benefit humans and the surrounding ecosystem simultaneously. Stormwater runoff, an environmental problem that many urban areas suffer from, carrying pollutants and causing overflown sewage systems is one of the most important problems partially mitigated via green roofs (Dover, 2015). The area of impervious surfaces is reduced after installing green roofs, thus larger amounts of rainfall are detained and retained for larger periods of time before being released into the environment, allowing better absorption into the ground and reducing the pressure on the sewage networks (Oberndorfer *et al.*, 2007). Green roofs also play a role in filtering stormwater from pollutants that can deteriorate the quality of existing water resources. Moreover, green roofs function in extending the longevity of the roofs, improving energy conservation in buildings, mitigating the effects of the urban heat island, as well as promoting habitats and increasing biodiversity rates by serving as nesting grounds for various fauna species. (Oberndorfer *et al.*, 2007)

2. Green Walls

As part of the greening practices used to increase the vegetative cover in urban areas where space is limited, green walls are considered an efficient practice, whereby vegetation is vertically incorporated along the walls of the buildings. According to Dover (2015), green walls could be categorized as either direct or indirect green walls. Direct green walls (Figure 5), where plants directly adhere to the wall structure, include surface climber plants that are directly rooted in the ground or plants that are directly rooted in the wall structure. This type of green walls can develop naturally on its own, or can be intentionally planted (Dover, 2015).

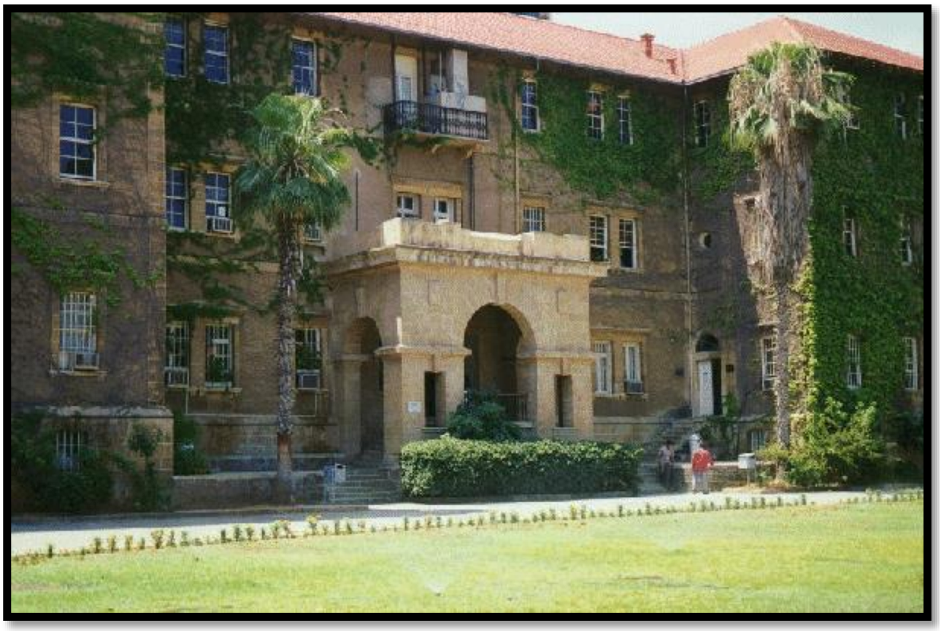

Figure 5 Direct green wall at AUB Fisk Hall (Source: www.aub.edu.lb)

On the other hand, indirect green walls are those that develop on a separate support structure adjacent to the wall. These include climbing vegetation from the ground/planters or by dangling vegetation from the roof downwards, also known as green facades (Dover, 2015). Another type of indirect green walls includes living walls (Figure 6) which are designed to permit the installation of green walls on regular buildings as well as high-rise buildings (Manso & Castro-Gomes, 2015). They are characterized by pre-vegetated elements grown in special media held together using a structural frame. The elements of the living wall could be continuous such as a permeable screen where plants are inserted in between the holes, or modular whereby separate elements such as trays and planters of different specifications are installed side by side and fixed onto the wall (Manso & Castro-Gomes, 2015).

Figure 6 A living green wall (Source: *http://www.greenroofs.com/*)

Like most green infrastructure typologies, green walls are multifunctional, thus providing several benefits. It has been shown (Chiquet, Dover, & Mitchell, 2012; Dover 2015) that green walls can reduce noise pollution, protect the building walls from environmental influences such as sunlight, rain, and wind; improve the visual value of buildings, improve the energy savings by controlling the buildings' microclimate, besides green walls can capture rainwater thus reducing the amount of stormwater runoff. Moreover, green walls have been associated with improving the ecological biodiversity in urban areas by serving as a habitat for species such as birds. (Chiquet, Dover, & Mitchell, 2012)

3. Parks

Parks are open greenspaces with varying natural features classified differently based on their scale, context, and function; and range from huge greenspaces that extend over entire regions to small local parks. National parks and natural reserves are greenspaces spread over large landscapes and are considered to hold a cultural or national value for a country, attracting numerous visitors each year. On the other hand, smaller scale parks so-called regional parks, are more directed to attract the residents of the same geographical region. District parks aim to serve a number of neighborhoods at the same time, while smaller neighborhood or community parks are utilized by a single neighborhood only. Finally, local parks function as an open greenspace for a street or a block such as community gardens and small playgrounds. (Byrne and Sipe, 2010)

Figure 7 Sanayeh Park in Beirut (Source: www.beirut.com)

The presence of parks can provide multiple benefits that enhance ecosystems, human wellbeing, as well as the local economy. On the ecological level, the benefits of parks include attenuating stormwater, improving air quality, carbon sequestration, and promoting biodiversity amongst others as well (Byrne and Sipe, 2010). Alternatively, parks have been shown to provide several social benefits which include stress reduction, increased human interaction, aesthetic and recreational value; and health promotion through encouraging people to exercise thus reducing risks of contracting diseases associated with sedentary lifestyles. Economically speaking, parks can boost tourism levels, improve real estate values nearby parks, as well as reducing healthcare expenditures due to promoting people to engage in physical activities and improving the ambient air quality (Byrne and Sipe, 2010).

4. Greenways

Greenways are linear corridors in urban areas utilized for non-vehicular activities such as walking and cycling, and in some cases are connected to natural areas in and beyond the urban zone (Rouse & Bunster-Ossa, 2013). Greenways could be found across varying landscapes such as river and stream banks, floodplains, waterfronts, lakefronts, and woodlands. They also exist in areas of varying land uses, whereby greenways can traverse vacant lands, developed lands, or simply natural areas. (Byrne and Sipe, 2010)

Figure 8 An urban greenway in Charlotte, USA (Source: http://www.carolinathreadtrailmap.org/)

Plenty of studies have examined the advantages of having greenways, especially in urban environments, whereby they mainly focused on highlighting the aesthetic and recreational values that greenways provide. In addition, research also pointed out the important role that greenways could play in promoting public health through encouraging communities to enjoy a physically active lifestyle. Additionally greenways provide ecological benefits associated with stormwater management, air purification, and provision of habitats amongst other as well. (Byrne and Sipe, 2010)

5. Bioretention Practices

a. Bioswales

Bioswales, are long linear street-scale channels mainly used to manage stormwater runoff and reduce their negative impacts in case of rain events, especially in urban settings. Considered one the best practices for managing stormwater, properly designed bioswales collect stormwater, filter it from its pollutants via a deep and special soil and gravel medium and is then released into the ground or into a conveying pipe for storage or release into a water body elsewhere (Kazemi, Beecham, and Gibbs, 2011). They are designed in a sloped manner and are planted on top with a vegetative cover that is capable to absorb and filter out existing pollutants in stormwater (Novotny & Ahern, 2010). Typically, bioswales are designed to manage large quantities of stormwater runoff generated from large areas such as roads and parking lots. (Soil Science Society of America, 2015)

Figure 9 A large bioswale (Source: www. nationalgeographic.com)

As mentioned earlier, bioswales are generally utilized to manage stormwater due to their design capabilities that allows them to reduce the runoff flow velocities, thus reducing the amount of stormwater discharged at peak and decreasing the stress on grey infrastructure systems. This is also enhanced by the increase in the area of permeable surfaces which allows stormwater runoff to percolate into the ground rather than flowing on impermeable surfaces. Bioswales also play a role in filtering stormwater out of pollutants via phytoremediation, improving the overall quality of existing water resources (Novotny & Ahern, 2010). Other studies recently conducted, suggest that bioswales can increase the rates of biodiversity in urban areas, whereby increased number of species have been observed in areas equipped with bioswales along their streets. Moreover, bioswales have been associated with improving the visual scene of the area surrounding them. (Kazemi *et al*., 2011)

b. Rain Gardens

Similar to bioswales but wider in size and aimed towards residential application, rain gardens are slightly depressed landscapes with a vegetative cover on top designed to manage stormwater runoff generated due to impermeable surfaces by flow velocity reduction, infiltration and filtration allowing groundwater recharge and removal of pollutants from stormwater runoff (Soil Science Society of America, 2015). A drainage pipe located at the bottom of a rain garden, may be used to convey water to wastewater network, however this practice is not encouraged due to the fact that rain gardens mainly aim to maximize the natural movement of water and its infiltration into the ground. Since rain gardens have a vegetative cover of different trees and shrubs, they also serve to provide habitats and improve biodiversity, as well as can improve the aesthetic value of the surrounding area. (Dietz & Clausen, 2005)

Figure 10 A rain garden (Source: http://www.e-landscapellc.com/)

c. Planter Boxes

Planter boxes are classified by the EPA as urban rain gardens that can manage stormwater runoff in dense urban areas generated from streets, sidewalks, and parking lots. Planter boxes are ideal in urban areas since they occupy small areas in a space-limited context (EPA, 2014). They are of two types, infiltration planter boxes which are constructed in the ground (Figure 11), and contained planter boxes (Figure 12) which are constructed above the ground in a contained box (Southeast Michigan Council of Governments, 2015). Both types of planter boxes could have a pervious bottom allowing captured rainwater and runoff to infiltrate into the ground, or they could be designed with an impervious bottom to store stormwater and slowly release it into a drainage pipe conveying it elsewhere. Other than stormwater management by reducing runoff volume and improving water quality, planter boxes can improve biodiversity in urban areas, improve air quality, and improve the aesthetics of the area where they are located due to the appealing vegetative cover that could be planted on top (Southeast Michigan Council of Governments, 2015).

Figure 11 An infiltration planter box (Source: http://www.madrono.org/)

Figure 12 A contained planter box (Source: http://www.interiorfoliage.com/)

6. Tree Canopy

Tree canopy is another typology of green infrastructure that is multifunctional and provides several ecosystem services that benefit humans and nature alike. Urban tree canopies comprise of trees along the city streets, in yards and parks; and other public areas forming all together a unique urban ecosystem (American Forests, 2015). Urban trees have a direct positive impact on the communities dwelling the city since they purify the air out of high pollutant levels usually present in urban environments, thus promoting a healthy living environment as well mitigating the impacts arising from climate change. Trees also serve to mitigate the effects of the urban heat island and reduce energy demands by cooling the ambient air temperatures and providing shade (Dover, 2015). In terms of water management, trees can intercept runoff stormwater reducing the amount of runoff entering the sewers and promoting groundwater recharge via soil infiltration. Additionally, tree canopies provide habitats for species and increase biodiversity levels; improve aesthetics, increase property values, calm down traffic, reduce stress levels, and offers people the chance to participate in recreational activities. (Young, 2011)

Figure 13 Tree canopy over Las Ramblas Avenue in Barcelona (Source: www.usatoday.com)

7. Permeable Pavement

The use of permeable pavements is a type of green infrastructure practice that deals mainly with sustainably managing stormwater. Its concept is based on managing stormwater at the source, by allowing runoff to percolate into the pavement and infiltrate into the ground, rather than continue flowing on the ground surface as in the case of nonporous surfaces (Dover, 2015). Beecham, Pezzaniti, & Kandasamy (2012) conducted studies on the efficiency of permeable pavements to reduce the pollutant load gained by stormwater runoff. They concluded that permeable pavements have the potential to lower the concentrations of suspended solids, nutrients, and heavy metals (such as zinc and lead), thus permeable pavements play a role in protecting surface and groundwater resources from high contamination levels, allowing the recharge of aquifers, reducing the costs and the need of grey infrastructure to convey and treat lower volumes of stormwater runoff; and eventually protecting human health and ecosystems by eliminating an important nonpoint pollution source (contaminated runoff). Permeable pavements are best suited for urbanized and well developed areas, where they replace conventional impermeable streets, sidewalks, and parking lots. (Beecham, Pezzaniti, & Kandasamy, 2012)

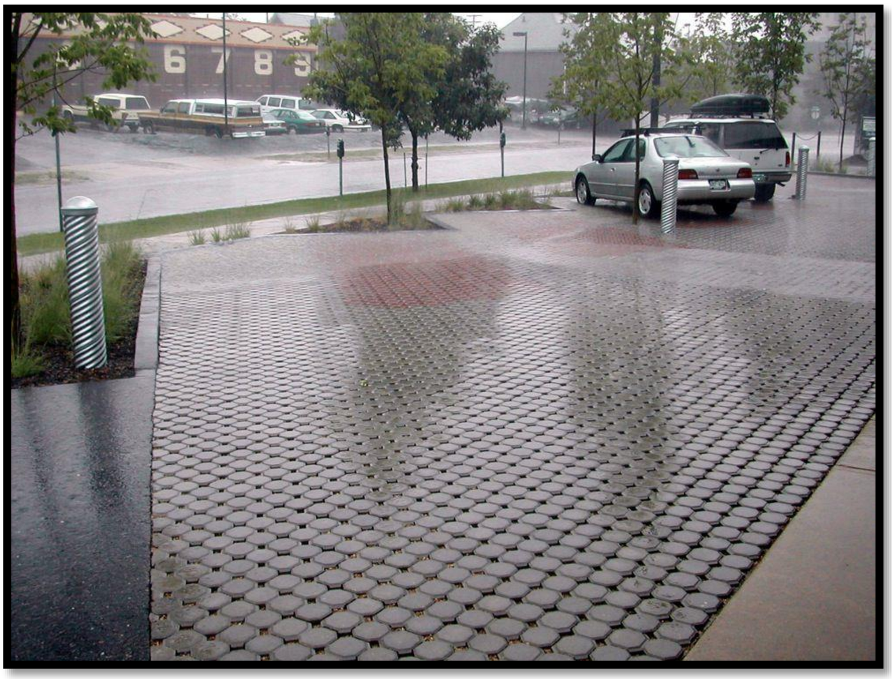

Figure 14 A type of permeable pavement (Source: www.nacto.org)

8. Rainwater Harvesting

Rainwater harvesting is an important green infrastructure practices that utilizes rain barrels and rain cisterns in order to capture rainwater on site for later use. This method is an important management tool which can reduce the demand on water resources and reduce the dependency on water provided by the mains for non-potable purposes, especially in arid and semi-arid regions. Rainwater harvesting can also reduce the amounts of generated stormwater runoff. The advantages of the rainwater harvesting tools is that they are easy and inexpensive to install and maintain; and can reduce water fees. (EPA, 2014)

Figure 15 Rain barrels for rainwater harvesting (Source: www.offgridquest.com)

9. Downspout Disconnection

Effective especially in cities that have a combined sewer system, downspout disconnection is a simple green infrastructure practice that redirects stormwater runoff from rooftops from entering the sewer pipes, and drains them onto soils and other permeable surfaces for infiltration and promotion of the natural movement of water; or rainwater harvesting systems for water storage. This practice can reduce water pollution levels due to decreasing the amount of contaminated runoff, allows groundwater aquifers to recharge, and decreases the pressure on grey infrastructure systems. (EPA, 2014)

In summary, green infrastructure is composed of a mixture of typologies that work at multiple scales, from regional large typologies such as national reserves to small site-based practices like green roofs (Table 3). The totality of all these practices forms a multi-scalar, multifunctional green infrastructure network.

Table 3 Different green infrastructure typologies classified by scale (Rouse & Bunster-Ossa, 2013; Abunnasr, 2013)

Region	**City**	**Neighborhood**	**Site**
Regional parks and natural reserves	Urban parks	Neighborhood Parks	Rain Gardens
River corridors	Waterfronts	Tree Canopy	Planter Boxes
Greenways/ Ecological networks	Boulevards/parkways	Vegetated Swales (bio-swales)	Green Parking
	Plazas and Squares	Porous Pavements	Rain Barrels
			Green roofs and walls
			Downspout Disconnection
			Yards and Gardens

On the other hand, the elaborated practices above are considered the most prominent typologies associated with developing a green infrastructure network, however other typologies were identified. These typologies include green streets, boulevards, and green parking lots amongst others, nonetheless the latter typologies are composed of a mixture of the practices elaborated above (San Mateo County, 2009)). Integrated together, these typologies allow the formation of a comprehensive network that is capable of providing multiple ecosystem services proficiently due to the diversity and the redundancy of practices (Novotny & Ahern, 2010) and functions provided by each. As an example, green streets could be designed in a manner that integrates permeable paving, street trees, planter boxes, and green walls along both sides.

C. Green Infrastructure Benefits

In their article, Alberti et al. (2003) describe urban ecosystems as complex entities having distinctive biophysical characteristics (land cover, species richness, ecological patches…) due to high and continuous human interferences that ultimately reshape its ecological composition and disturb the natural flow of energy and matter. Furthermore, due to intense human interferences over time, the urban ecosystem remains at early successional stages and at varying degrees of species colonization affecting the overall level of biodiversity in cities (Niemela, 1999). All these factors minimize the ability of the urban ecosystem to supply essential ecosystem services that are required for a healthy and stable ecosystem. However, green infrastructure systems have the ability to provide ecological functions and services lacking in urban environments as elaborated below. Accordingly, by increasing the total surface area of green infrastructure across a city, ecosystem services provision can be increased since the urban ecosystem will become more stable, possess multiple energy flow pathways, include diverse populations of species, and have an increased net gross productivity.

Over the years studies conducted to highlight the benefits of utilizing green infrastructure practices in urban environments have resulted in acknowledging the multifunctionality of green infrastructure in providing multiple ecosystem services that play a major role in achieving sustainability. As shown in Table 4, the ecosystem services provided by green infrastructure could be classified into four general categories based on the Millennium Ecosystem Assessment of the United Nations which are: supporting services, provisioning services, regulating services, and cultural services (Novotny & Ahern, 2010). These services have a positive feedback and provide several benefits to the surrounding environment, improve the wellbeing of societies, and boost local economies, the three pillars of sustainability.

Table 4 Ecosystem services provided by green infrastructure (Frantzeskaki & Tilie, 2014)

Ecosystem Services	**Major benefits provided by GI**
Supporting Services	Habitat for different species Ecological biodiversity
Provisioning Services	Fresh Water Food
Regulating Services	Local climate regulation Air filtration and carbon sequestration Flood Protection Soil Protection Water purification Noise regulation
Cultural Services	Recreation and exercise Boosts Tourism and the economic cycle Aesthetics Cultural identity Sense of place

The benefits of green infrastructure on the environment include the filtration of air from pollutants, the mitigation of the urban heat island effects, flood protection, protection and improvement of water quality, increased replenishment of groundwater (EPA, 2010a), soil protection, as well as adapting to and mitigating the effects of climate change (Abunnasr, 2013). Additionally, the environmental benefits of green infrastructure also include positive outcomes on the ecological level since it provides and conserves habitats for species, promotes biodiversity, and contributes to nutrients' cycling processes. (Abunnasr, 2013)

On the other hand, the social benefits resulting from having a green infrastructure system in place include educating and increasing the community on the important role of green infrastructure and how can they get involved, improving the aesthetics of the area, establishment of open green spaces for recreational purposes and leisure (EPA, 2010a), as well as improving the mental and physical health of the community through better access to exercising outdoors (Llausas & Roe, 2012). In addition to strengthened sense of place and community interactions. (Abunnasr, 2013). Tzoulas *et al.* (2007) conducted a study to gather relevant literature to explain the relationship between green infrastructure and public health, the study was based on data gathered from previous epidemiological, experimental, and survey studies. The study highlighted a positive relation between senior's longevity, the ability to relax, increased physical activity, and reduced severity of symptoms with children suffering from attention deficits in areas nearby open green spaces. Managed green spaces have also been found to improve residents' relationships among each other as well as reinforce their connection to their neighborhood and overall community.

On the economic level, the main benefits provided by green infrastructure are the ability to produce food, increased land values, attraction of tourists, improving employees' productivity (Llausas & Roe, 2012), and creation of new jobs related to the construction and maintenance of green infrastructure amongst others as well (Dunn, 2010). Additionally, green infrastructure is proving to be cost-effective when compared to conventional grey infrastructure in delivering similar services. For instance, a study conducted by Jaffe (2010) in the state of Illinois, United States to monetize the value of green infrastructure using an economic model, green infrastructure was found to save 24% of direct costs than conventional grey infrastructure in terms of stormwater management. The same study highlights the indirect cost savings from implementing green infrastructure practices such as having an urban tree canopy. An estimate of over $13,000 of combined savings can be achieved via the removal of 1 ton of each air pollutant from nitrogen dioxide, particulate matter, sulfur dioxide, and carbon monoxide by urban trees. The latter figure would increase even more if the health benefits from reduced air pollution levels are considered (Jaffe, 2010).

Table 5 below, summarizes some of the major benefits of each of the previously explored green infrastructure typologies.

Table 5 Benefits of green infrastructure typologies (Adapted from: Center for Neighborhood Technology, 2010)

Green Infrastructure Typology	**Benefits**									
	↓ Runoff	↑ Water Quality	↑ Groundwater Recharge	↑ Air Quality	↓ Urban Heat Island	↓ Energy Use	↓ Noise	↑ Recreation	↑ Aesthetics	↑ Biodiversity
Green Roofs	●	●		●	●	●	●		●	●
Green Walls				●	●	●	●		●	●
Parks	●	●	●	●	●		●	●	●	●
Greenways	●	●	●	●	●		●	●	●	●
Bioswales	●	●	●	●	●				●	●
Rain Gardens	●	●	●	●	●				●	●
Planter Boxes	●	●	●	●	●				●	●
Tree Canopy	●	●	●	●	●	●	●	●	●	●
Permeable Pavement	●	●	●							
Rain Barrels	●									
Downspout Disconnection	●									

D. Green Infrastructure Policy

So far this thesis has explored the various typologies of green infrastructure and the benefits accrued from implementing them. However, to realize the application of green infrastructure on the ground, relevant policies need to be developed. This section will survey policies adopted mainly in the United States and Europe that target facilitating the use of green infrastructure especially in urban contexts.

The proper implementation of an effective green infrastructure network across a city requires the existence of a comprehensive policy framework. Many cities worldwide, especially those in Europe and the United States have formulated policies and frameworks that enhance urban planning and design practices which rely on green infrastructure and facilitate their implementation to improve urban ecological health and the quality of life.

A successful green infrastructure system in urban areas basically depends on coherent and robust environmental policies that reflect the socio-economic and ecological goals that need to be achieved via green infrastructure implementation (Carter & Fowler, 2008). Such environmental policies should not be formulated in a stand-alone context by single environmental stakeholders, on the contrary effective environmental policies are produced when integrated with different sectors that play a role in urban planning and design, where decision making is conducted in an inter-organizational collaborative manner (Simeonova & Van d, 2009). This form of environmental policy integration serves as a good governance tool through combining socio-economic and environmental targets together to support sustainable development. Although environmental policy integration is a complex issue, several approaches exist that can facilitate the collaboration between organizations to come up with comprehensive policies. These approaches primarily depend on regular and direct communication between departments at the same governance level (horizontal integration) and across all governance levels (vertical integration). (Simeonova & Van d, 2009)

Moreover, green infrastructure projects implemented in urban settings, which primarily aim at promoting urban ecosystem services, should be based on proper urban ecosystem governance processes and practices. For example, in a study conducted in the Dutch city of Rotterdam, a framework was developed to assess its urban ecosystem governance and policies. This was achieved by evaluating the planning and long term goals of the policies in place, the activities designed in order to implement these policies, the manner of implementation, and the evaluation of the policies and results achieved over time. The ecosystem services targeted and improved by that system were also identified and categorized based on an ecosystem services framework that divided them into supporting services, provisioning services, regulating services, and cultural services (Frantzeskaki & Tilie, 2014).

The case study of Rotterdam can be related to a green infrastructure planning project, whereby a multi-level governance system can be analyzed to highlight the planning process and what is being done on the ground to apply a city-wide green infrastructure network and what are the major ecosystem services promoted that can help achieve the ultimate goal and objectives of the project.

Furthermore, several cities in the United States for instance have developed integrated policies to enhance the use of green infrastructure in the public and private sectors alike. Different types of policies function at different spatial scales, some policies might target the establishment of a green infrastructure structure at the site, neighborhood, or regional scale. Such policies should take into consideration the different land uses and conditions of certain urban areas, thus they should be spatially directed and applied in selected urban areas that will yield greatest results or in areas that are in utmost need for green infrastructure practices (Carter & Fowler, 2008). These policies are mainly driven by the needs of governments to adhere to national environmental regulations such as protecting water quality from degradation, improve their financial resources since green infrastructure has been proved to be cost effective by reducing maintenance costs of grey infrastructure as well as reducing the need for additional ones. Additionally, green infrastructure practices are important mitigation and adaptation measures against future climatic changes and floods (EPA, 2010a).

One of the most important policy applications necessary for successful green infrastructure projects is to conduct a thorough review of existing policies and revise existing ordinances if needed to facilitate adequate implementation. As stated before, environmental policy integration is a crucial stepping stone to come up with comprehensive policies, by means of inter-organizational collaboration and cooperation that consider the ecological and socio-economic aspects alike. When different organizations from different disciplines jointly revise existing and new legislations and codes they will contribute to removing any existing barriers, contradictions, and work duplication that might exist when formulating policies that aim to promote the use of green infrastructure, and thus ensure that all the policies and codes function smoothly to achieve the objectives set in the first place. Furthermore, these policy review sessions should be conducted as early as possible before any new legislation comes into effect to simplify its implementation and to raise the public's approval and will to abide by the new legislation (EPA, 2010a).

In summary, green infrastructure emerged as a multifunctional tool that is implemented through various typologies on different scales and varying contexts providing multiple ecosystem services that can promote the livelihoods of the surrounding residents as well as the environment. Several transdisciplinary policies could be enacted in order to enhance the development of green infrastructure measures especially in urban areas in order to mitigate some of the environmental impacts escalating in such areas. As with any green infrastructure planning program, it is important to identify in the beginning the overall need for green infrastructure by assessing the available ecosystem services to be enhanced. In densely populated urban areas with limited space it is important to assess any available space for their suitability in harboring a mixture of green infrastructure practices modified to fit in the overall context of the area.

E. Green Infrastructure Projects

1. The High Line Park

Description: The High Line in New York City, USA opened in 2009. It was developed on an abandoned elevated railway system that was used back in the 1930s to transfer industrial goods from and to Manhattan. The idea of developing the park was advocated by the neighborhood community surrounding the railway in an effort to create a new public green space for recreation, art, and education (Friends of the High Line, 2016).

Typology: Urban Park / Greenway

Planning and Design: The High Line is a 2 .3 Km long public park developed on a neighborhood scale in the lower west side of Manhattan Island in New York City. The plant species used to green the park are mainly native and drought tolerant plants, of which many originally grew on the abandoned railway (Friends of the High Line, 2016).

Benefits: The Park ensures sustainable management of water through drip irrigation and enhanced stormwater retention using special soil media. In addition the park creates a diverse habitat for flora and fauna, helps ameliorate the air quality in the neighborhood, improves the aesthetics of the urban neighborhood, and creates a new open space where people can relax and interact with other members from the community.

Related Policy Tools: The High Line Park was mainly created after public requests and advocacy groups that emerged in the 1990s to persuade the officials New York City to preserve the railway and transform it into a public park (Friends of the High Line, 2016).

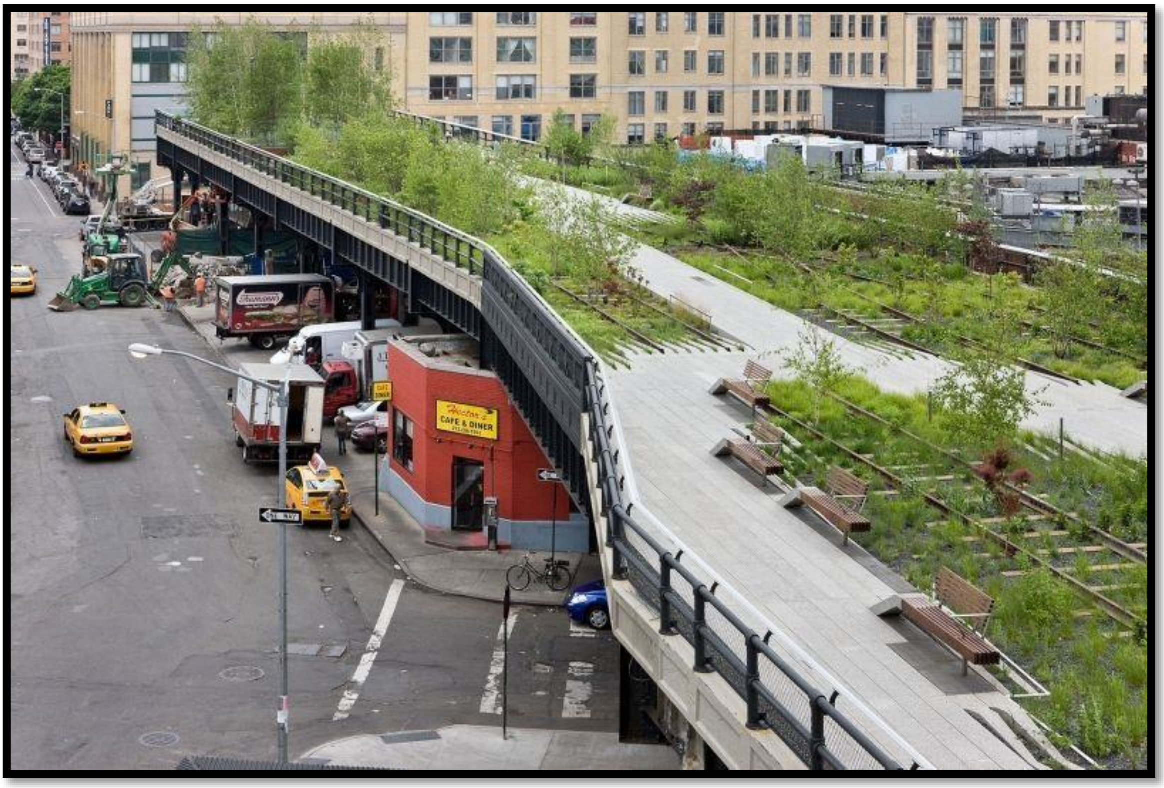

Figure 16 The High Line (Source: http://www.nycgovparks.org/)

2. The Green Carpet Project

Description: The Green Carpet Project is a large transportation project in Maastricht, The Netherlands which significantly incorporates green infrastructure within its design. The project which is still under construction, aims to remove the current surface highway that divides that city of Maastricht and reconstruct it as a tunnel underground. The former site of the highway will be then transformed into a green area that only supports local traffic (Strukton, 2016).

Typology: Greenway

Planning and Design: The green carpet will host across the city tree canopy of around 2,000 trees, cycling lanes, and other recreational areas.

Benefits: The project will improve the ecological integrity of the city, reduce air and noise pollution that were previously generated from the highway, and create new public green spaces to be utilized as a meeting and recreational area for the surrounding neighborhoods once completed in 2025. (Strukton, 2016)

Related Policy Tools: During the design and construction phases of the project, a steering committee was formed to involve all the stakeholders to share ideas and thoughts. These included members from the involved governmental ministries, the municipality of Maastricht, and the public community (A2 Maastricht, 2016).

Figure 17 Master Plan of the Green Carpet Project (Source: http://www.tunnel-online.info/)

3. Chicago's Green Infrastructure Program

Description: The city of Chicago in the United States pays significant attention to implementing city-wide green infrastructure practices, and has been developing over the years several programs to expand its urban green infrastructure system. For this reason the city has developed the Green Alley Program, the Green Streets Program, and the Green Roofs program (EPA, 2010a).

Typology: Permeable pavements, Trees, and green roofs.

Design and Planning: The Chicago green infrastructure programs were implemented on a city-wide scale:

- The Green Alley Program which has retrofitted since 2006 more than 14 Km^2 of the city's alleys with pervious pavement (EPA, 2010a).
- The Green Streets Program, which was launched in 1989, helped increase the urban tree canopy by 600,000 trees in 2010 (EPA, 2010a).
- The Green Roof Program is an incentive-based program launched in 2005 that offers financial grants for developing green roofs on residential and commercial buildings in the city. By 2010 the program has been responsible for the development of more than 300 green roofs across the city (EPA, 2010a).

Benefits: The three programs combines helped decrease local flooding events, enhance stormwater management, beautify the city streets, as well as to improve the city's air quality and biodiversity.

Related Policy Tools: The implementation of these programs relied on the use of several policy tools such as: the adoption of stormwater management ordinance to oblige private owners to reduce the amount generated on their properties, incentives and funds for green roof development, as well as the implementation of the Green Permit that offers accelerated construction permitting process and reduced fees for new projects that incorporate green infrastructure (EPA, 2010a).

Figure 18 Before and after Chicago's Green Alleys Program (Source: https://architectureboston.wordpress.com)

4. San Francisco Green Infrastructure Projects

Description: Like many cities in the United States the City of San Francisco has launched in the past few years several green infrastructure-based projects. An interesting project is the Mission and Valencia Streets Gateway which aims to retrofit a neighborhood in the city with green infrastructure (San Francisco Public Utilities Commission, 2016).

Typologies: rain gardens, street trees, and open spaces.

Design and Planning: The 500m long project involves adding rain gardens, trees, and new plazas along neighborhood streets. It was planned by the collaboration of several departments in the San Francisco City Council and the community groups. Those entities organized several community meetings to gain additional feedback and get to know local community needs (San Francisco Public Utilities Commission, 2016).

Benefits: The project will eventually improve stormwater management, create habitats, improve the walkability and aesthetics, as well as create new spaces for social interaction and gatherings for the neighborhood community (San Francisco Public Utilities Commission, 2016).

Related Policy Tools: The green infrastructure projects planned for San Francisco are part of the Sewer System Improvement Program that aims to reduce the amount of stormwater runoff generated in the city to minimize the impacts on the environment and communities (San Francisco Public Utilities Commission, 2016).

Figure 19 Plan for the Mission and Valencia Streets Gateway (Source: http://sf.streetsblog.org/)

F. The non-State of Urban Green Infrastructure in Lebanon

After exploring the prevalence of green infrastructure projects in several countries around the world that are currently integrating this concept in future urban plans and policies due to its multiple benefits, introducing this concept in Beirut and proposing green infrastructure-based projects in the city is possible and essential. For this purpose, it is necessary to gain background information on urban greening in Lebanon from a political point of view and by exploring urban greening initiatives and projects in Beirut. Hence, this section surveys relevant urban greening policies and regulations in Lebanon, as well as the current urban green cover in Beirut and related projects.

1. Political Dimension

To examine the possibility of enhancing the urban landscape of Beirut through the introduction of green infrastructure elements within its context, it is important to understand the organizational structure and to review the existing Lebanese policies that deal with protecting and promoting greenery.

a. Administrative Structure

Several governmental agencies in Lebanon play a role in managing green spaces in general, these are according to MEPI – Lebanon Alumni Association (MEPI-LAA) (2013):

- General Directorate of Urban Planning

An entity under the Ministry of Public Works and Transportation that operates on a national scale. Its duties include developing master urban plans, defining land uses, and assigning locations for public green spaces.

- Ministry of Environment (MoE)

One of the major roles of the MoE in Lebanon with regards to protecting green spaces in the country is restricted to setting out the standards for allowing development and large construction projects in environmentally sensitive/ important areas.

- Ministry of Agriculture (MoA)

MoA's main duties in managing green spaces in Lebanon, is associated with the protection and conservation of forests, as well as planning for future reforestation initiatives across the country.

- Council for Development and Reconstruction (CDR)

The CDR played a role in the management of green spaces in Lebanon by developing a database on land use and land cover on a national scale back in 2004.

- Municipalities

Local municipalities have a significant role in managing green spaces across their juridical boundaries which range from the protection of the existing green spaces to the development of additional ones as well.

- Supreme Council for Urban Planning

Due to the interdisciplinary nature and the overlapping duties between the different governmental agencies that have a role in managing green spaces, the Supreme Council for Urban Planning was created as a platform to enhance the coordination amongst them.

b. Existing Policies

By reviewing the existing Lebanese laws and policies, none mention the concept of green infrastructure as a whole system in urban areas. Nevertheless, there are a few laws that are related to urban greening practices as well as stormwater management (which could be greatly enhanced through the use of green infrastructure practices). However, regardless of finding policies that can encourage protecting and developing urban green infrastructure in Lebanon, inefficient policy implementation, corruption in governmental agencies, lack of budget, and private interests remain the primary obstacles that hinder the success and realization of green infrastructure projects in Lebanese cities. The main laws that are explored below are the following:

i. Urban Planning Law 1983/69

The Legislative Decree 1983/69 (Urban Planning Law) regulates urban planning and development in Lebanon by setting out the guidelines that classify the specified land use and zoning in each city or village. The law briefly mentions in its contents the issue of green spaces in urban centers.

المرسوم الأشتراعي رقم 1983/69 – قانون التنظيم المدني
المادة 8
ان التصميم والنظام التفصيلي يحدد القواعد والشروط لاستعمال الارض ضمن المنطقة بما فيه إمكانية منع البناء ويعين على الأخص :
الفقرة 8
حدود وتنظيم الساحات والحدائق العامة والملاعب الرياضية والجنائن والفسحات الحرة المختلفة وما يجب الإبقاء عليه من أماكن مشجرة أو تعديله أو إنشاؤه

Figure 20 Excerpt from the Urban Planning Law 1983/69

Article 8 of the law (Figure 20), which addresses the terms of land use in a certain area with a possibility of prohibiting development, is too general. It does not stipulate the detailed terms and conditions that can affect land use, and it does not enforce allocating a specific area of green spaces.

ii. Building Law 646/2004

The Building Law in Lebanon is the main law that deals with regulating building codes such as height, setback, allowable development area (Samaha, 2011). The application decree (Nb. 15874) of the Building Law gives little attention to green spaces in the design standards for newly-erected buildings. The few existing articles in the application decree either refer to possible environmental requirements as per the Environment Protection Law, or to improving the aesthetics of the building via obliging the owner to plant a few trees on the property, and assigning certain area of the property as gardens.

Figure 21 presents an example of the law, whereby it states that the administration can impose on the owner to have a certain area assigned as gardens, however this remains non-mandatory. In cases where allocating certain areas as gardens is imposed by the administration, the law does not provide sufficient information and design requirements that the owner must follow.

المرسوم التطبيقي للقانون 646 – قانون البناء

المادة العاشرة: إرتفاقات خاصة بالسلامة والصحة العامة والمنظورات المعمارية

أولا: إن الإرتفاقات والاحكام الخاصة التي تفرض عند منح الترخيص بالبناء يمكن أن تشمل كافة العناصر المعمارية والإنشائية والتنظيمية للبناء ومحيطه ، ويحق للإدارة أن تفرض على المالك تأمين تجهيزات تتناسب وأهمية البناء لا سيما لجهة التقيد بأصول حماية البيئة وإستدامة مواردها الطبيعية (مياه ، هواء أرض وكائنات حية) كما حددها القانون رقم444 (قانون حماية البيئة) عندما يتضمن المشروع ترك فسحات في العقاربمستوى الأرض بعد التسوية، يجب تخصيص نصف مساحة هذه الفسحات كحدائق ما لم يتم الإبقاء عليها بحالتها الطبيعية.

ثالثا: يمكن للادارة أن تفرض على المالك شرطا لمنحه رخصة الاشغال يقضي بغرس أشجار ضمن عقاره.

Figure 21 Excerpt from the application decrees (nb. 15874) of the Building Law 646

On the other hand, the excerpt from Figure 22 states that at least 25% of the land area of compound projects must be allocated as gardens. However, it does not provide design standards and specific requirements for these gardens, and the owner can leave such areas undeveloped and non-vegetated.

المرسوم التطبيقي للقانون 646 – قانون البناء
المادة الرابعة عشر – المجموعات الكبرى
أولا بالإضافة الى ما نصّت عليه في المادة 16 من قانون البناء رقم 646 تاريخ 2004/12/11
يجب أن يشتمل ملف طلب الترخيص لبناء أية مجموعة كبرى على المستندات التالية:
1-تقريرا مفصلا يشرح هدف المشروع ويبين المواصفات المعمارية التي يتميز بها والفوائد التي
تطال المنطقة من جراء تنفيذه (تطوير، إنماء).
2- مخطط حجمي (Plan masse) وخرائط أولية (Plans preliminaires)
ورسمات توضيحية(Croquis) وصورة أو صور ا ًُ(Photos montage)
تظهر المشروع مع محيطه ضمن مسافة ثلاثماية متر أ على الأقل من حدود عقار أو عقارات
المجموعة من جميع الجهات وتبين مدى إنسجامه مع طبيعة وخصائص المنطقة المحيطة به بما فيه
المحافظة على نسبة لا تقل عن 25 % من مساحة أرض العقار كحدائق.

Figure 22 Excerpt from the application decrees (nb. 15874) of the Building Law 646

The Building Law also briefly considers the issue of stormwater whereby in Article 13 – Section 4 it states that the owner might be obliged to construct a tank for rainwater harvesting.

iii. Property Law 3339/1930

The Property Law (Law no. 3339/1930) in Lebanon refers to the issue of stormwater generated on private properties in Articles 60 and 64 (Figure 23). These articles state that a property owner can use the stormwater generated on his land, but it does not mention that landowners should reduce the amount of stormwater generated from their properties, and it also does not mention the need and benefits for rainwater harvesting. On the contrary, the law gives the owner the right to divert the generated stormwater from the property to the streets, clearly conflicting with the green infrastructure concept.

قانون الملكية 1930/3339

المادة 60- لكل صاحب عقار الحق في أن يستعمل مياه الامطار الساقطة في أرضه وأن يتصرف بها أما إذا كان استعمال هذه المياه أو الاتجاه الذي توجه إليه من شأنه أن يزيد عبء الارتفاق الطبيعي الناتج عن المسيل، والمذكور بالمادة السابقة، فيجب التعويض على صاحب الأرض الوطيئة

المادة 64- على كل صاحب عقار أن يبني سطوحه بحيث تسيل مياه الامطار في أرضه أو في الطريق العمومية إلا في حالة تطبيق الانظمة الخاصة المتعلقة بالطرقات، ولا يجوز له إسالة هذه المياه في الأرض المجاورة.

Figure 23 Excerpt from the Property Law 3339/1930

iv. Environment Protection Law 444/2004

The Environment Protection Law in Lebanon presents a legal framework that is supposed to prevent environmental deterioration and enhance environmental protection and conservation in the country, especially through enforcing environmental impact assessment studies (EIAs) for large projects with possible significant negative effects on the environment. With regards to urban landscapes, the law has been found to dismiss the issue of urban greening and the promotion of urban greenery. Moreover, the law does not clearly focus and present the concept of ecosystem services along with their benefits to the environment and humans. It is noteworthy to mention that the Environment Protection Law still lacks its application decrees which can facilitate its direct and clear implementation in reality (MOE/UNDP/ECODIT, 2011).

c. Urban Planning in Beirut

Rene Danger, a French urban planner was the first to propose an urban plan to Beirut in 1931, the Danger Plan followed a model where Beirut would seamlessly combine its old structures with the new. The plan focused on hygiene, circulation, and designated areas for industry and commerce (Hastaoglou-Martinidis, 2011). Danger also emphasized the importance of maintaining natural settings, planned to create new public spaces within the city, and even wanted to set residential quarters within garden suburbs and garden city planning (Hastaoglou-Martinidis, 2011). The plan designed by Danger, however, was never fully implemented (El Hayek 2015). Soon after, in 1941, Michel Ecochard was assigned to design another urban master plan for Beirut. The plan included the development of new neighborhoods such as Bir Hassan and Chiah, while green spaces on the other hand weren't given much importance (Verdeil, 2004). In the following years, President Foad Shehab assigned again in 1964 Ecochard to prepare an urban plan for Beirut, however his plans were not fully implemented due to the strong opposition from developers on the strict policies proposed which would have increased their restrictions and prevented them from gaining more profits (Yassin, 2012).

2. *Green Cover in Beirut*

a. Existing Green Spaces

Beirut is a city that is clearly short on abundant green spaces, however it does host 49 green public spaces scattered all around the city, excluding the Corniche (Shayya, 2010). The largest green spaces include Horsh Beirut (330,000m^2) that constitutes 72% of the total public green spaces in Beirut, Sanayeh Garden in Hamra (22,000m^2), and Sioufi Garden in Achrafieh (19,000m^2), while the smallest green public green space is Al Houry Garden (85m^2) located in Mazraa (Shayya, 2010). These public green spaces, along with the Corniche form integral, yet fragmented, elements of the overall green infrastructure system in Beirut. Additionally, there are many green spaces of varying areas that exist on private properties such as the gardens surrounding some buildings or old houses in the city. Such green spaces also include those located on properties owned by organizations, mostly educational ones, such as the campuses of the American University of Beirut (AUB), the Lebanese American University (LAU), and the Saint Joseph University (USJ). Other green features in the city are those that grew naturally in undeveloped properties, as well as on and around abandoned properties/ buildings. (Région Île-de-France & Bureau CGLU-BTVL, 2012a)

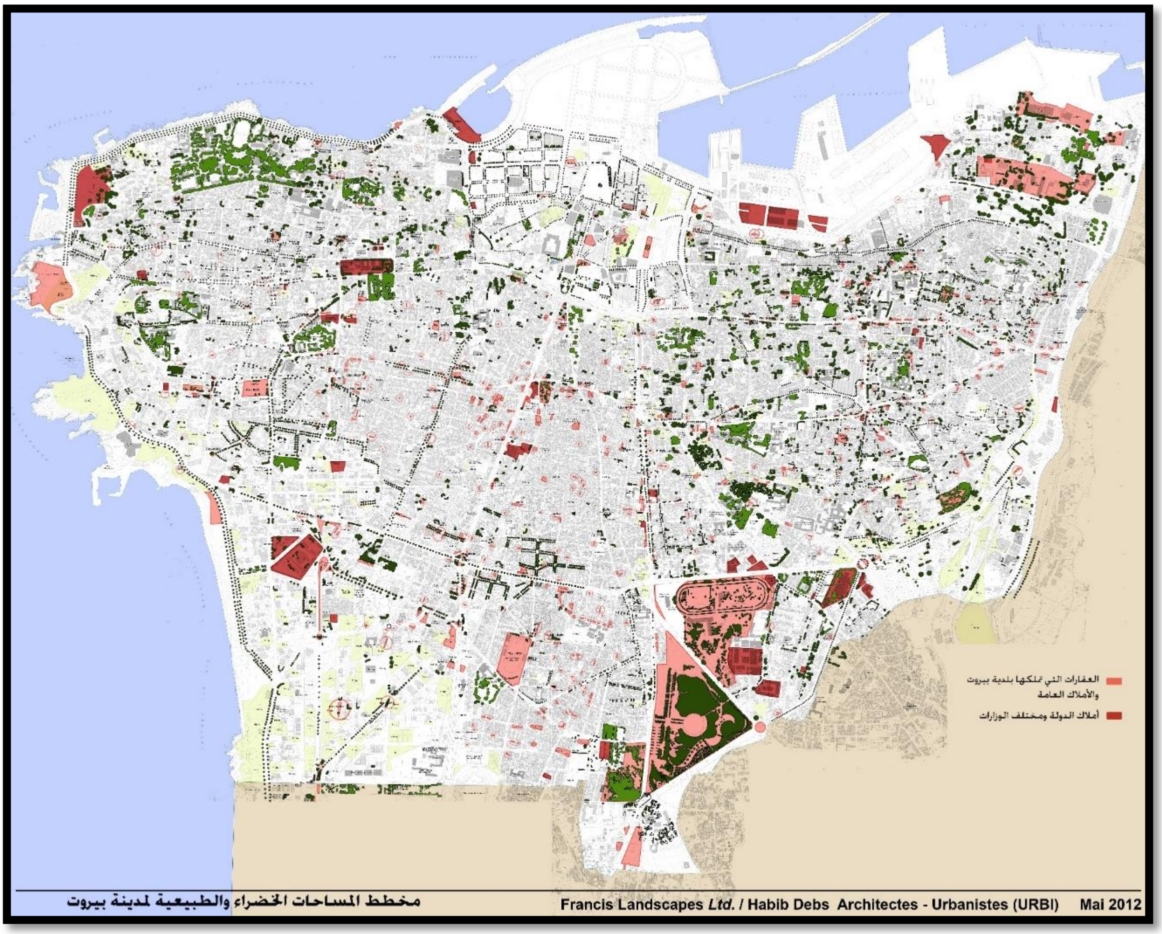

Figure 24 Green spaces and municipal lots (in red) in Beirut (Source: Région Île-de-France & Bureau CGLU-BTVL, 2012)

Figure 25 Green wall growing over an abandoned building in Beirut (Source: http://spatiallyjustenvironmentsbeirut.blogspot.ae/)

At the same time, an interesting urban green infrastructure feature that was recently developed in Lebanon is located in the city of Jounieh. The city now hosts a green strip that runs in between its urban landscape in a unique initiative implemented by the local municipality in 2014 (Figure 26). The 750m long strip is planted with various tree species, supports diverse habitats, and allows the neighborhood residents to relax and enjoy various recreational activities amidst a concrete-filled landscape. (Beirut Green Project, 2015)

Figure 26 Jounieh Green Strip (Source: https://beirutgreenproject.wordpress.com)

b. <u>Green Plan for Beirut</u>

In an effort to improve the urban landscape and the environment in Beirut, the Municipality of Beirut in partnership with Ile de France and Bureau Technique Des Ville Libanaises compiled a Green Plan for Beirut. The study, which started in 2011, assessed the existing urban landscape and proposed strategies that serve to improve the quality of life in the city, promote the existing urban ecosystem, and to beautify the city landscapes (Région Île-de-France & Bureau CGLU-BTVL, 2012a).

The study partly focused on incorporating green infrastructure within the city context, mainly through street trees and pocket parks, along main transportation routes. It also aimed at improving the walkability within the city and transforming it into a pedestrian friendly environment. This was evident in suggesting several smooth pathways (Liaison Douce) that connect different areas of the city and in turn creates a connected network of green infrastructure. Thus, through increasing the greenery along these routes, modifying the streets, and adding traffic calming features to make them more walkable; several pathways have been suggested, most notably is the one connecting Horsh Beirut with Downtown Beirut amongst others as well (Figure 27). The plan also recommended some policy changes that should be put in place in order to facilitate its implementation. These include modifications in the Building Law, the role and communication between the various stakeholders, which include the public community (Région Île-de-France & Bureau CGLU-BTVL, 2012b). The assessment and planning phases for this plan are now complete, however the timeframe for implementation and realizing the outcomes of the study on the ground is still undefined.

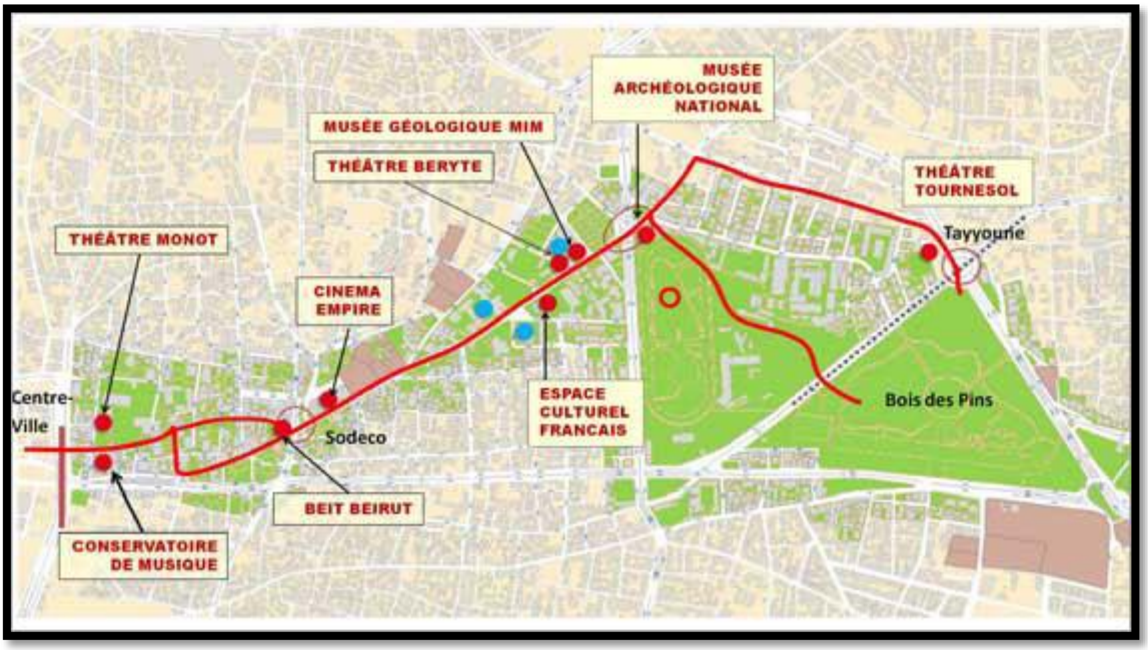

Figure 27 Master plan for the “Liaison Douce” connecting Horsh Beirut and Downtown (Source: http://www.agendaculturel.com)

Figure 28 Suggested greening of Bliss Street (Région Île-de-France & Bureau CGLU-BTVL, 2012b)

Figure 29 Suggested greening of Hamra Street (Région Île-de-France & Bureau CGLU-BTVL, 2012b)

In summary, the low urban green cover in Beirut, due to haphazard planning and dense morphology, is countered by minute government efforts aiming to rectify the situation. This is also coupled by the lack of holistic and proper urban policies that can enhance urban greenery and promote its development. From the literature reviewed, green infrastructure planning, which is currently being adopted across various cities worldwide, can act as a possible approach to improve and green the urban environment in Beirut due to its various and flexible typologies. Hence, the subsequent chapters of this thesis will present a systematic methodology to identify opportunities for green infrastructure in a dense neighborhood in Beirut, and will continue to explore the required municipal actions needed for implementation.

CHAPTER III

METHODOLOGY

The methodology aims to develop a sample spatial data set in a neighborhood case study area in Beirut on the applicability of urban green infrastructure typologies that will inform an evidence based green infrastructure municipal guidelines applicable for the city of Beirut. The process includes generating spatial data from the case study area and suggests new municipal guidelines through the analysis of the international and local polices explored in Chapter II. These steps are summarized below are explained in the subsequent sections. The methodology comprises of two main areas of inquiry that merge to form the said guidelines.

The first is data gathered from the case study area will be used in order to identify availability and suitability of space for different green infrastructure practices, as well as the opportunity for implementing each. The result is mapped in a manner that shows the range of opportunities for implementing each green infrastructure practices, resulting in a spatial plan of the neighborhood.

Second, is desk research to explore the needs and goals of green infrastructure in Beirut to recommend specific municipal guidelines applicable in Beirut to realize the proposed green infrastructure results from the case study, as well to promote the use of green infrastructure across the city. The guidelines revolve around suggested modifications to the administrative work and structure of the Municipality of Beirut, the analysis of the available urban greening regulations in Lebanon, and potential new policy programs to be adopted by the Municipality. More detailed information is mentioned in the subsequent sections of this chapter.

A. Study Area

1. Study Area Profile

The neighborhood selected is located in the Hamra district in Ras Beirut (Figure 30), a densely built urban hub that consists of a mix of residential buildings, commercial offices and outlets; and governmental agencies. The area is also home for several major healthcare centers such as the American University of Beirut Medical Center (AUBMC), and large educational institutions like the American University of Beirut (AUB) and the Lebanese American University (LAU), in addition to several schools.

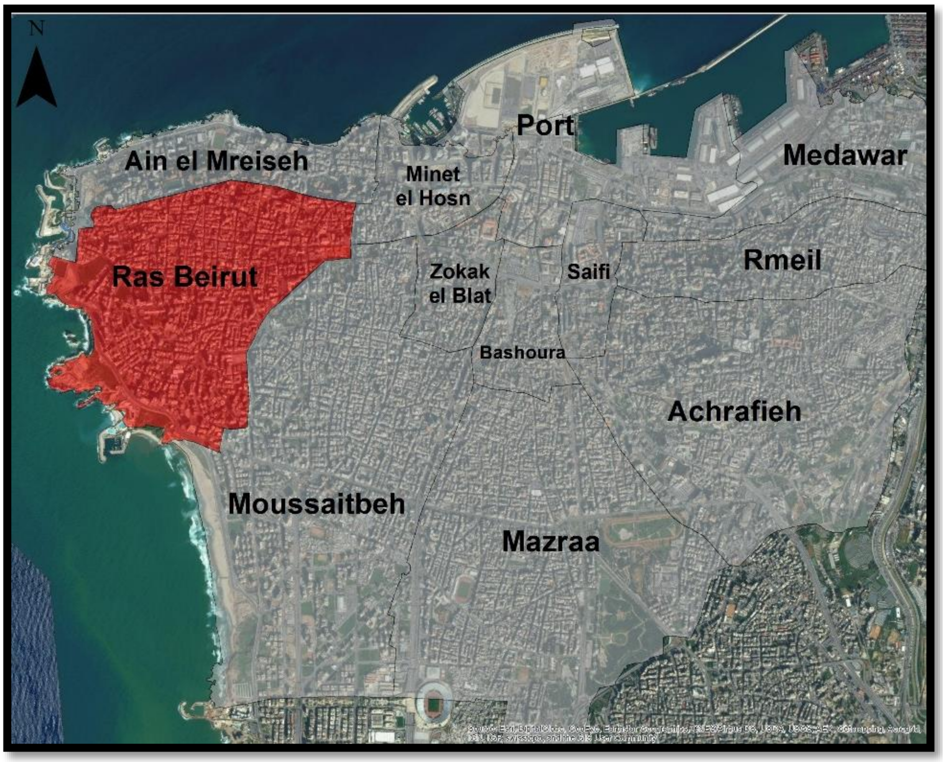

Figure 30 Location of Ras Beirut within municipal Beirut

Historically, Hamra district in Beirut started developing after the founding of the American University of Beirut in 1866, where it was gradually transformed from an area used for farming activities into a dense urban district (Ozturk, 2006) (Figure31). Most of the houses back then were surrounded by gardens and cultivated lots (Figure 32), however due to the increasing influx of people to the area over time, apartment buildings started to emerge erasing the greenery that once existed. (Ozturk, 2006)

Figure 31 Map of Ras Beirut in 1876 (Adapted from: Ozturk, 2006)

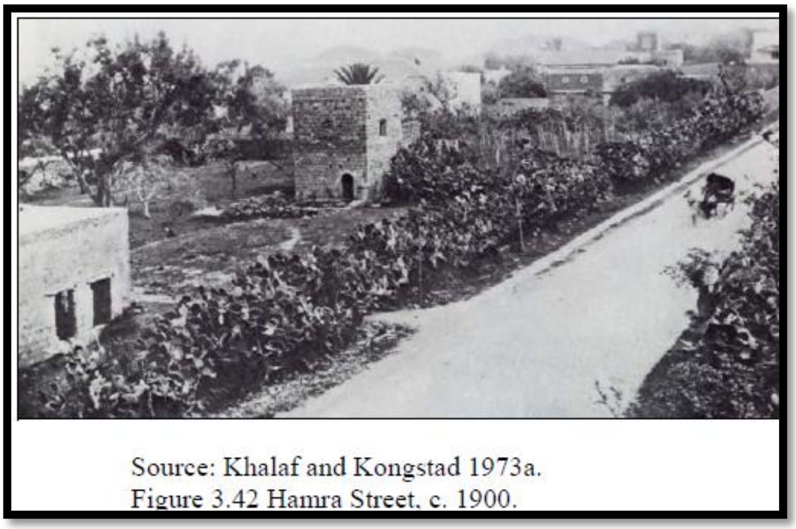
Source: Khalaf and Kongstad 1973a.
Figure 3.42 Hamra Street, c. 1900.

Figure 32 Hamra Street in the early 20th century (Ozturk, 2006)

From an urban planning perspective, Hamra district nowadays is characterized by its mostly narrow streets, lack of public green spaces, and minimal street greenery that can contribute to improving the overall wellbeing of the residents as well as the overall urban environment of the area. This is primarily the result of private land ownership and real estate centered zoning plans. The area is majorly dominated by back to back buildings alternating between modern high rises, low-rise apartment buildings, and a few old small houses/villas. The only major green spaces are the campuses of the American University of Beirut and that of the Lebanese American University which bound the study area from the North and partially from the South side respectively.

2. Study Area Selection

The selected case study area boundaries follow the streets of: Bliss, Sadat, Mahatma Gandhi, Hamra, and Omar Bin Abdul Aziz; and it includes the rest of area in between those streets, as portrayed in Figure 33.

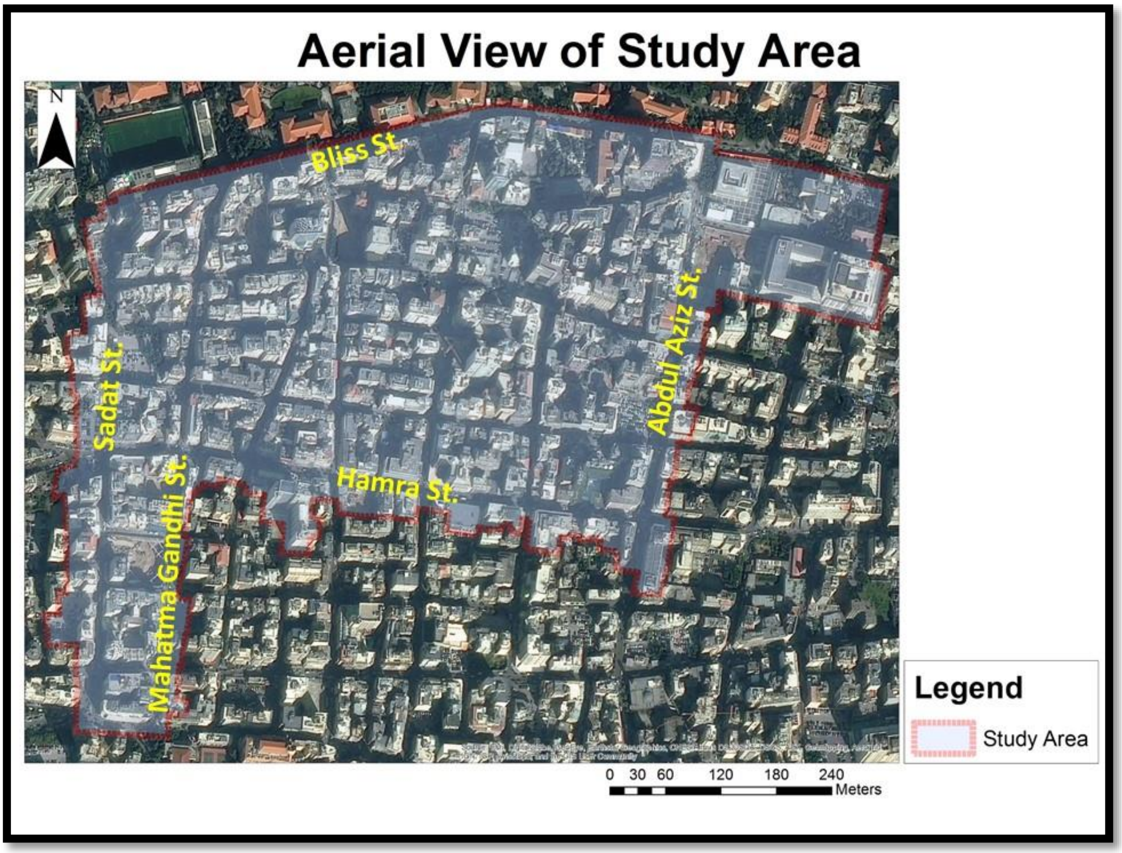

Figure 33 Satellite image of the study area

The reasoning behind selecting this specific study area is elaborated below:

- It's a dense neighborhood, thus presenting a challenging task to explore the potential of introducing green infrastructure in a space-limited context.
- Based on previous studies conducted by AUB faculty and students (Said, 2015; Myntti & Mabsout, 2014) these streets along with other secondary streets in the study area are the most used by students walking to AUB from the Hamra district, so it would be worthwhile to explore how they could be enhanced with green infrastructure, thus

transforming them into more pedestrian-friendly streets providing ecosystem services.

- All of the aforementioned streets act as connectors to the busy commercial strip of Hamra Street, which is highly visited by AUB students, LAU students, and other people as well.
- The area includes many open spaces in the form of parking lots and to lesser extent unbuilt lots, as well as alleyways which could host different green infrastructure practices.
- From an ecological point of view, the study area provides the possibility to connect the green hubs in AUB and LAU (which can be considered as patches of potentially providing ecological hubs in a densely developed urban area) using green infrastructure. Linear street green infrastructure typologies can act as corridors, whereas larger-sized typologies such as green roofs or parks can act as small habitat nodes throughout the study area. Eventually, a connected network via green infrastructure can play a vital role in species movement, providing habitats, and promoting energy flows, thus improving the overall urban ecosystem and boosting the provision of ecosystem services.

B. Selection of Green Infrastructure Typologies and Identification of Potential Space

Since the study area is highly dense, not all green infrastructure typologies that were investigated in the literature were considered in the study. Table 6 below, presents a list of the typologies that were included or eliminated along with the respective reasoning. Further details on each of the included green infrastructure typologies is provided in the subsequent sections.

Table 6 Green infrastructure typologies included and eliminated from the case study

<table>
<tr><th rowspan="2"></th><th colspan="2">Green Infrastructure Typology</th><th rowspan="2">Reasoning</th></tr>
<tr><th>Category</th><th>Subcategory</th></tr>
<tr><td rowspan="6">Included Green Infrastructure Typologies</td><td>Green roofs</td><td>Extensive Green Roofs</td><td>- Building roofs are widely available in the study area which might act as potential spaces for green roofs.

- Extensive green roofs are cheap to install and maintain, and are light in weight.</td></tr>
<tr><td>Green walls</td><td>Direct green walls with surface climbers</td><td>- Vertical in nature, thus they are not space intensive as compared to other typologies.

- Direct green walls are cheap, and are easier to plant and maintain.</td></tr>
<tr><td>Street Trees</td><td>N/A</td><td>- If sidewalks are wide enough, street trees could be planted along numerous sidewalks in the study area.

- Street trees could be also planted in open/unbuilt spaces in the study area.</td></tr>
<tr><td>Bioretention practices</td><td>Infiltration Planter Boxes

Rain Gardens

Bioswales</td><td>- If sidewalks are wide enough, planter boxes could be developed along numerous sidewalks in the study area.

- Bioretention practices could be also developed in open/unbuilt spaces in the study area.</td></tr>
<tr><td>Parks</td><td>Pocket Parks</td><td>Small pocket parks could be developed in the study area in open/unbuilt spaces.</td></tr>
<tr><td>Permeable Pavement</td><td>N/A</td><td></td></tr>
</table>

	Rainwater Harvesting	N/A	Do not require space, and could be incorporated over the whole study area.
	Downspout Disconnection	N/A	
Eliminated Green Infrastructure Typologies	Greenways	N/A	Space-intensive and require long unbuilt areas that could be transformed into green pathways, which are not available in the study area.

Since space to implement green infrastructure is limited, an analysis of spaces that might accommodate green roofs, green walls, street trees, bioretention practices, and parks was carried out by conducting extensive field visits around the study area over a period of four months (September-December 2015). The data was mapped using ArcGIS. Additional types of green infrastructure such as permeable pavement and rainwater harvesting using rain barrels were considered but the latter are not space-intensive and have not been considered in the field study.

The available typology of spaces for green infrastructure in the dense urban study area are categorized as building roofs, building walls, street sidewalks, and vacant lots. Of these available spaces, some might not have the criteria needed to accommodate a green infrastructure practice, hence a suitability analysis of the aforementioned available spaces was carried out to identify which of those spaces are practically suitable. The analysis was presented by identifying the types of applicable green infrastructure, the available spaces for such typologies, and the criteria used to allocate a suitable space for implementation. The following criteria for each green infrastructure typology was used to identify suitable spaces:

1. Green Roofs

There are two main types of green roofs: extensive and intensive green roofs as mentioned in the literature review. In this research only extensive green roofs are considered for implementation due to several factors explained below.

- Extensive green roofs are the cheapest to install and maintain.
- Extensive green roofs are much lighter in weight hence they will not add a lot of structural pressure on old buildings.
- Extensive green roofs might be affected by the dry season (May-October) in Beirut. In a phone interview with Green Studios, a company specialized in green roof installations in Beirut, they stated that they only install irrigated semi-intensive green roofs to encounter the issue of drought during summer. However, some cities like San Francisco, USA which enjoy a similar climate to Beirut have city-wide green roofing programs that install extensive green roofs planted with native drought-tolerant plants (City and County of San Francisco, 2015). A possible solution for irrigation is to use the AC condensate (EPA, 2010b) since many buildings have their centralized AC units on the roof.

a. Identify total pool of potential green roofs

For the process of identifying potential roofs that can accommodate extensive green roofs, both satellite images of the case study area downloaded from ESRI® on ArcGIS 10.3 and Google Earth Pro® for verification were used in order to calculate the area of usable roof space for each building. Using the "Measure" tool on ArcGIS and the "Ruler" tool on Google Earth Pro® the areas not suitable for green roofs were measured and recorded in the attributes table for the “Buildings” Shapefile in ArcGIS. After measuring the un-suitable area (i.e. occupied by building functions such as elevators, stair wells, water tanks, and equipment) for all building roofs, it was subtracted from the total area of the roofs in order to identify the suitable area of the free roof space (in m^2).

As a result, all the roofs that have a free roof space are considered as potential spaces for extensive green roofs. Buildings with slanted roofs were excluded from the pool of potential roofs.

b. Selection of Opportunity roofs for extensive green roofs

The areas generated from the first step provided a varying area of roofs that were suitable for extensive green roofs. The selection of the final qualifying existing roofs for extensive green roofs cannot be determined based only on surface area, since the literature does not provide the area as a sole criteria, but rather is connected to the economic feasibility of green roofs (United States General Services Administration, 2011; Newton Creek Alliance, 2015). In order to reach a reasonable suitability criteria that differentiates between the different free roof spaces, looking at the approximate financial costs of installing and maintaining a green roof was deemed as a good indicator. This resulted in identifying that the cost of installing a green roof diminishes and the monetary value of its benefits rises as its area increases in size, as shown in Figure 34 (United States General Services Administration, 2011; Newton Creek Alliance, 2015).

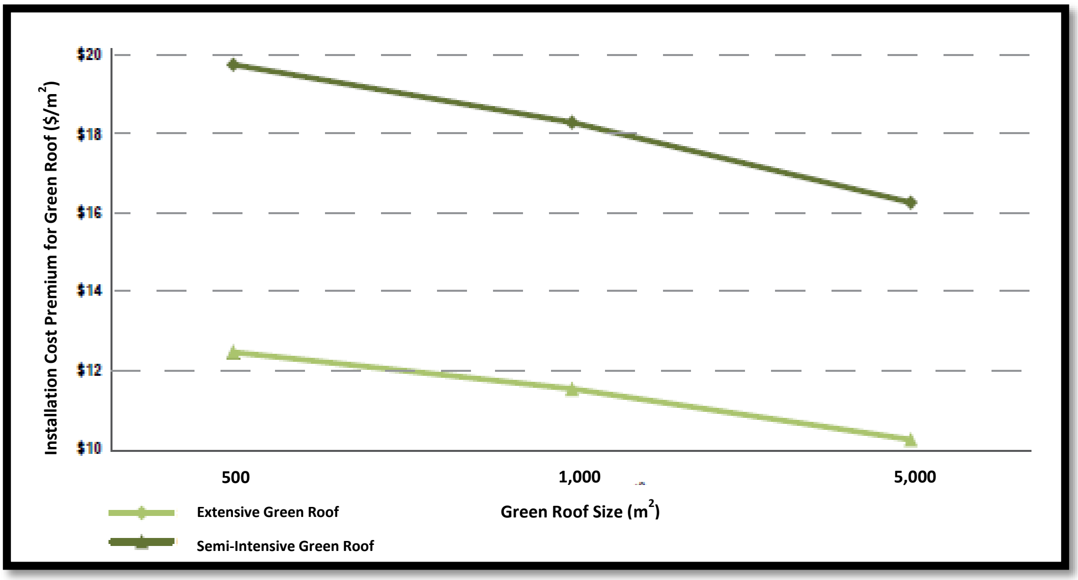

Figure 34 Variation of the Green Roof Cost per Size (Adapted from U.S General Services Administration, 2011)

Based on the above, the categories of suitable roofs for greening were defined as opportunities for greening (low, medium, and high) based on the area of free roof space that reflects the economic feasibility. It is important to note that these figures reflect costs within North America. Yet, the trend is assumed the same for Beirut (while the actual cost may be higher).

Table 7 Opportunity criteria for green roofs

	Opportunity for Installing Green Roofs		
	Low Opportunity	***Medium Opportunity***	***High Opportunity***
Building Free Roof Space (m^2)	< 500	500- 1000	>1000

The final results of the roofs of buildings were presented as a GIS map that indicates a range of opportunities based on the criteria above (Table 7). The low opportunity indicates that the cost versus the area being transformed into extensive green roofs is relatively high.

Note that the structural stability of the roof and the extent of weight loading are not considered in the analysis since it was not feasible to survey each building and the data on each building was not readily available for inclusion.

2. Green Walls

Green walls are another typology of green infrastructure addressed in this research, and are proposed as another practice that can enhance the urban green cover and improve the urban ecosystem. Green walls vary in types and range from simple direct wall greening practices to complex designed modular frames, as explained in Chapter II. In this research however, only direct wall greening practices, with climbing plants directly planted in the ground, were considered since they are easier to plant, require less maintenance and are significantly cheaper to install and maintain than the other types of green walls.

Finding the proper suitable locations for implementing direct green walls in the study area was based on three different criteria:

- The type of building façade;
- The availability of pervious surfaces near the buildings;
- The orientation of the buildings walls intended for greening.

The methods used for identifying suitable locations for green walls is elaborated below.

a. Identifying Existing Conditions

Field visits around the study area were conducted in the beginning to identify existing green walls. Existing green walls were mapped according to their types;

whether direct surface climbers, green facades, or buildings with dangling vegetation from their balconies or vertical planters along their exterior walls. On ArcGIS a new polyline shapefile for green walls was created, where all the data gathered on existing green walls was entered into its attribute table.

b. Identifying Building Facades

Building facades were considered as an important aspect that can affect the potential walls applicable for greening in the study area. Since this research focuses on greening walls using surface climbers that adhere to the walls without the use of additional structural support systems, the building façade material will affect the extent of vertical growth of the plants and adherence to the façade. Hence through several field visits in the study all the buildings' facades were identified and categorized as shown in Table 8.

Table 8 Types of building facades identified in the study area

Façade Material Type	**Description**
Glass	The major facades of the buildings are covered in glass
Concrete	The major facades of the buildings are uninterrupted concrete walls
Balconies	The major facades of the buildings have balconies
Mixed (Glass/ Concrete)	Buildings have facades that are covered in glass and the others are uninterrupted concrete walls
Mixed (Glass/ Balcony)	Buildings have facades that are covered in glass and the others have balconies
Mixed (Concrete/ Balcony)	Buildings have facades that are uninterrupted concrete walls and the other have balconies

These categories from the field survey were entered in the attribute table in ArcGIS to be used in analysis. It is important to note here that some of buildings' facades, especially those that are not directly facing the streets, could not be observed and identified due to physical obstacles (fences/ lack of pathways, i.e. lack of access) that prevented documenting the whole facades of the buildings, hence the dominant type of façade observed was documented for each case where access was difficult.

c. Availability of Pervious Surfaces

Direct wall greening, as considered in this research, depends on plants rooted in the ground. Availability of unbuilt pervious surfaces (existing soil in the ground to be used for planting) is a significant factor that limits the location where green walls can be realized.

Field visits were conducted in the study area in order to identify, locate, and map the locations of the pervious surfaces in the study area. The data gathered was entered into ArcGIS by adding two new shapefiles to derive a map that shows the availability of pervious surfaces in the study area. Large surfaces were digitized in the form of polygons, and their areas were derived directly from ArcGIS. On the other hand, small pervious surfaces were digitized as point locations so that they could be considered in the analysis. The areas of the small pervious surfaces were manually measured using a measuring tape.

d. Orientation of the Walls and Building Facades

The orientation of the walls and building facades subject to greening can considerably affect the growth rate of the climbing plants. The walls that are exposed to higher amounts of sunlight are of better quality to be greened than those which get less light exposure. Since Lebanon is located in the northern hemisphere of the earth, the north side of the building walls usually receive less or no sunlight than the walls facing other orientations.

Using ArcGIS, a new shapefile for building walls was developed whereby the walls of the buildings were digitized and their respective orientation was entered into the attribute table (north, south, east, and west).

e. Selection of Opportunity Walls for Greening

The identification and mapping of the criteria above results in the total potential locations for developing green walls at varying extents. In order to differentiate between the resulting possibilities, the walls eligible for greening were classified based on their opportunity for hosting a green wall as described in Table 9.

Table 9 Opportunity criteria for green walls

	Opportunity for Green Walls			
	High	**Medium**	**Low**	**Not Applicable**
Building Façade Type	Concrete Balconies Mixed	Concrete Balconies Mixed	Glass	---
Availability of pervious surfaces directly adjacent to the wall	Yes	Yes	Yes	No
Wall Orientation (directly adjacent to the soil)	South/ East/ West	North	Any Orientation	---

Based on the above, a map that shows the location and opportunity for developing green walls in the study area was presented.

3. Street Trees

Trees make up another typology of green infrastructure which provide multiple ecosystem services. In this section the issue of increasing the street tree canopy in the study area is addressed by identifying the streets which possess the highest opportunity for greening. The highest opportunity means that a largest number of trees can be planted with respect to the length of the sidewalk. Therefore, the subsequent method will be followed to reach the final selection of opportunity streets in the study area:

- Mapping the existing street trees in the study area.
- Identifying the potential and applicable sidewalks that could be planted with street trees.
- Selecting the streets and identifying their relative opportunity for greening using street trees.

a. <u>Mapping Existing Street Trees</u>

To map the street trees in the study area, street by street field visits were conducted in order to map the location of each existing tree. The data gathered was then entered into ArcGIS by adding a new point shapefile for street trees.

b. <u>Identifying Applicable Sidewalks for Street Trees</u>

In order to identify the applicable sidewalks that could be potentially enhanced with street trees, the width of each sidewalk in the study area was manually measured using a measuring tape by conducting street by street field measurements. Measuring the sidewalks' width is deemed necessary since the sidewalk has to be wide enough to host trees and at the same time allow unobstructed pedestrian movement. By entering the data gathered into ArcGIS, a new polyline shapefile for sidewalks was added where the measured widths for each sidewalk were added in the attribute table. The length of each sidewalk segment was also generated using ArcGIS.

The total pool of sidewalks was shortlisted based on the width of each as explained below:

- To allow smooth pedestrian movement along the sidewalks, the unobstructed pathway on the sidewalk should not be less than 1.5m (City of San Diego, 2002; City of Toronto, 2004; United States Federal Highway Administration, 2014)
- The existing sidewalk curbs in the study area have a width of 0.2m, where trees cannot be located.
- The new street trees to be added shall be planted in 0.8m x 0.8m tree pits which have similar dimensions to those already existing in the study area (Figure 35).

Figure 35 Existing Tree pits in study area

Based on the above the sidewalks which are applicable for accommodating additional street trees shall be equal or wider than 2.5m. All sidewalks that have a width that is smaller than 2.5m were regarded as not applicable, and were not regarded as an opportunity for street greening.

c. Selection of Opportunity Sidewalks for Street Trees

Based on the literature, well-planned streetscapes define specific standards for street tree spacing. Varying standards have been identified that ranged from 6m to 10m for medium sized trees (City of New York, 2014a; City of Toronto, 2010; Republic of Cyprus, 2010). For this research a threshold distance of 6m/tree spacing has been considered to allow for the largest number of trees along the sidewalks.

To identify which of the applicable sidewalks can contribute more to urban greening using trees, the length of each was divided by the threshold in order to know the maximum number of trees that could be planted along the length of the sidewalk. The difference between the maximum number of trees and the existing number of trees was then generated to know the number of trees that could be added on each sidewalk. Finally a ratio for the number of new trees to be added to the existing number of trees was calculated. This ratio was used to define the extent of opportunity for adding street trees. This presents us with the following opportunities for each sidewalk as shown in Table 10.

Table 10 Opportunity criteria for street trees

	Opportunity for Street Trees		
	High	**Medium**	**Low**
Ratio (Nb. of New Trees to be added ÷ Existing Nb. of Trees	> 1	= 1	< 1

The final result for street trees is an ArcGIS map that shows a range of opportunities based on the criteria presented above. Higher opportunity ratio signifies a larger number of trees could be planted along the length of the sidewalk.

4. Bioretention Practices

Bioretention practices which include bioswales, rain gardens, and planter boxes are green infrastructure typologies introduced mainly along street sidewalks. The implementation of these practices is dependent upon the width of the sidewalks.

By reviewing available resources it was found out that several cities worldwide have specific design standards regarding the dimensions of the bioretention practices so that to optimize their performance especially with regards to enhancing their stormwater reduction and infiltration capabilities (Table 11).

Table 11 Commonly used design standards for bioretention practices

Bioretention Practice	**Width Standard**	**Reference**
Bioswale	Minimum 1.5m wide	City of New York, 2014b
Rain Garden	Minimum 2m wide	San Mateo County, 2009
Infiltration Planter Boxes	Minimum 1m wide	City of Los Angeles, 2009

From the table above, it is evident that rain gardens and bioswales require wider space than infiltration planter boxes. Additionally bioswales are long linear structures that can affect road crossing for pedestrians, thus their applicability diminishes in the narrow streets of the study area. Hence, given that 83% of the sidewalks in the study area cannot host bioswales and rain gardens due to their narrow width, the latter practices were not considered as street greening practices. However, they were considered as potential typologies to be implemented in open and unbuilt spaces in the study area as discussed in subsequent sections.

a. Identifying Applicable Sidewalks for Bioretention Practices

The sidewalk width measurements taken to determine applicable sidewalks for street trees above, were also used in determining the potential sidewalks that could host bioretention practices. Similarly, all sidewalks that have a width that is less than 1.7m were eliminated to allow for smooth pedestrian movement.

Moreover, to take into consideration the standard width of the infiltration planter boxes (1m), the sidewalks that are 2.7m and wider were applicable only.

b. Selection of Opportunity Sidewalks for Bioretention Practices

For feasibility and practicality reasons, infiltration planter boxes can be developed around the pits of existing trees. Therefore, the opportunity for developing infiltration planter boxes in the study area will follow the opportunity results for street trees along the sidewalks that are equal to or wider than 2.7m only.

As such, the opportunity was based on a ratio that reflects the extent of developing infiltration planter boxes in the study area, whereby a higher opportunity means that a larger number of planter boxes could be added along the sidewalks.

The result is a map presented from ArcGIS that shows the opportunities for intervention to add infiltration planter along the applicable sidewalks in the study area.

5. Green Infrastructure in Open Spaces

The study area contains several large unbuilt open spaces that could host various green infrastructure practices such as trees, parks, bioretention practices, and permeable pavements in combination. These unbuilt spaces, if incorporated with green infrastructure can contribute highly to the provision of ecosystem services.

a. <u>Mapping Existing Unbuilt Spaces</u>

The unbuilt open spaces were identified at first by conducting field visits around the study area and then digitized on ArcGIS as either parking lots or vacant lots. The land tenure for each was also entered in the attributes table on ArcGIS using a map obtained from the Ile de France study for Beirut which shows the land ownership in the study area (Figure 36).

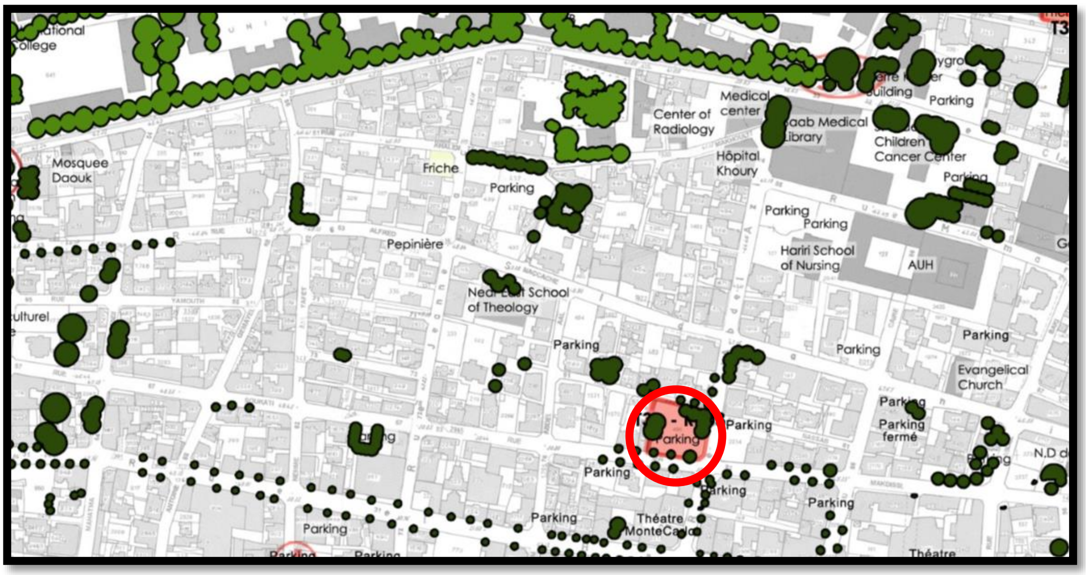

Figure 36 Map showing the municipal lots in Hamra district (circled in red) (Adapted from: Région Île-de-France & Bureau CGLU-BTVL, 2012)

b. <u>Identifying the Opportunity for Intervention</u>

For the purpose of retrofitting these unbuilt spaces with green infrastructure, the opportunity for intervention was based on the land tenure and land use of each, which can eventually facilitate the process. The classification of each unbuilt lot and its corresponding opportunity for intervention are presented in Table 12.

Table 12 Opportunity criteria for green infrastructure in open spaces

	Opportunity		
	High	**Medium**	**Low**
Land Use	Vacant Parking Lot	Vacant	Parking Lot
Land Tenure	Municipal	Private	Private

The result is an ArcGIS map that shows a range of intervention opportunities in unbuilt spaces in the study area, with the highest being in municipal lots.

6. Summary of Metrics for Green Infrastructure Typologies

A summary of the identification and selection of potential and suitable spaces for the above green infrastructure is presented in Table 13 showing that the values of opportunity (low, medium, and high) are the common evaluation values across varying metric units.

Table 13 Summary of the opportunity criteria for each green infrastructure practice

Green Infrastructure Typology	**Potential Space or Surface**	**Opportunity Criteria / Metrics**	**Opportunity for Implementation**
Green Roofs	Flat building roofs	< 500m^2 free roof space	Low
		500-1000 m^2 free roof space	Medium
		>1000 m^2 free roof space	High
Green Walls	Building walls with adjacent soil	- Glass façade - Wall facing any orientation	Low
		- Non-glass façade - Wall orientation towards north	Medium
		- Non-glass façade - Wall orientation towards south/east/west	High

Street Trees	Sidewalks (width ≥2.5m)	Ratio of new to existing trees < 1	Low
		Ratio of new to existing trees = 1	Medium
		Ratio of new to existing trees > 1	High
Infiltration Planter Boxes	Sidewalks (width ≥2.7m)	Ratio of new to existing trees < 1	Low
		Ratio of new to existing trees = 1	Medium
		Ratio of new to existing trees > 1	High
Multiple GI Practices in Open Spaces	Undeveloped lots	Private parking lots	Low
		Private vacant lots	Medium
		Municipal parking/ vacant lots	High

Table 13 will inform a combined and overall spatial strategy that can be implemented using the green infrastructure typologies and based on the identified opportunities.

7. Identifying Opportunity Zones for Green Infrastructure

By developing spatial opportunity maps for each of the five green infrastructure typologies, it was possible to develop a combined map for each typology having a similar opportunity level. This would eventually identify the overall urban morphology that can enhance the development of green infrastructure projects in an urban neighborhood.

To do so, three maps were generated using ArcGIS that present the combined high, medium, and low opportunity spaces for all the green infrastructure typologies. Using these three maps, green infrastructure opportunity zones were identified in the study area. The opportunity zones were categorized as high, medium, or low based on the number of green infrastructure typologies a zone hosts. The zones were primarily identified for being areas that either include a concentration of green infrastructure typologies or areas that do not provide suitable locations for a variety of green infrastructure typologies. (Table 14)

Table 14 Opportunity zones criteria for green infrastructure typologies

Zone Opportunity for Green Infrastructure	**Number of Green Infrastructure Typologies Available**
High	3+
Medium	2
Low	1

Consequently, by classifying the opportunities for green infrastructure in these zones, it would be possible to define the urban morphologies that can either support or limit the development of green infrastructure projects in them. In both cases this should entail future municipal action to promote the development of green infrastructure in Beirut, as explained in the subsequent section.

C. Suggest Municipal Green Infrastructure Guidelines

This final phase of the research targets suggesting specific guidelines to be adopted on the municipal scale in Beirut in order to promote the development and implementation of green infrastructure by the municipality and the communities within the city.

Based on the data results, the spatial strategy, and analyzing the literature (governmental reports, journal articles, and legislations) explored in Chapter II of this research related to green infrastructure governance and policies, the following was conducted to devise the municipal guidelines for urban green infrastructure in Beirut as a suggested upscaling from the case study neighborhood.

1. Exploring the Drivers

Reviewing the literature to explore some of the major environmental problems that Beirut suffers from, which could also be ameliorated through urban green infrastructure practices. The environmental and health impacts arising from these problems should in turn act as the drivers that urge the municipality to consider green infrastructure as a viable option to minimize their effect.

2. Identifying the Goals

Based on the identified benefits of urban green infrastructure in the literature, context-specific goals for developing a municipal green infrastructure program in Beirut are discussed. These goals vary between environmental, social, health, and economic goals.

3. Suggesting Specific Municipal Policy Guidelines and Tools

Promoting the use of urban green infrastructure practices in Beirut requires specific changes to the way that the municipality of Beirut is currently functioning as well as new methods/means to approaching green infrastructure implementation. Moreover, since the Lebanese regulations related to urban greening (explored in Chapter II) can play a vital role in enhancing the use of green infrastructure in Beirut and elsewhere in Lebanon, certain amendments to these regulations are suggested for this purpose. Based on the aforementioned the following was covered:

- The need for gathering and compiling comprehensive baseline data on Beirut for accurate future planning for green infrastructure.
- The suggested administrative changes within the municipality of Beirut.

- The suggested adjustments to some Lebanese regulation that can have an effect on urban green infrastructure development in Beirut.
- Potential policy programs that could be adopted by the municipality.
- Transforming the top-down approach usually followed by the municipality of Beirut to become a bottom-up approach by involving a transdisciplinary body of stakeholders in planning, reviewing, and managing green infrastructure projects to be developed in the city.

4. *Identifying Opportunities for Stakeholders Involvement in Developing Green Infrastructure*

After identifying and suggesting municipal policy guidelines and tools that can facilitate the implementation of green infrastructure in Beirut, a rapid assessment was conducted of the potential public and private stakeholders that can play a role in supporting, planning, financing, and implementing green infrastructure programs in the case study neighborhood in specific and all over Beirut in general, based on their technical, financial, and political capabilities and willingness. An opportunity (high, medium, or low) was assigned to each stakeholder based on the number of criteria (technical capabilities, financial capabilities, political capabilities, and willingness to support) they meet, with one being the low opportunity and more than three being the high opportunity.

CHAPTER IV

RESULTS

A. Opportunity for Green Roofs

The search for potential roofs that could be retrofitted with green roofs in the study area following the method explained in Chapter III revealed that 83% of the buildings have free roof space of varying areas.

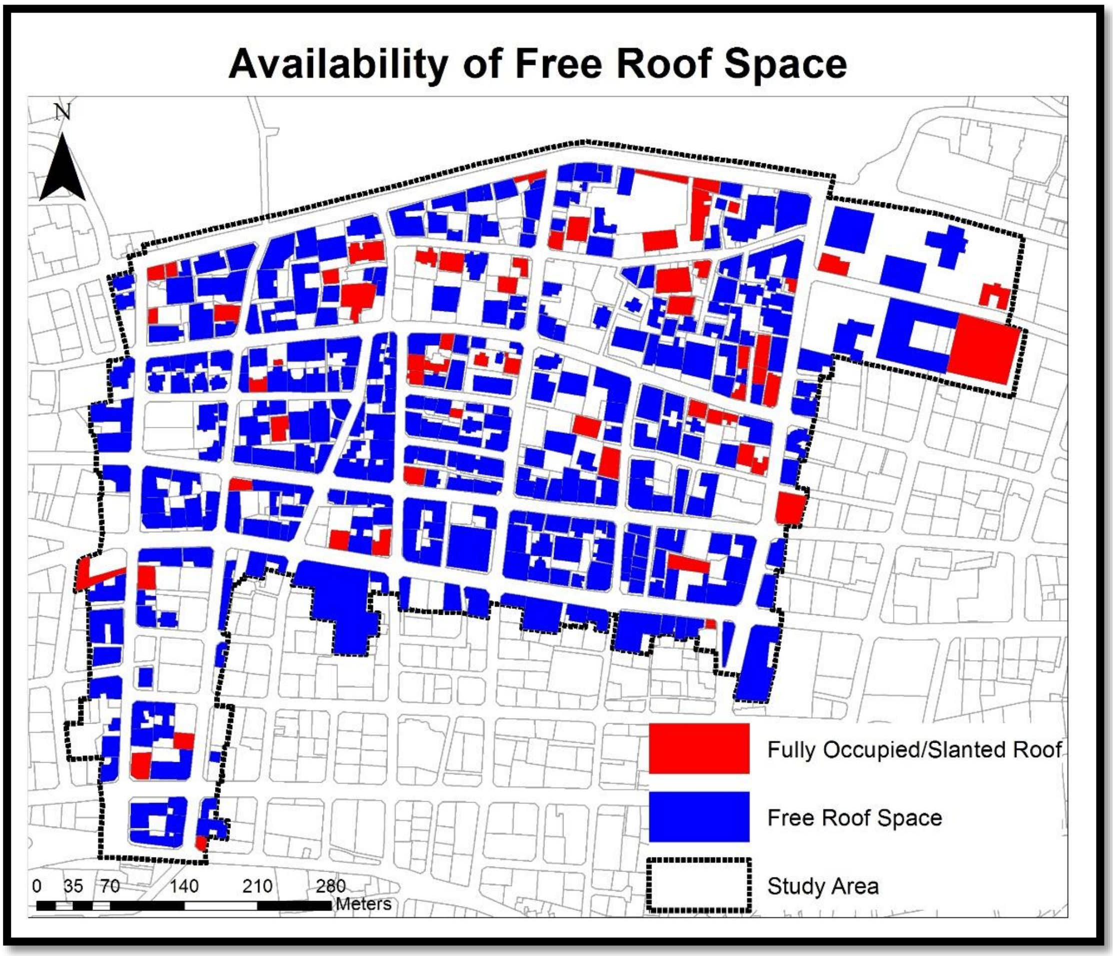

Figure 37 Distribution of buildings with free roof space

From the buildings identified in Figure 37 as having free roof space, the opportunity of each for being retrofitted with an extensive green roof was based on the area of the free roof space. Figure 38 shows the opportunity for extensive green roofs for each building, whereby a roof having a free space higher than 1000m^2 was considered as highly suitable in terms of financial feasibility as per the cost-benefit studies explored in the literature. The twelve (12) high opportunity roofs in the study area are primarily buildings associated with AUBMC and a couple of others near it. Additionally some high opportunity roofs are concentrated along Hamra Street. On the other hand, medium opportunity roofs are mainly concentrated in the western part of the case study area. Low opportunity roofs are scattered all around the neighborhood, and they compose the largest number of roofs given that most of the buildings are small in size, and many residents use the roofs for placing the AC units, water tanks, and other materials.

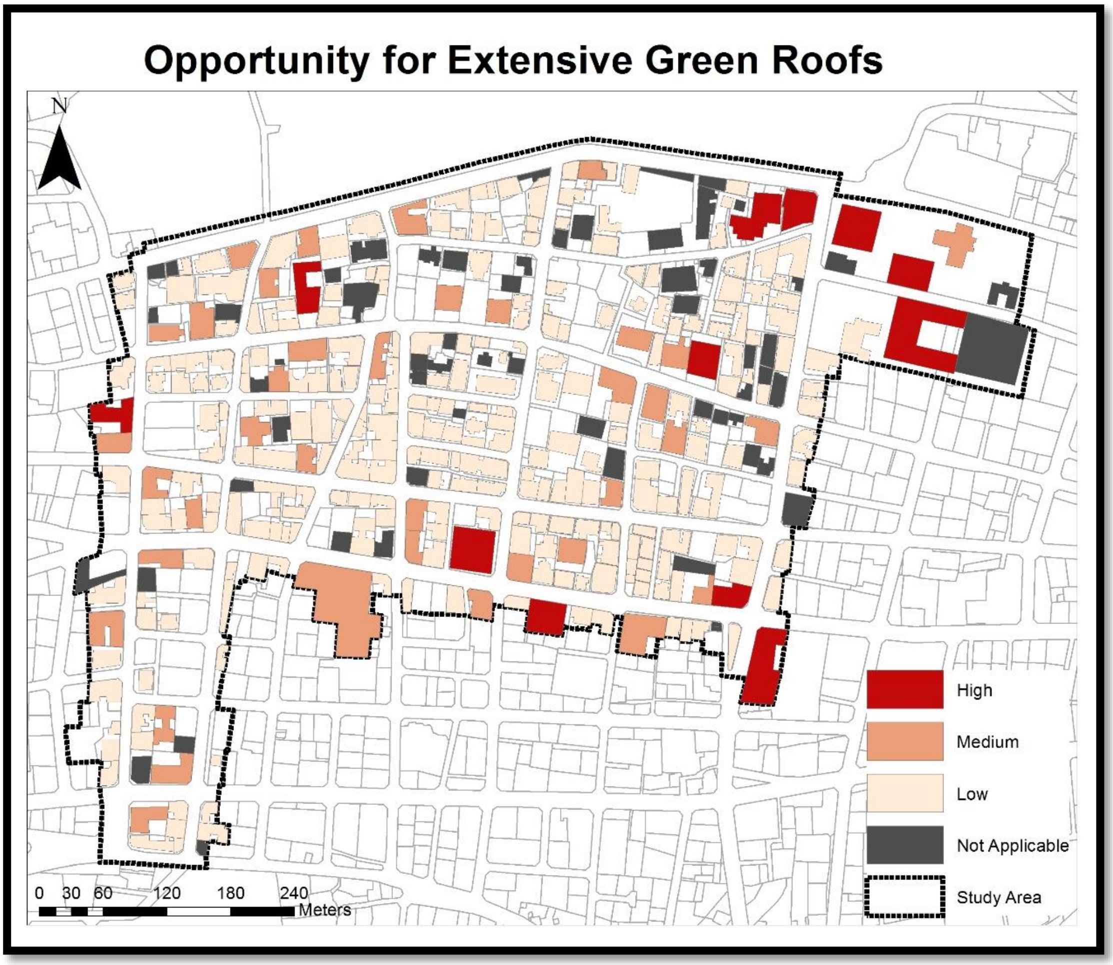

Figure 38 Opportunity for developing extensive green roofs

Hence, with a total area of 143,298m^2 of total roof space in the study area, an area of 105,301 m^2 could be retrofitted with extensive green roofs in varying levels of opportunity as shown in Table 15.

Table 15 Distribution of the roof space as per the opportunity for extensive green roofs

	Opportunity for Extensive Green Roofs			
	Low	Medium	High	Not Applicable
Area (m^2)	61,587 m^2	25,158 m^2	18,556 m^2	37,997 m^2
Percentage (out of free roof space)	58.5%	24%	17.5%	0%
Percentage (out of total roof space)	43%	17.5%	13%	26.5%

B. Opportunity for Green Walls

Adding direct green walls (surface climbers) around the study area was limited by three factors: 1) the façade of the buildings, 2) the availability of pervious surfaces (soil) directly adjacent to the building wall, and 3) the orientation of the wall that determines the amount of sunlight exposure.

Prior to identifying potential spaces for direct green walls, it was important to highlight the existing green walls in the study area that were observed while conducting the field visits. The study area was found to include a few green walls that varied in type, some seemed accidently/naturally growing while others were intentionally planted and properly maintained. The distribution, location, and type of the existing green walls in the study area are shown in Figure 39.

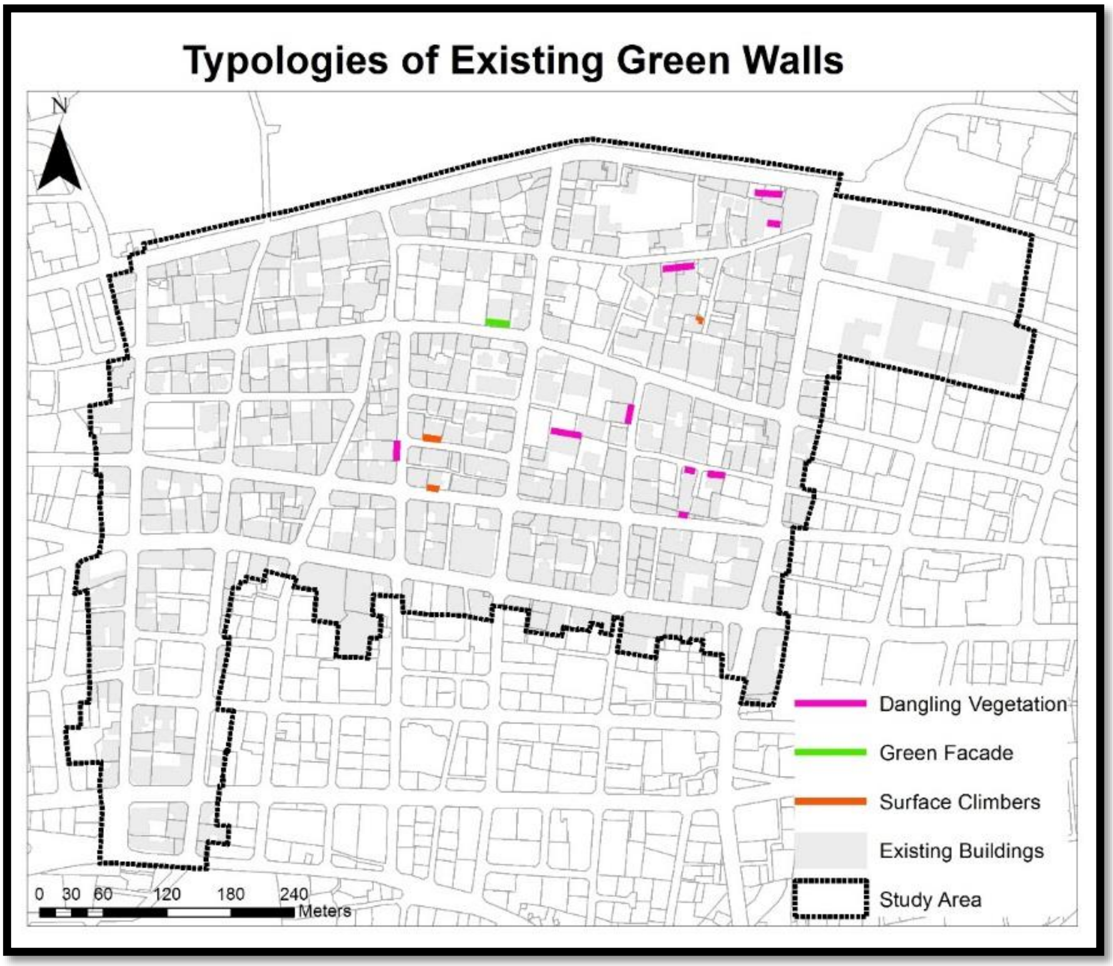

Figure 39 Distribution of the different types of existing green walls in the study area

Those observed were either direct surface climbers, green façades, or dangling vegetation from the buildings' balconies or wall planters (Figures 40, 41, and 42).

Figure 40 Existing direct green walls in the study area

Figure 41 Existing building with a green facade and dangling vegetation

Figure 42 Existing building with dangling vegetation from wall planters

On the other hand, the first step in determining the potential locations for direct green walls around the study area aimed to categorize the existing buildings based on their exterior façade. The field visits conducted resulted in categorizing the major type of the buildings' facades into six different categories by façade material as explained in Chapter III and shown in Figure 44. The number of buildings having the same façade material is shown in Table 16. It is noteworthy to mention, that the façade of the buildings with exiting green walls identified earlier were not included in this map.

Figure 43 Examples of building facades material

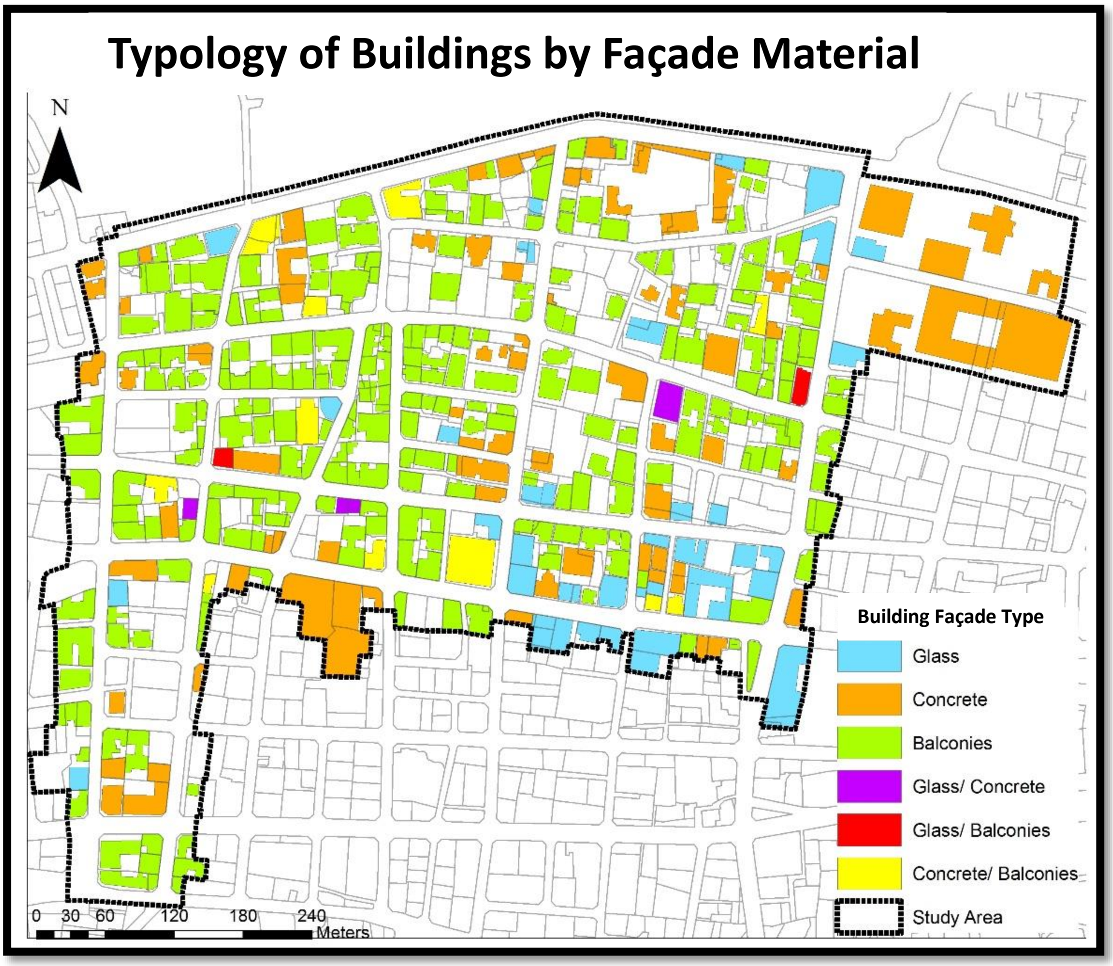

Figure 44 Types building façade material in the study area

Table 16 Number of buildings of each facade material type

Façade Material Type	**Number of Buildings**
Glass	37
Concrete	77
Balconies	232
Mixed (Glass/ Concrete)	3
Mixed (Glass/ Balcony)	2
Mixed (Concrete/ Balcony)	11

The next step was also based on the field visits around the study area to assign the location of available soil patches that are directly adjacent to the building walls. Figure 45 below shows the location of each.

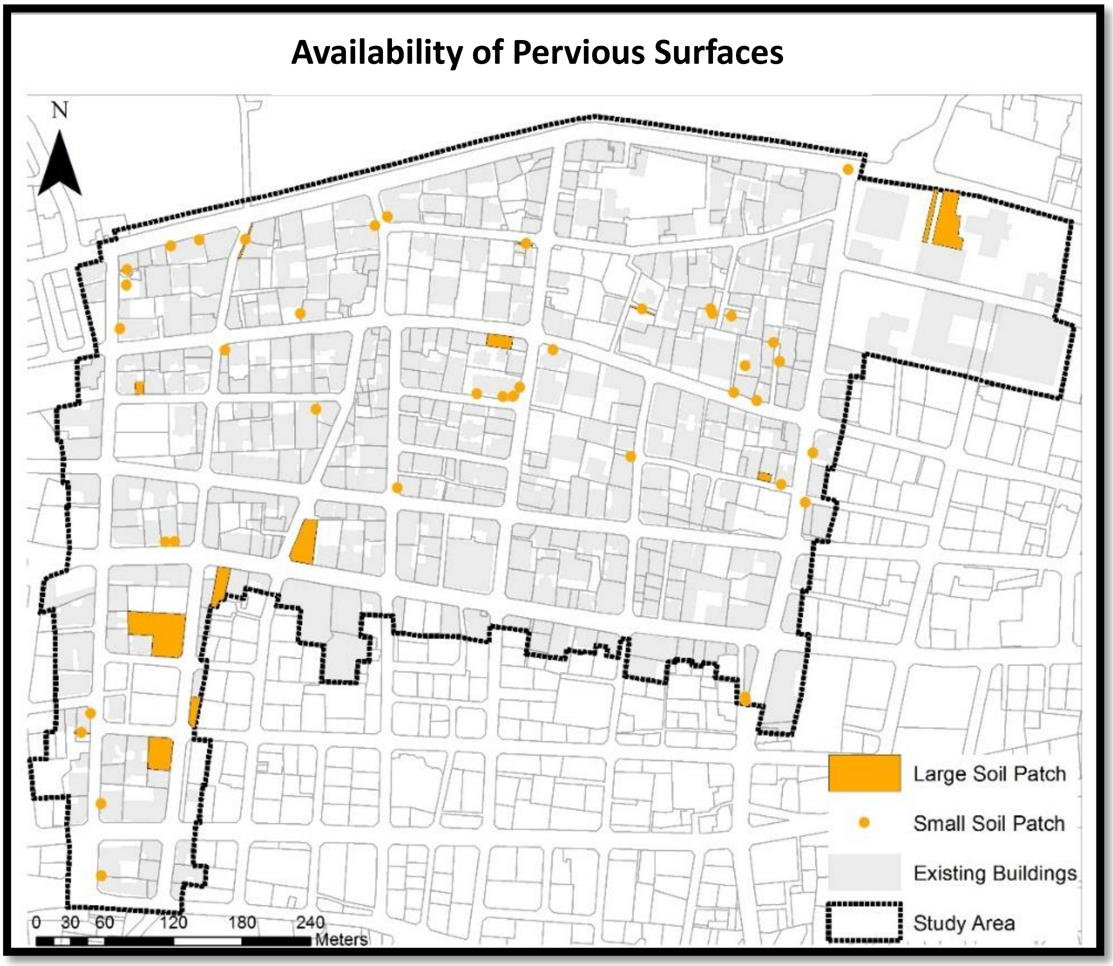

Figure 45 Availability of pervious surfaces in the study area

As explained in Chapter III, large pervious surfaces were digitized as polygons, whereas small pervious surfaces were digitized as point locations. The respective number and area of each is shown in Table 17.

Table 17 Number and area of existing pervious surfaces

	Number	**Area (m^2)**
Large Pervious Surface	15	4,751
Small Pervious Surfaces	40	360
Total	55	5,111

Finally, the orientation of each building wall was mapped using ArcGIS resulting in the Figure 46.

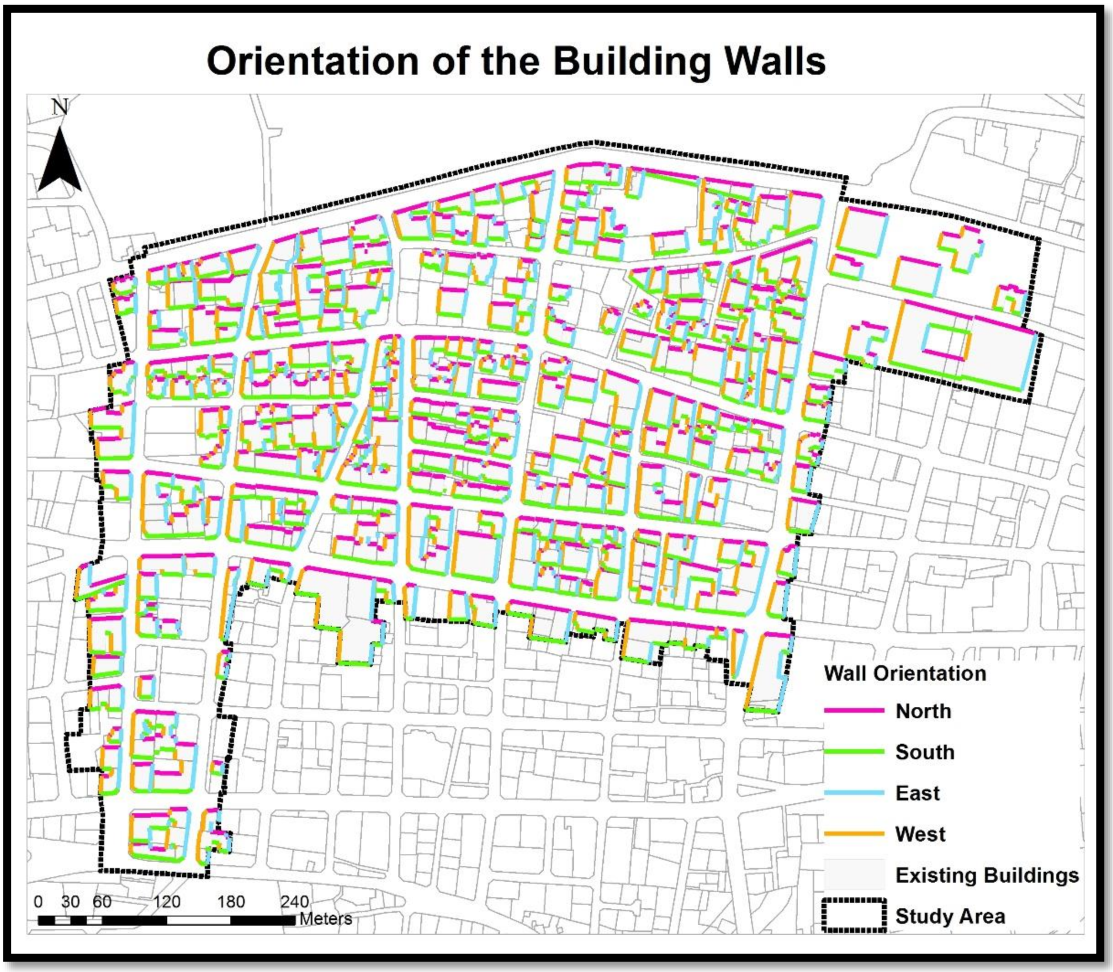

Figure 46 Orientation of the building walls in the study area

By considering all the three preceding criteria, the opportunity for growing direct green walls around the study area was assigned for each building wall where soil was readily available next to it as explained in Chapter III. All other building walls that did not have adjacent pervious surfaces were not applicable. Figure 47 shows the opportunity for each, whereby a high opportunity wall is a building wall that does not have a glass façade and is not north-oriented. Medium opportunity walls do not have a glass façade but are north-oriented, and lastly low opportunity walls are characterized by having a glass façade.

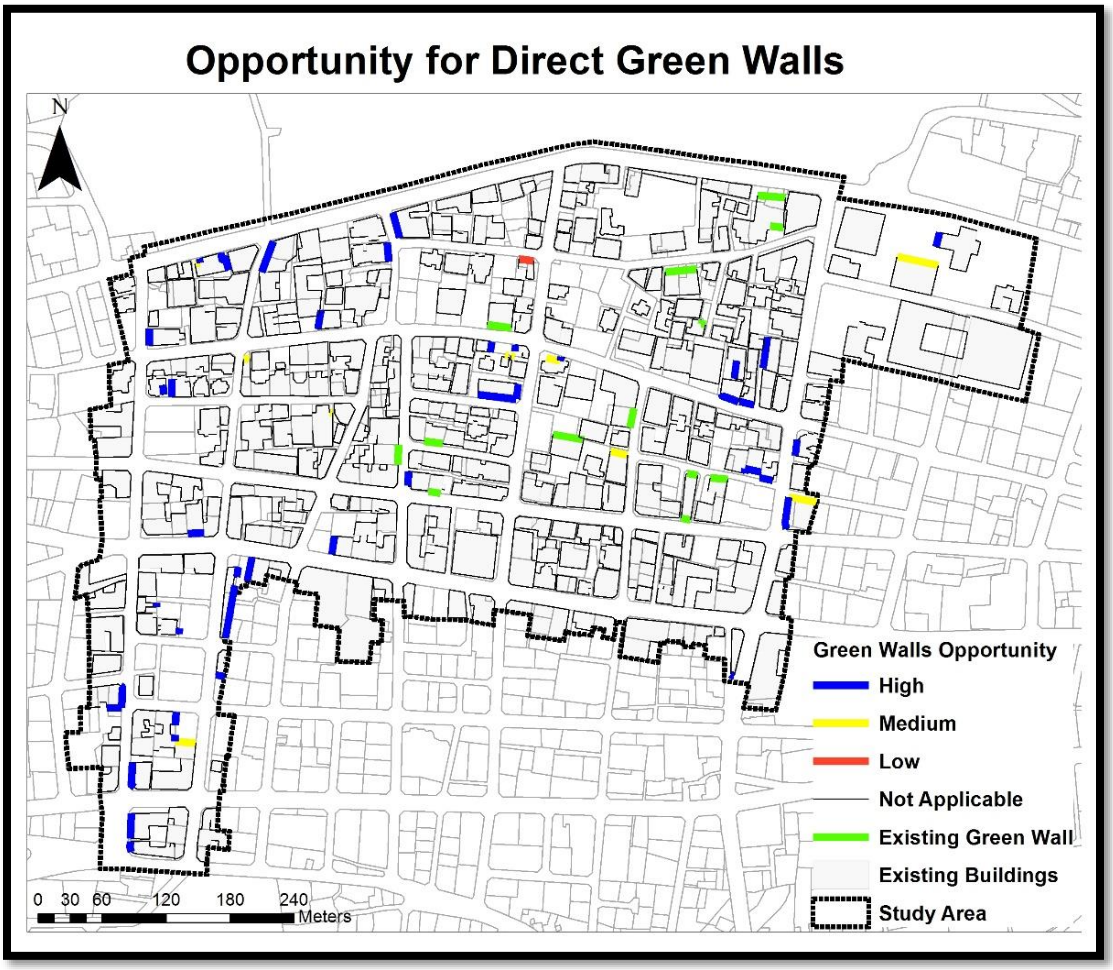

Figure 47 Opportunity for developing direct green walls

Thus, the search for potential locations for green walls resulted in qualifying 53 locations in the study area, out of which 41 are highly suitable since they meet the optimal conditions (building exterior façade material, availability of pervious surface, and sun exposure) allowing the adequate growth of surface climbers. Most of the high opportunity locations identified are located in the west and east section of the study area near Sadat and Bliss Street; and Abdul Aziz Street respectively. The only low opportunity location is located at the intersection of Jean d'Arc Street and Khalidi Street.

It is also noteworthy to mention that from the results attained above, 232 buildings (62%) out of the 377 total buildings in the study area have balconies, thus encouraging balcony greening initiatives using potted dangling plants is highly recommended given the nature of the building designs in the area.

C. Opportunity for Street Trees

Mapping the street trees in the study area was completed by conducting field visits in the beginning to count and pinpoint the actual location of each tree, then the data gathered was entered into ArcGIS (Figure 48). After compiling all the data, it was evident that the presence of street trees along the sidewalks in the study area was not consistent. Sidewalks in Hamra and Yamout Street, as well as parts of Sidani and Makdisi Street have the highest existing tree cover. On the other hand, sidewalks in Bliss and Antoun Gemayel Streets were completely bare. It was also noted that the spacing between the planted trees was not unified and did not follow a certain spacing guideline.

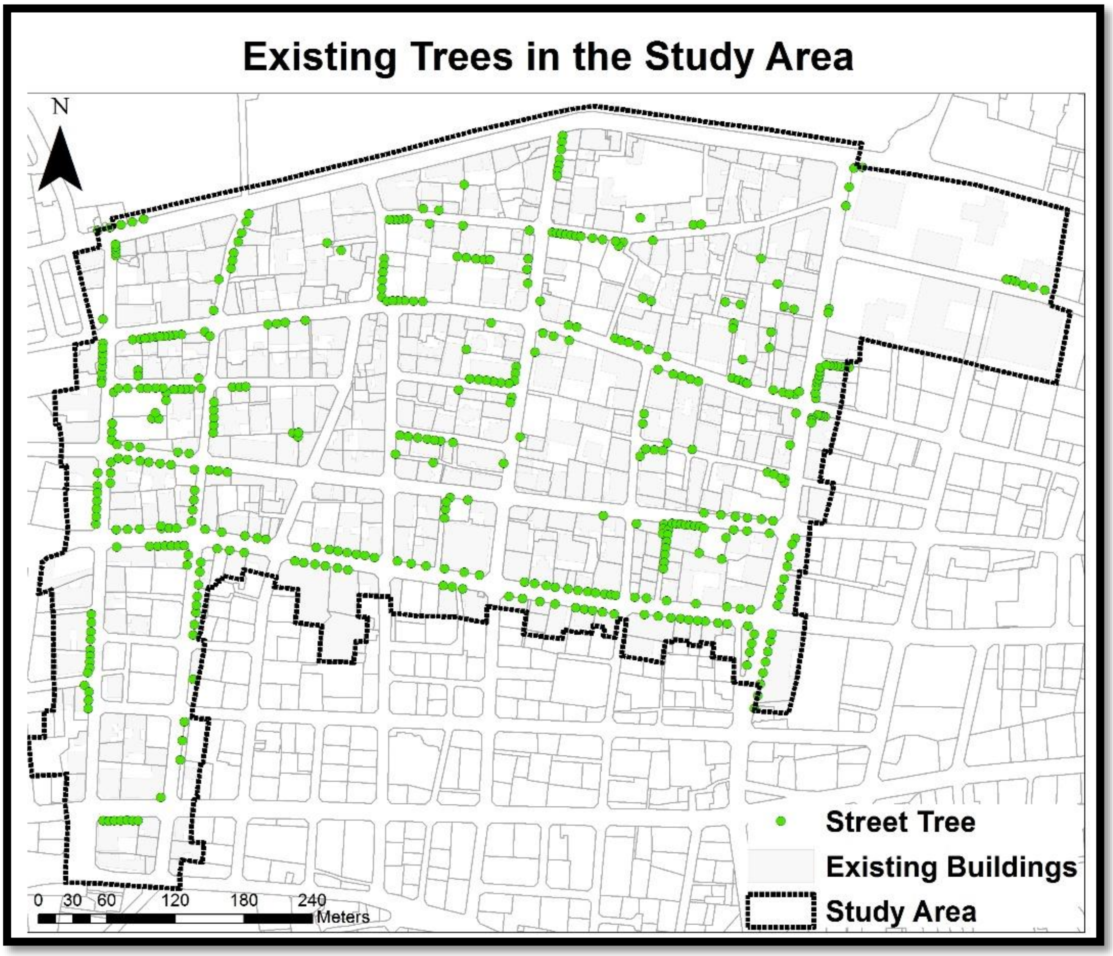

Figure 48 Distribution of existing street trees in the study area

Planting trees on urban sidewalks greatly depends on the width of the sidewalks. Trees along the sidewalks require space and thus can interfere with pedestrian movement. For this reason another round of field visits in the study was conducted to measure the width of the existing sidewalks using a tape meter. Figure 49 below shows the different sidewalk width ranges in the study area. The widest sidewalks (wider than 3 meters) are primarily located along Hamra Street which reflects its commercial nature and attractiveness to a high number of visitors. A part of Abdul Aziz Street that is near Hamra Street has relatively wide sidewalks as well. To a lesser extent Bliss Street also has wide sidewalks so that they can accommodate the high influx of AUB staff and students every day. As for the majority of the remaining streets their sidewalks are below 2 meters wide as they are secondary or tertiary streets of lower commercial significance compared to the other major streets in the study area. The mean width of the sidewalks, as generated using ArcGIS, is 2 meters. Figure 50 shows examples of different sidewalk width ranges existing in the study area,

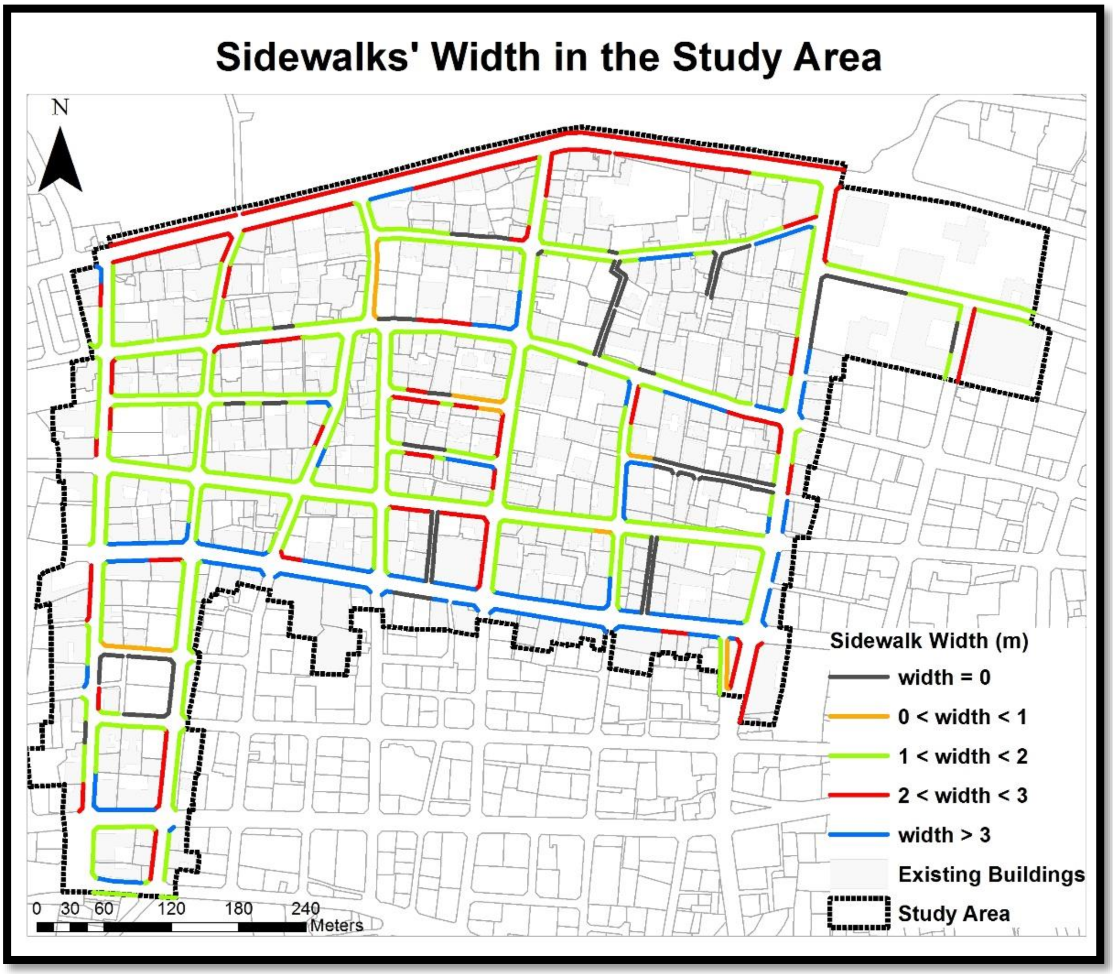

Figure 49 Existing sidewalk width ranges in the study area

Figure 50 Examples of sidewalks in the study area

By acquiring data on the width of the existing sidewalks, a new shortlisted pool of applicable sidewalks for street trees was generated, whereby only sidewalks that are equal to or wider than 2.5m are applicable. This specific figure was considered to allow a remaining width of at least 1.5m unobstructed pathway in addition to taking into account the 0.2m wide sidewalk curb, and the tree pit size (0.8x0.8m). The result is depicted in Figure 51. From the total measured sidewalks, only 28% were applicable for greening using street trees. These sidewalks are mainly located along Hamra Street, Bliss Street, and parts of Abdul Aziz; Sidani; Jean d’Arc, and Sadat Street.

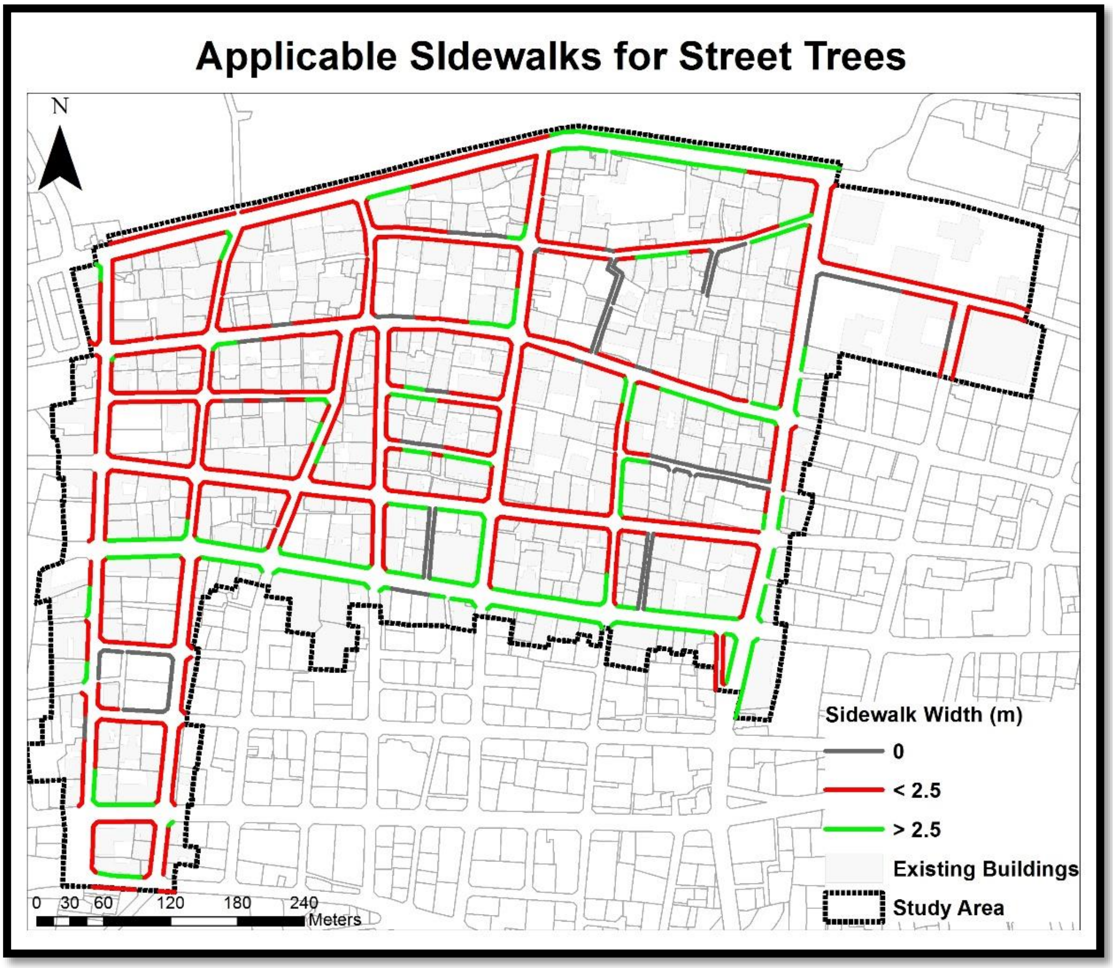

Figure 51 Distribution of sidewalks applicable for street trees (width>2.5m)

Following the method elaborated in Chapter III, the applicable sidewalks identified above were divided into three opportunity categories based on a ratio that reflects the number of new trees to be added with respect to the total length of the sidewalk. The larger the number of trees that could be planted along the total length of the sidewalk, signifies a higher opportunity. The opportunity map for street trees is presented in Figure 52, and the number of sidewalks pertaining the same ratios is shown in Table 18.

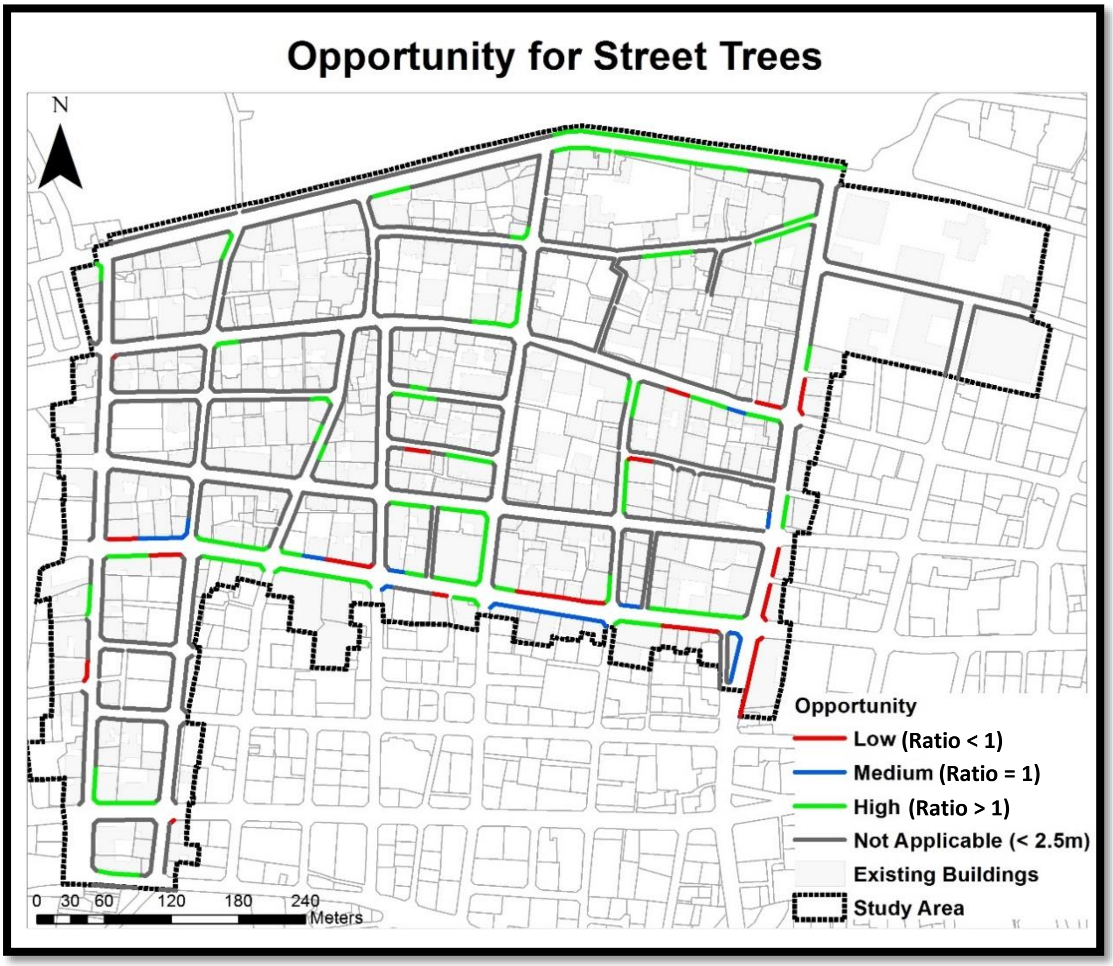

Figure 52 Opportunity for planting street trees

Table 18 Number of sidewalks and their respective opportunities for street trees

Opportunity (ratio)	Low (<1)	Medium (=1)	High (>1)
Nb. of sidewalks	19	11	48

The opportunity for greening sidewalks as identified is mainly located along the sidewalks in the study area that are deficient in trees or completely bare. High opportunity sidewalks are predominantly those along the main streets of Hamra and Bliss. Others are also located along secondary streets in the middle of the study area. Low opportunity sidewalks, like those located along Abdul Aziz Street and some sections of Hamra Street reflects that the number of trees to be added is low with respect to the length of the sidewalk, and given that some of these sidewalks are already covered with trees. Table 19, illustrates an example from the field on how different applicable sidewalks located along Hamra Street of equal number of trees and close lengths differ in opportunity.

Table 19 Field example of sidewalks of different opportunities

	Length (m)	**Nb. of existing trees**	**Nb. of trees that can be added**	**Ratio**	**Opportunity**
Sidewalk 1	44	5	2	0.4	Low
Sidewalk 2	59	5	5	1	Medium
Sidewalk 3	69	5	7	1.4	High

D. Opportunity for Bioretention Practices

The addition of infiltration planter boxes along the streets was also dependent on the width of the sidewalks so that not to disrupt pedestrian movement. Bearing in mind the narrowest width of the planter should be 1m, as well as the required unobstructed pathway is 1.5m, and the sidewalk curb that is 0.2m, all the sidewalks which are equal to or wider than 2.7m are applicable to host infiltration planter boxes as illustrated in Figure 53.

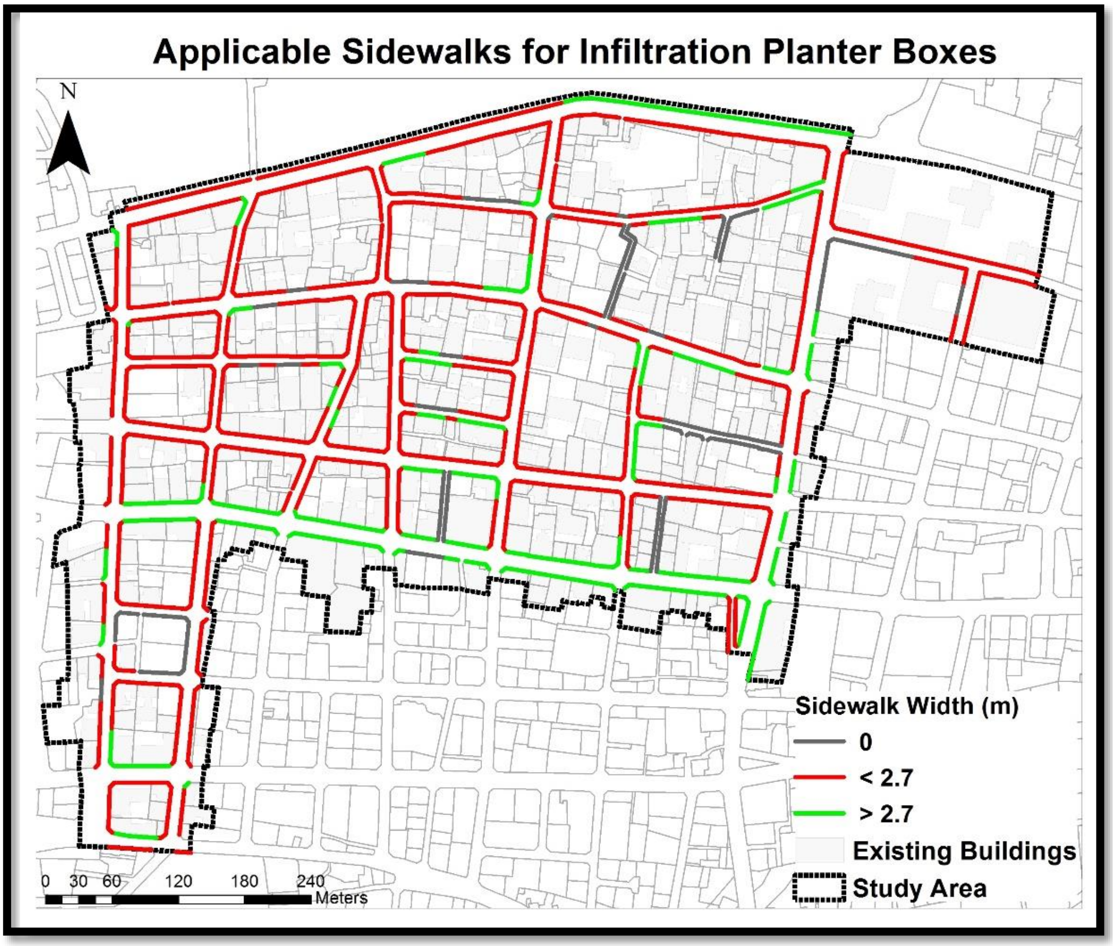

Figure 53 Distribution of sidewalks applicable for infiltration planter boxes

The resulting opportunity map for infiltration planters was formulated on the basis of the previous opportunities for street trees, since they will be developed around the tree pits of existing or additional trees to be planted along the applicable sidewalks (width ≥2.7m). Thus, the ratio of new trees to be added to the existing number of trees determined whether the opportunity to develop infiltration planters was high, medium, or low, as explained in Table 10 above. This method was followed to identify the sidewalks that could host the maximum number of planters. The resulting opportunity map is shown in Figure 54.

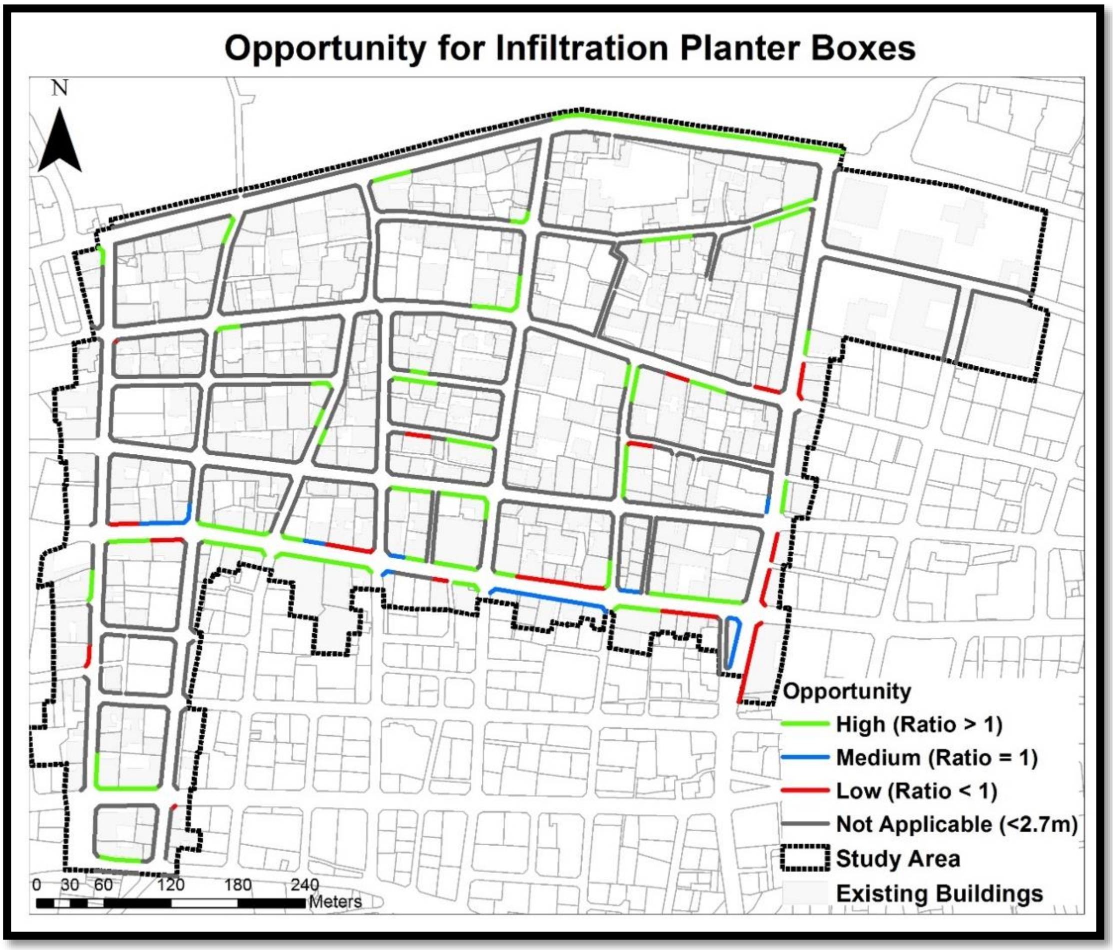

Figure 54 Opportunity for developing bioretention practices

Table 20 Number of sidewalks and their respective opportunities for infiltration planter boxes

Opportunity (ratio)	**Low (<1)**	**Medium (=1)**	**High (>1)**
Nb. of sidewalks	19	10	44

Thus, it is evident from the map and Table 20, that most of the sidewalks that are applicable for greening using infiltration planter boxes have a high opportunity. These sidewalks are mainly concentrated along Hamra Street and the eastern part of Bliss Street. Most of the remaining high opportunity sidewalks are concentrated at the center of the study area, between Sidani Street and Hamra Street. Medium and low opportunity sidewalks are primarily located along Hamra and part of Abdul Aziz Street, reflecting a low number of trees that could be added along them due to the presence of a high number of existing trees along these sidewalks.

E. Opportunity for Green Infrastructure in Open Spaces

The available open spaces in the study area provide an opportunity to host different typologies of urban green infrastructure at once. The total area of the open spaces in the study area amounts to 20,976m^2 distributed over parking lots (18,000m^2) and vacant lots (2,976m^2). The parking lots are scattered all around the study area, while the vacant lots are concentrated in a close area to the west of the study area. The land tenure of these spaces is dominantly private, except one parking lot located on Abdul Aziz Street which is publicly owned by the municipality as shown in Figures 55 and 56.

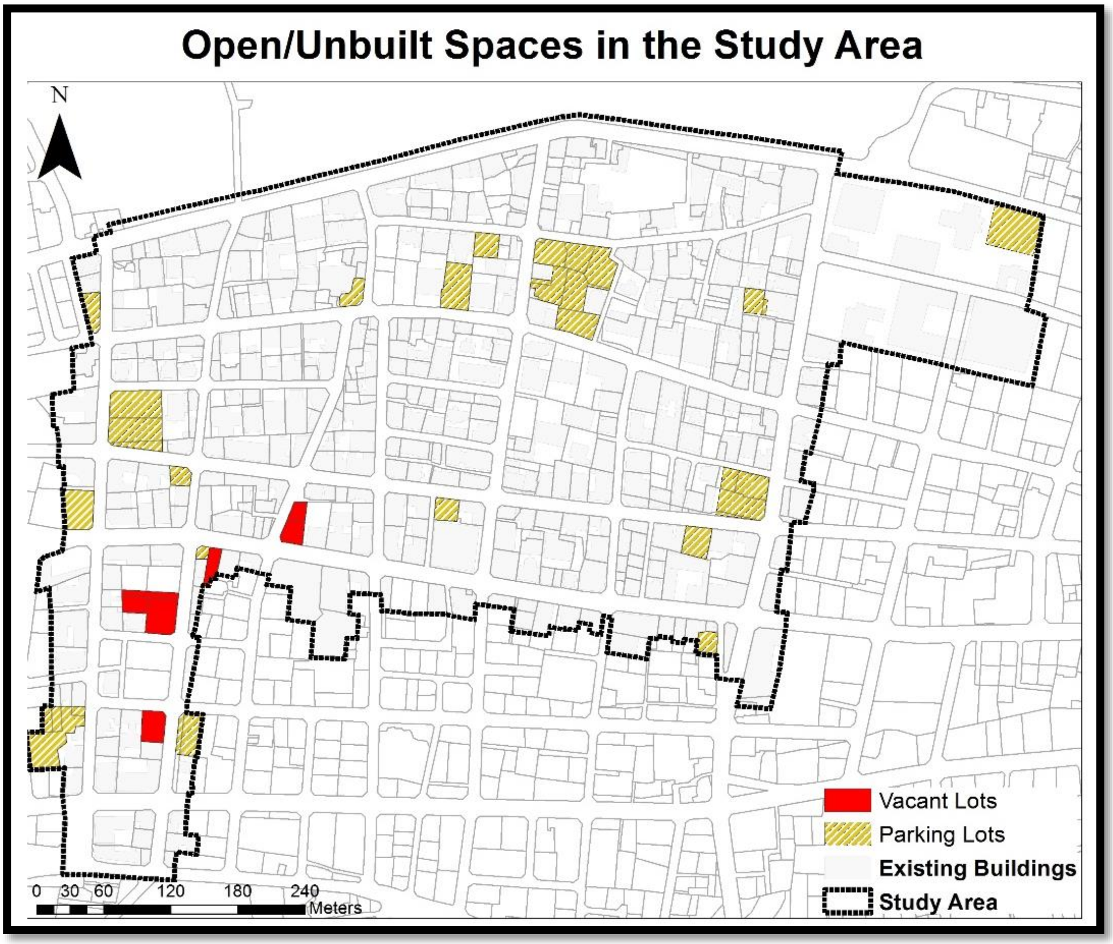

Figure 55 Distribution and type of the open/unbuilt spaces in the study area

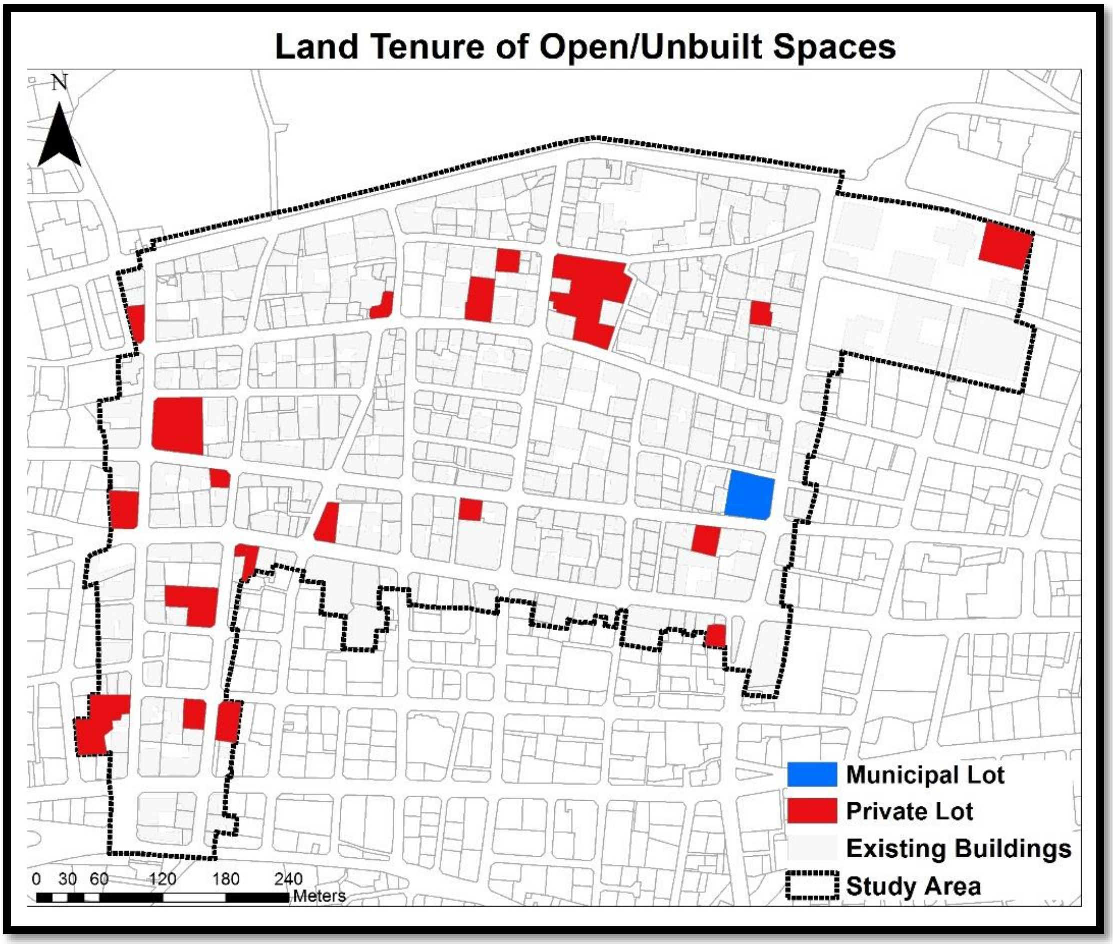

Figure 56 Land tenure of the open/unbuilt spaces in the study area

Based on the methodology proposed in Chapter III, the opportunity for implementing green infrastructure in the identified open spaces was based on two criteria, the land use and land tenure of the respective lot. Figure 57 shows the opportunities of the different open spaces in the study area.

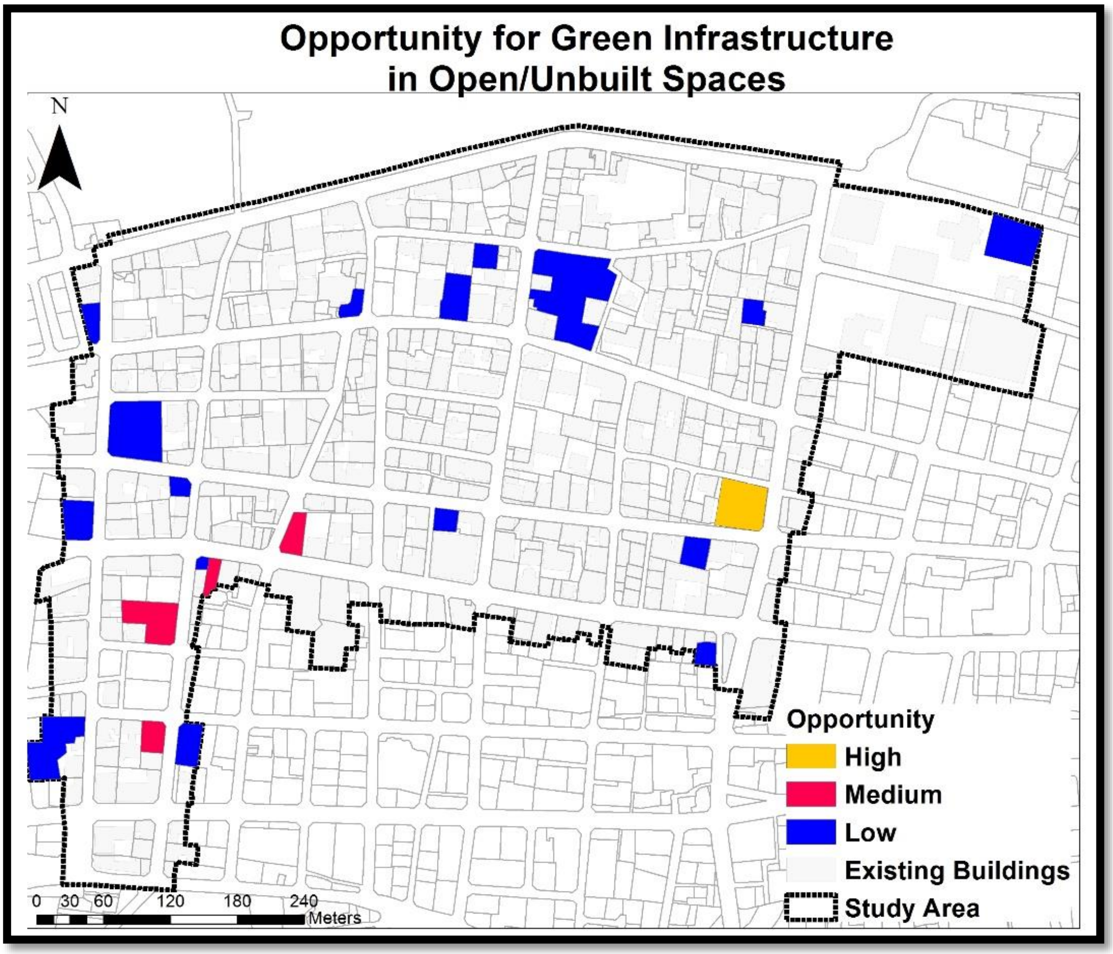

Figure 57 Opportunity for developing green infrastructure in open/unbuilt spaces

The municipal parking lot was considered as highly potential since it is owned by the municipality, thus modifying its land use to a green space or retrofitting the existing parking with green infrastructure would be much easier and attainable. As for the other lots, private vacant lots have a medium opportunity for green infrastructure since they could be leased to or bought by the municipality and redesigned as public neighborhood parks. On the other hand, these undeveloped spaces currently function as green infrastructure to a certain extent since they are pervious and host natural vegetation. However, if no municipal action was taken they remain highly susceptible to being replaced by new buildings, Lastly, private parking lots were considered as having a low opportunity since they are highly susceptible to change, and they are considered as a source of income to their owners until new building are erected instead, as is the case with most of the parking lots in Beirut. The only action to be taken in this case by the municipality, if not purchased and changed to green infrastructure, is enforcing the owners to transform into green parking lots by planting trees, adding bioswales or rain gardens, and retrofitting them by permeable surfaces.

Therefore, one could comprehend from the above that the opportunity of developing urban green infrastructure in the open spaces in the study area is possible in all the lots regardless of their use and tenure. However, this requires direct municipal intervention which can protect these lots from further development and transform them into green spaces, or enforce the private landowners to follow green design standards based on green infrastructure features.

F. Other Green Infrastructure Practices

When considering the remaining green infrastructure practices, such as permeable pavements and rainwater harvesting, the latter practices do not require space for implementation. Current sidewalk edges and parking lots could be retrofitted with permeable pavements to improve stormwater management across the whole case study area, but this would require municipal investments. As for the rainwater harvesting techniques using barrels for instance, which do not require major space, they could be installed in all buildings to increase water availability for households. In this case, municipal incentives will be needed for wide implementation by the residents.

Downspout disconnection, is a practice that was encountered in the literature but is not applicable in Lebanon, since none of the households directly link there downspouts to the existing stormwater pipe network. However one option to consider in the study area, is that downspouts should release the stormwater captured onto permeable areas or in areas adjacent to the planned on the ground green infrastructure practices mentioned above so that to reduce the amount of stormwater runoff flowing on the streets and increase stormwater infiltration into the ground. In this sense, the municipality could survey the buildings and require changes, in addition to adding this issue as a requirement to acquire a construction permit.

G. Opportunity Zones for Green Infrastructure

Based on the opportunity maps for each green infrastructure typology generated from the previous sections the following maps are presented in Figures 58, 59, and 60 that show the high, medium, and low opportunities for green infrastructure typologies in the study area respectively.

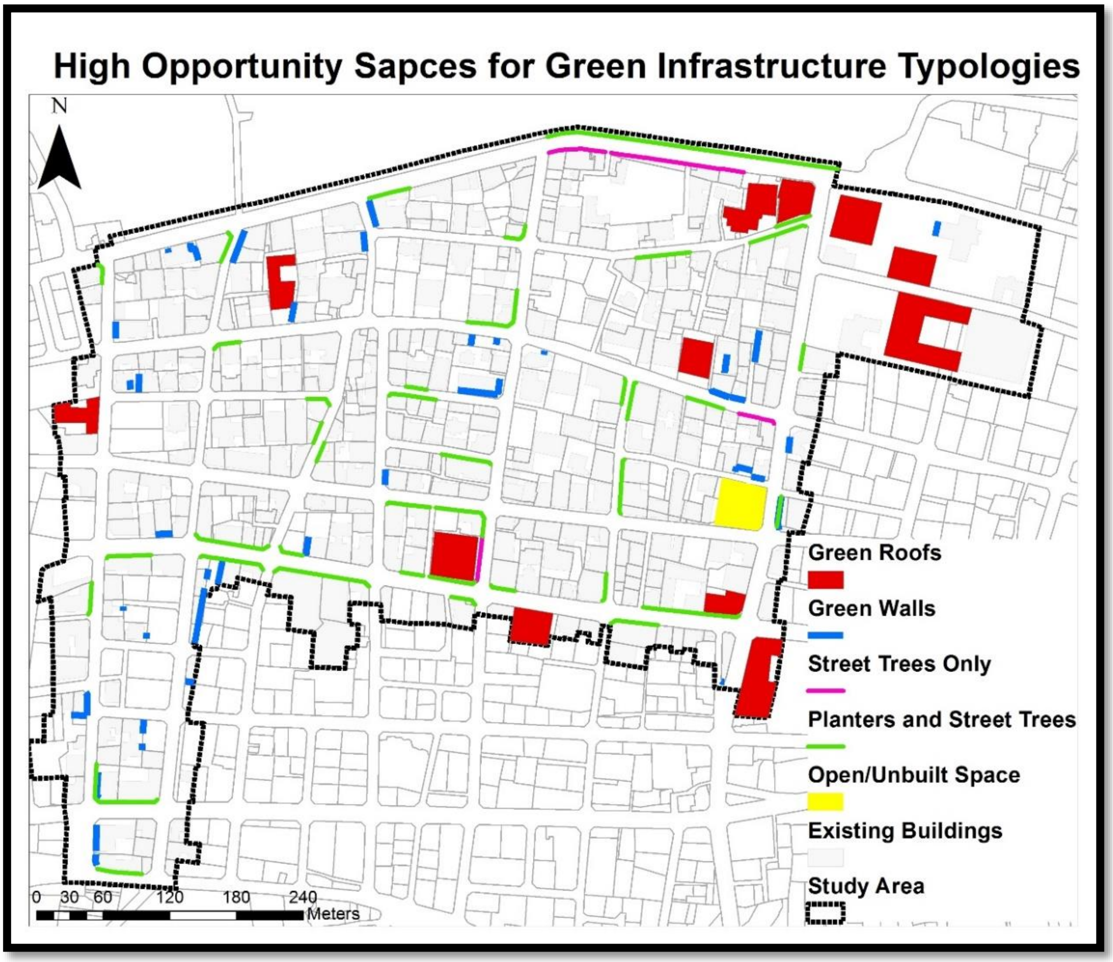

Figure 58 High opportunity map for all green infrastructure typologies

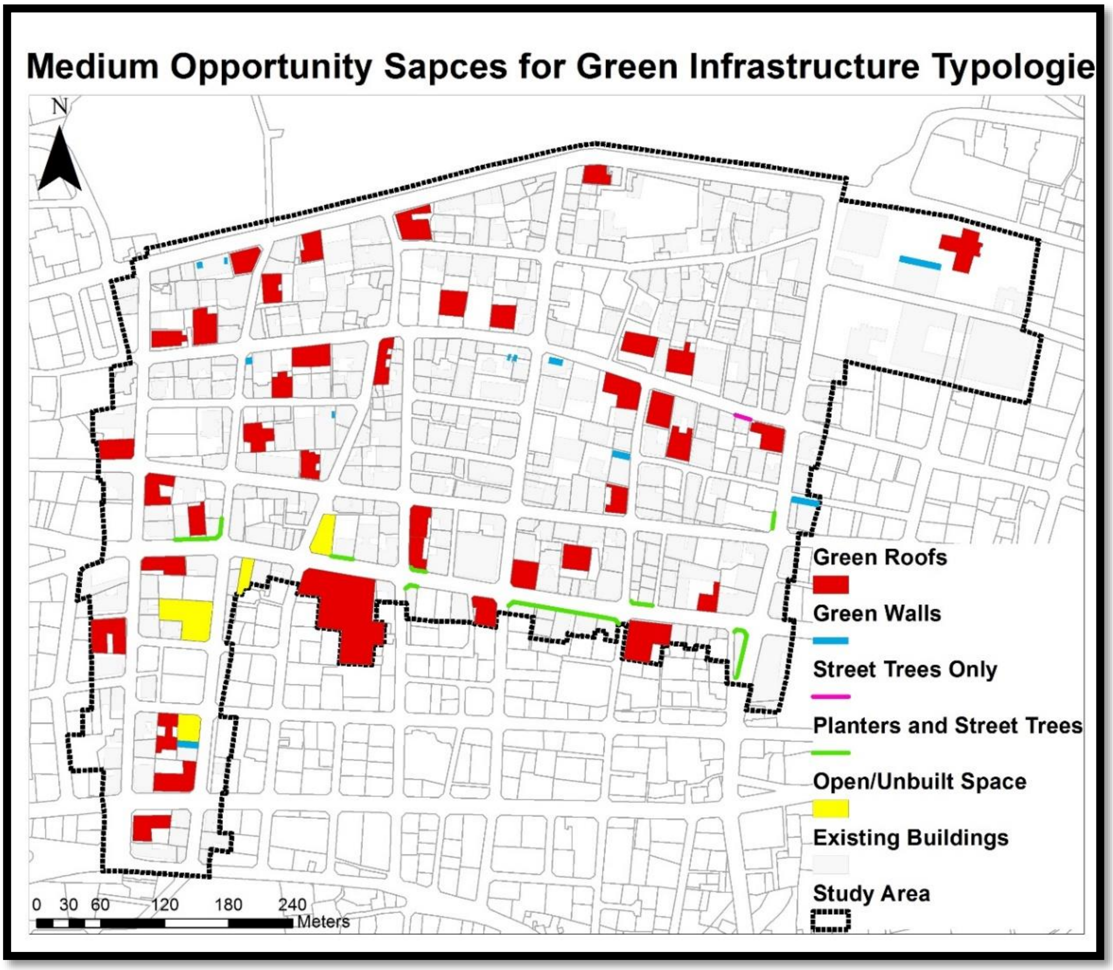

Figure 59 Medium opportunity map for all green infrastructure typologies

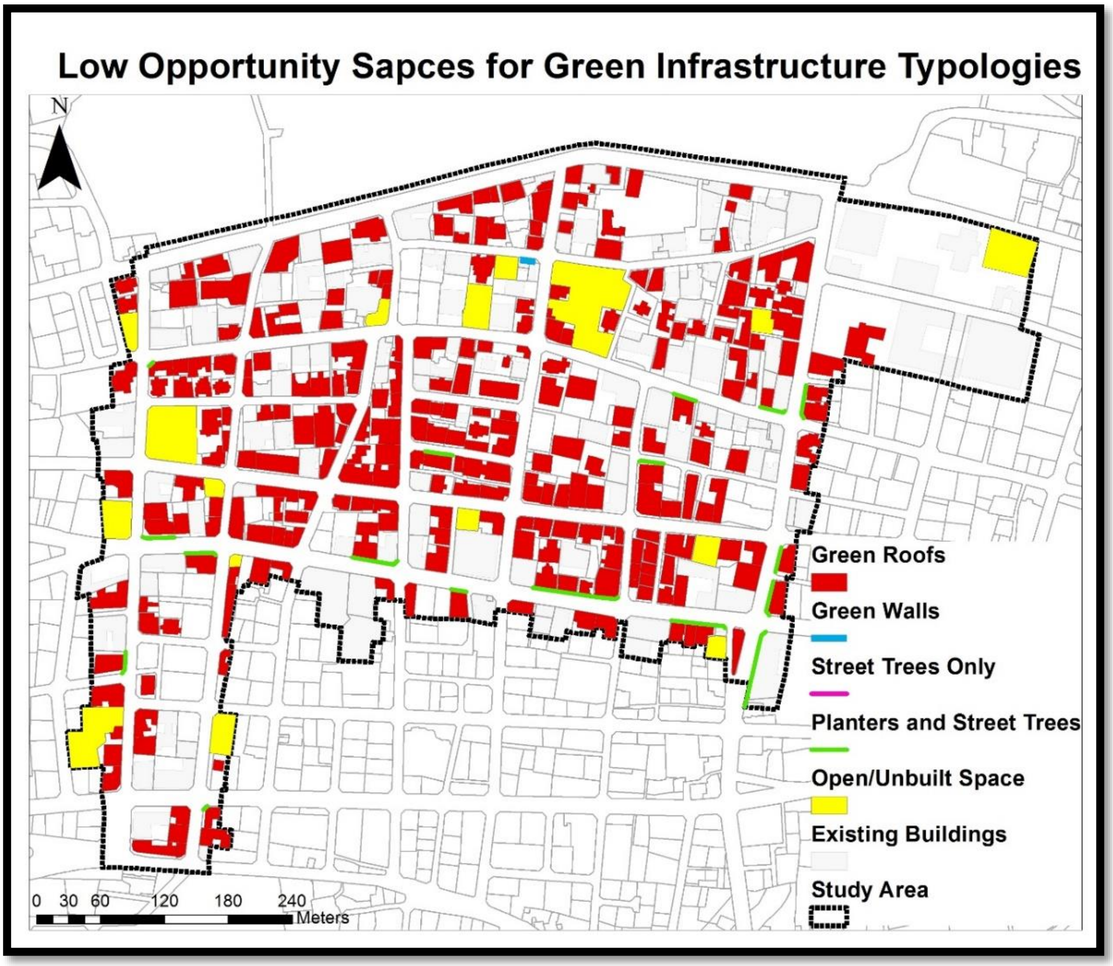

Figure 60 Low opportunity map for all green infrastructure typologies

The identified suitable spaces and their respective opportunities for the green infrastructure typologies, permit categorizing the urban study area into opportunity zones for green infrastructure based on their overall urban morphology that can host the typologies. The opportunity zones were identified in certain areas in the study area based on the number of green infrastructure typologies they include as explained in Chapter III.

Figures 61, 62, and 63 present the opportunity zones for high, medium, and low opportunity spaces for green infrastructure typologies respectively.

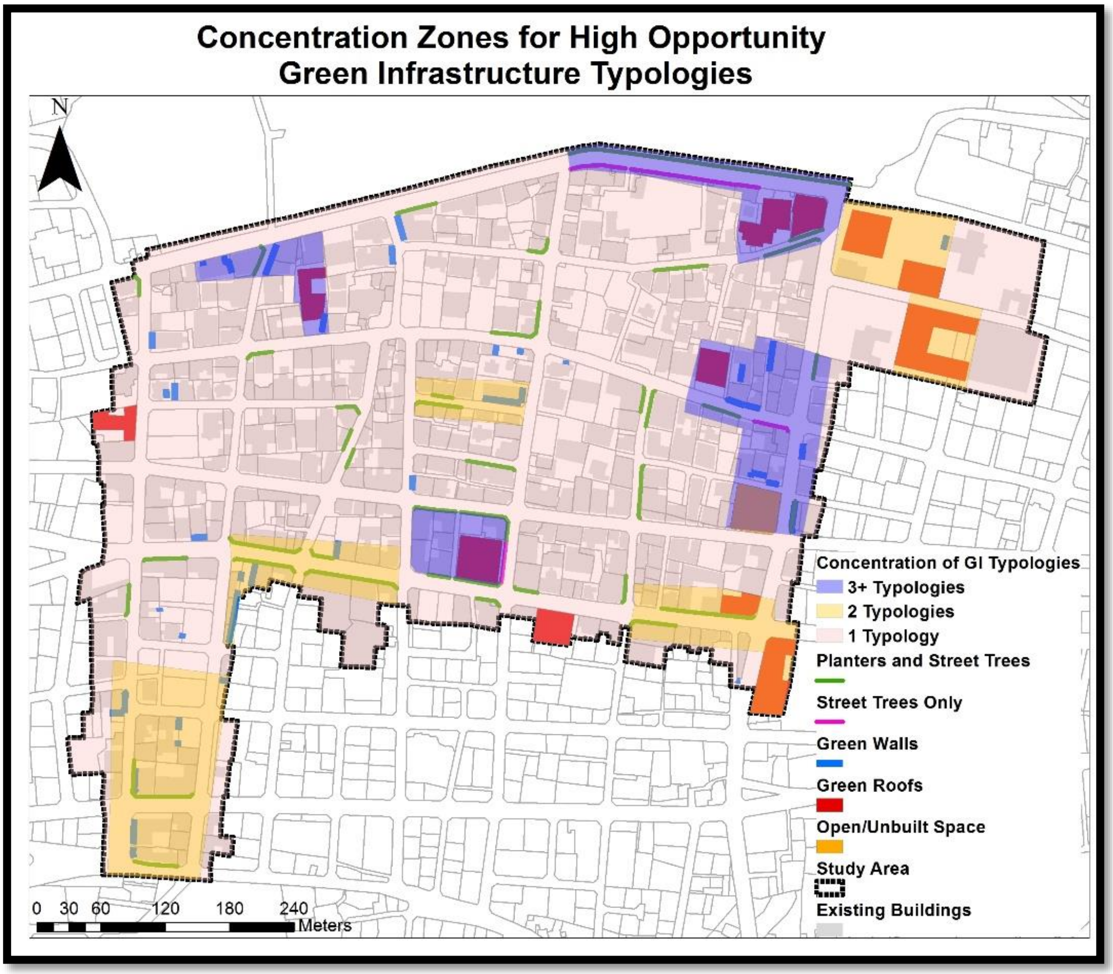

Figure 61 Opportunity zones for high opportunity spaces for green infrastructure

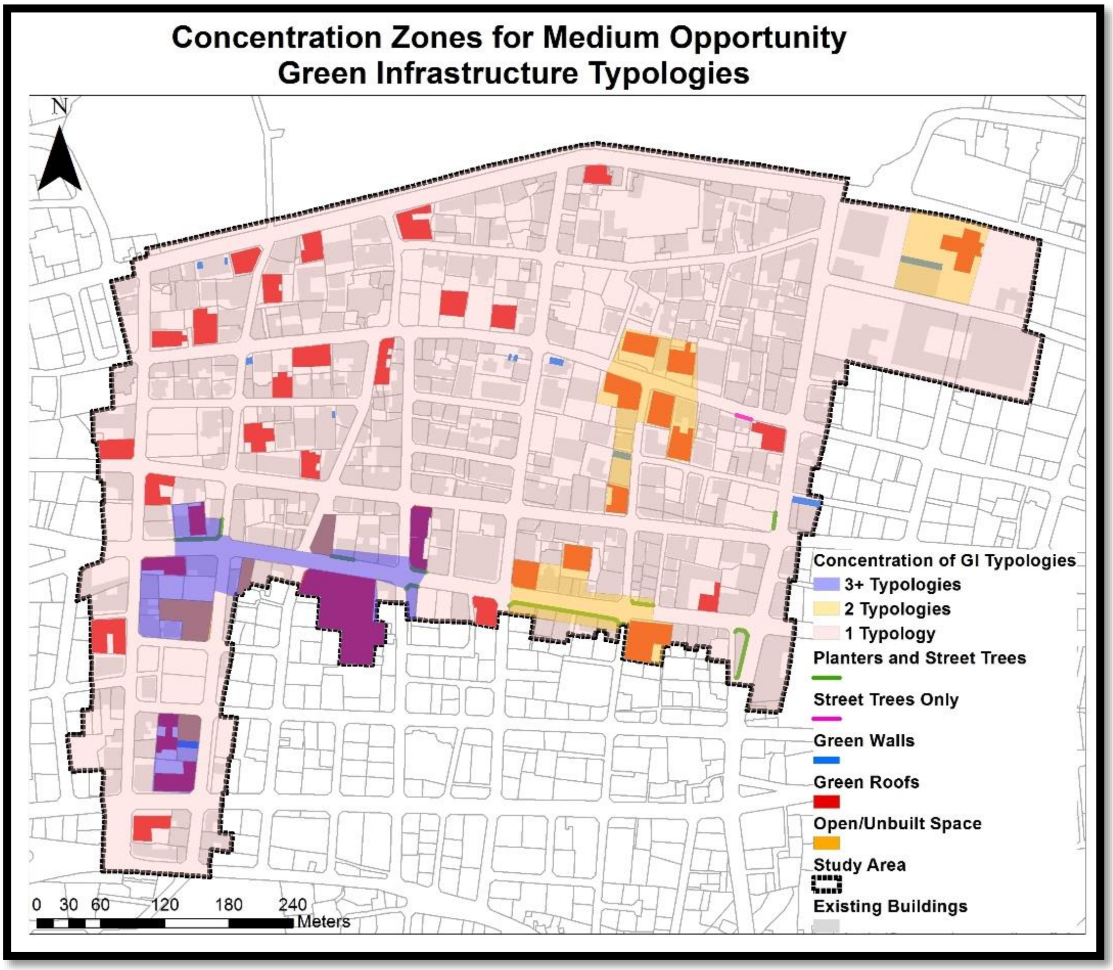

Figure 62 Opportunity zones for medium opportunity spaces for green infrastructure

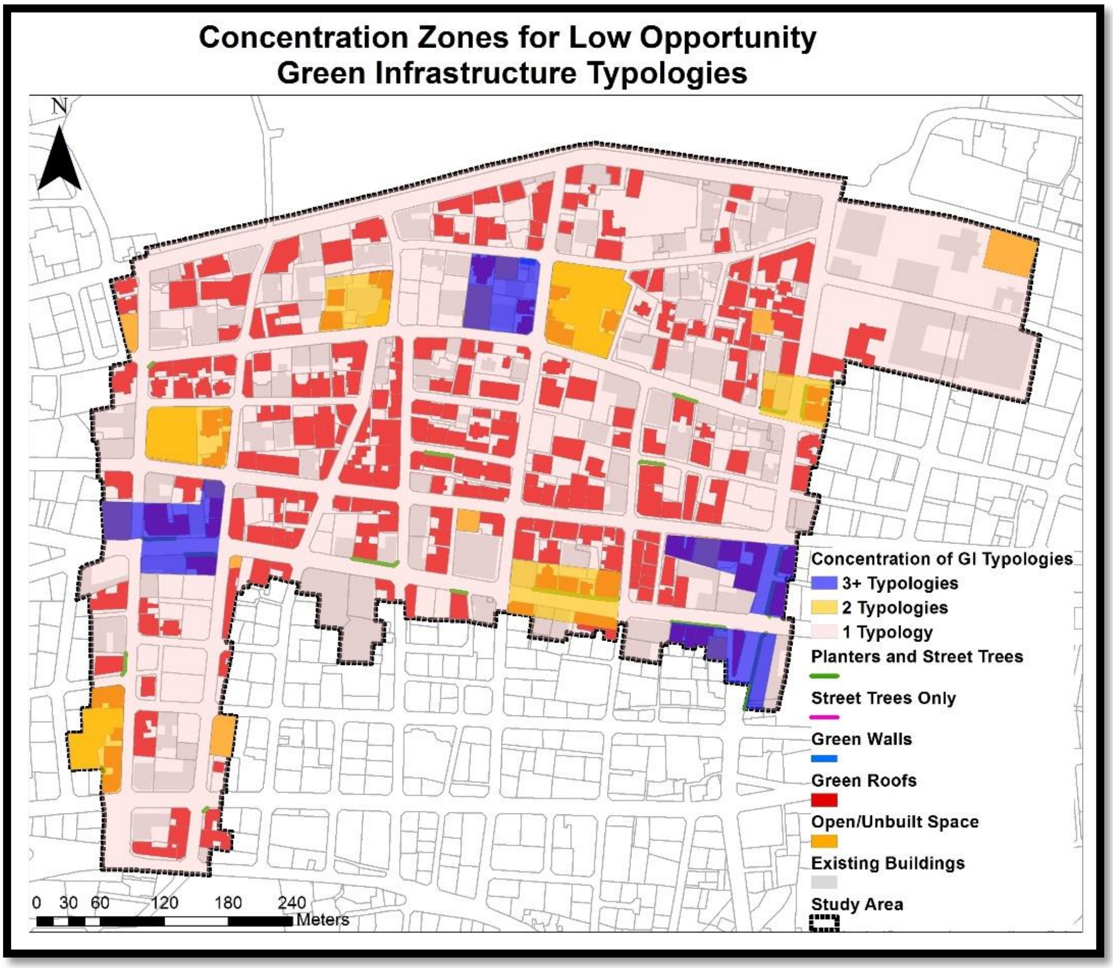

Figure 63 Opportunity zones for low opportunity spaces for green infrastructure

From the figures above, the high (3+ typologies) and medium (2 typologies) opportunity zones which can host the highest variety of green infrastructure typologies in the study area concentrated in small clusters are located more or less in similar locations across the study area, highlighting a unique urban morphology in these areas that can host green infrastructure. This is assured by overlaying the above three maps into one (Figure 64).

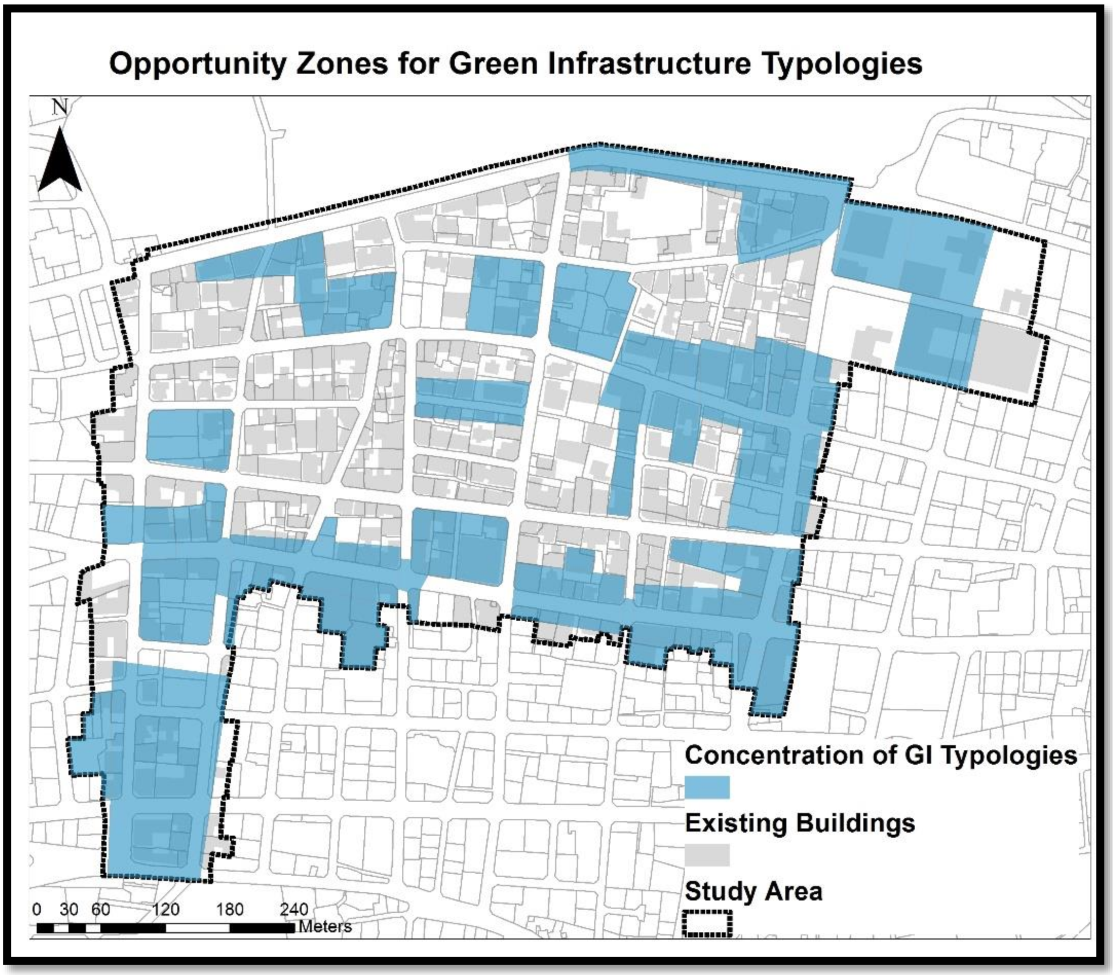

Figure 64 Combined opportunity zones of green infrastructure typologies across the study area

From Figure 64 above it is evident that the high, medium and low maps overlap to a high extent, therefore shedding light on common urban morphologies that can either support or restrain the development of urban green infrastructure typologies. Most of these overlapping zones occur along all of Hamra and Abdul Aziz Streets, and parts of Sadat and Bliss Streets.

This continuous stretch of the study area prevails as the highest suitable zone for green infrastructure in the study area since it has buildings with free roof space, several of them have large footprint with high free roof space (>1000m^2) such as the

AUBMC buildings, making them highly suitable for extensive green roofs. Additionally, many buildings in these zone have concrete façade material or balconies with abundant pervious surfaces adjacent to them making them suitable for direct green walls. On the other hand, the availability of wide sidewalks (≥2.7m) as those located along Hamra or Bliss Street that are not fully vegetated or bare also make this zone suitable for sidewalk greening practices through street trees and infiltration planter boxes. Finally, the prevalence of undeveloped lots in this zone (private or municipal ownership) provides us with multiple opportunities for intervention to retrofit such lots with green infrastructure practices. Therefore, this zone can readily host the green infrastructure typologies investigated without the need for major and costly modification works to their streets or buildings so that they become applicable for green infrastructure. Consequently, it is recommended that the municipality arranges green infrastructure programs in order to realize these opportunities.

Given their urban morphology, the opportunity zones identified in the study area can have a positive impact on the overall urban ecosystem through the provision of ecosystem services in the urban neighborhood in case green infrastructure was incorporated. Since green infrastructure is based on the use of natural features, namely vegetation, the urban ecosystem can become more stable due to the provision of essential ecological functions. The use of various typologies of green infrastructure can increase the amount of biomass in the area, boost energy flows, and create habitats that can support diverse organisms, including native species. Moreover, other benefits that can be accrued are the promotion of natural stormwater management since all of the discussed typologies increase the area of pervious surfaces and vegetation, the amelioration of the effects of the urban heat island in the densely built neighborhood as well as energy savings especially through the use of green roofs, green walls, and street trees; reduction in air pollution levels from traffic emissions, in addition to improving the aesthetics of the urban neighborhood through greenery.

On the contrary, other areas in the neighborhood that lack abundant opportunities for green infrastructure are mainly characterized by the dominant existence of small and old buildings that usually consume their roof space for utilities, thus rendering the opportunity for green roofs as highly expensive. In addition, such neighborhoods lack pervious surfaces, have narrow sidewalks (< 2.7m), and lack undeveloped lots. Such neighborhoods highly resemble the urban morphology which characterizes the north western zone of the study area. Although this zone includes private parking lots that could be retrofitted with green infrastructure, direct municipal intervention is required in order to enforce or encourage such actions.

CHAPTER V

MUNICIPAL GREEN INFRASTRUCTURE GUIDELINES

This thesis has so far explored the spatial suitability of several urban green infrastructure typologies such as extensive green roofs, green walls, trees, and bioretention practices in a space-constrained neighborhood in Beirut. However, realizing their development on the ground mainly requires adjustments to municipal programs so that to facilitate meaningful implementation.

Considering the small scale neighborhood that this study focused on, as well as the crucial role that municipalities should play in promoting green infrastructure, this chapter will discuss potential municipal green infrastructure guidelines to be adopted in the city of Beirut. The guidelines serve to promote the use of green infrastructure in the neighborhoods of Beirut with the possibility to be adopted across Beirut. The guidelines are based on the meta-analysis of policies and the results from the case study analysis.

A. Understanding the Drivers

Beirut is a city that suffers from various environmental problems due to unplanned urban development which has dominated its growth patterns over the years.

- Beirut suffers from local flooding of its streets during the winter season due to heavy rainfall events. These local floods occur at different severity rates and in different districts of the city depending on the extent of grey infrastructure maintenance, location, and proper urban planning (MOE/UNDP/ECODIT, 2011).

- Urban areas in Lebanon have witnessed deteriorating air quality levels over the past few years due to several anthropogenic sources that include industries, energy production, as well as transportation vehicles which are considered as the primary sources of air pollution in urban areas. The rates of air pollution in urban areas from the transportation sector have reached alarming levels causing several health complications to the exposed populations (MOE/UNDP/ECODIT, 2011).
- Vegetation in Beirut encompassing open green spaces is low, whereby very few places remain "natural" within its urban center. This situation exerts pressure on the remaining habitats and hinders the existence of biologically diverse communities within these remaining habitats. Additionally, the absence of green vegetation in the city makes it aesthetically unappealing.
- Given the existing road infrastructure in Beirut, the city is considered uncomfortable for walking due to the lack of maintenance of the streets and sidewalks, as well as the lack of urban greenery along most of these roads makes it even worse. (Myntti & Mabsout, 2014)

Bearing in mind the multifunctional benefits provided by urban green infrastructure, the aforementioned impacts of these problems in Beirut could be minimized if green infrastructure is implemented.

B. Defining the Goals

The overall goals to be achieved through the integration of green infrastructure among the urban fabric of Beirut shall take into account the improvement of the overall urban context at the ecological and socio-economic level by:

- Increasing natural stormwater management by increasing the area of permeable surfaces and vegetative cover in the city, thus increasing interception by plants, evapotranspiration, and ground infiltration. Therefore green infrastructure can reduce the volume of total generated runoff, reduce the amount of pollutants entering the receiving waterbodies, and enhance groundwater recharge.
- Reducing air pollution and reducing the concentration of air pollutants in the air since vegetation is a main component of most of the green infrastructure practices. Green infrastructure can also ameliorate the effects of the urban heat islands in the narrow streets of Beirut, especially during the hot summer months.
- Improving the urban ecosystem through the creation new micro-habitats which can increase the level of floral and faunal biodiversity in the city.
- Increasing the area of urban greenery thus beautifying the streets of Beirut, and giving them a unique cultural identity.
- Improving the overall health and wellbeing of the residents of the neighborhoods in Beirut since street level green infrastructure practices can encourage people to spend their time outside and practice outdoor physical activities. Additionally as mentioned in Chapter II, greenery has been shown to improve the mental wellbeing of nearby residents.
- Improving the walkability in Beirut since street level green infrastructure practices can make the walking experiences more enjoyable and safer as they can act as traffic calming features as well.
- Having small green open spaces in Beirut can help in creating spaces for social interaction between the neighborhood community members. This can also reflect on increasing the social cohesion between them.

- Creating new/additional job opportunities in the Lebanese market that include companies for installing/constructing certain green infrastructure practices such as green roofs and green walls, companies that supply the required material, as well as jobs related to the maintenance of green infrastructure. Thus this can play a role in boosting the economic cycle in the country and reducing to a certain extent the rate of unemployment.

The above goals, along with the drivers mentioned earlier, should be the basis for future green space municipal planning in Beirut along with local policy application and changes in order to develop a comprehensive green infrastructure program to be adopted and followed, and reviewed when necessary.

C. Municipal Green Infrastructure Policy Guidelines and Tools

This section shall present a set of municipal guidelines that are intended to facilitate the planning and implementation of green infrastructure in Beirut.

1. Green Infrastructure Policy Guidelines

The proposed green infrastructure guidelines emanate from the results of the case study analysis, and are based on the combined opportunities from the previous chapter. These guidelines will provide the basis of a municipal wide vision and suggested implementation recommendations followed by policy tools possibly applicable in Beirut.

a. <u>Develop Baseline Data</u>

Adequate future planning for green infrastructure requires the development of a wide database of baseline conditions and existing features in the city. Similar to what has been done by Ile de France for the "Green Plan for Beirut", the Municipality of Beirut should develop a regularly updated and comprehensive database for the city. Data on existing buildings, undeveloped land parcels, existing green features, infrastructure, and demographics ought to be gathered in order to plan for future green infrastructure projects based on scientific and realistic data. Other types of data to be developed include the assessment of pervious surfaces, the amount of stormwater runoff generated, and air quality.

The data to be assembled by the municipality is best organized and managed using GIS. All this information can facilitate the process of diagnosing the current situation, assessing existing problems, and finally identifying opportunities for incorporating green infrastructure within the city. Using the aforementioned database can also facilitate implementing suitability analyses in the city in order to identify spaces where various typologies of green infrastructure can be implemented. The use of GIS for green infrastructure planning is common in many cities across the United State, Europe, and Australia. Examples of those include the state of Massachusetts' MassGIS program that stores statewide information related to several fields such as environmental data, infrastructure, in addition to data on conservation and recreational programs (Commonwealth of Massachusetts, 2016).

Moreover, the city of New York for example has also developed a GIS database specifically for green infrastructure. The city has also published a web-based GIS application (Figure 64) for this matter allowing the public to gain information on existing and planned green infrastructure projects in the city (City of New York, 2016).

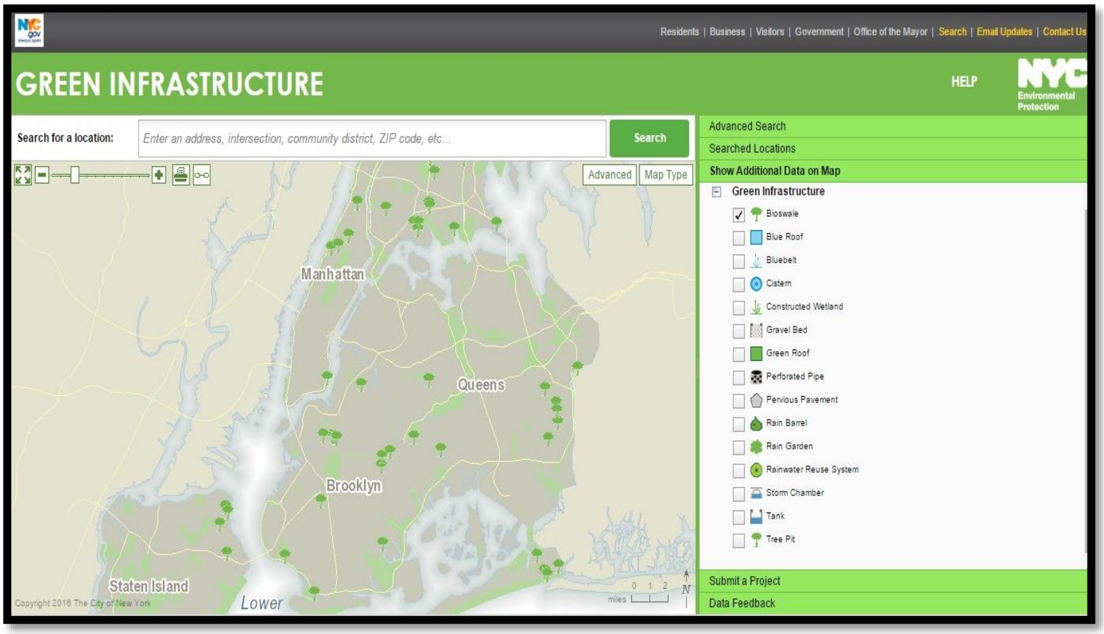

Figure 65 The green infrastructure web map for New York City (City of New York, 2016)

b. Identify Applicable Green Infrastructure Typologies

Drawing on the results from having a data base for the city of Beirut that cover all the required information needed to adequately develop green infrastructure, the municipality should work on identifying the applicable green infrastructure typologies suitable for each zone under study in the city based on its urban morphology. Additionally, the municipality can identify certain green infrastructure typologies necessary for the provision of specific ecosystem services in some city zones. In case these area do not have the required available space for implementation, the municipality should engage in developing innovative and alternative solutions that incorporate infrastructure as much as possible. For example, in case of a densely built neighborhood with narrow streets that lacks street vegetation, the municipality can consider vertical street greening strategies, or can encourage residents to green their balconies using dangling vegetation.

c. Define a Vision

Developing a strategic vision for green infrastructure in Beirut will help the municipality identify the objectives and the purpose behind a green infrastructure system for a specific area of study. The objectives can include setting targets to be met over a specified period of time such as increasing the number of trees in the city streets by 50% in five years.

d. Develop Standards for Applicable Green Infrastructure Typologies

Having clear standards for green infrastructure in Beirut can facilitate implementation. Such standards, developed by the municipality can include:

- Providing the public with specified cost ranges for the installation and maintenance of green roofs based on the evaluation of the general market prices.
- Setting design standards for the minimum width of sidewalks to be retrofitted with street green infrastructure practices and at the same time allow easy pedestrian movement. Sidewalks to be planted with tree should be at least 2.5m wide, while sidewalks to be retrofitted with planter boxes should be at least 2.7m wide.
- Setting design standards for tree pits while taking into consideration the size of the full-grown trees to be planted.
- Setting the required spacing (6-10m) between trees along the sidewalks to be planted to allow the healthy growth of the trees.
- Setting standard design requirements for developing green parking lots that incorporate green infrastructure typologies.

- Identifying the suitable plant species to be incorporated with green infrastructure given the climatic conditions of Beirut, and their maintenance needs.

2. *Green Infrastructure Tools*

To be able to achieve the aforementioned municipal guidelines, several actions need to be taken at the organizational and legislative levels of the Municipality of Beirut. These actions will serve as the tools that are needed to develop a comprehensive green infrastructure program in the city.

a. Suggested Administrative Changes

i. Collaborating Municipal Departments

Developing a green infrastructure program within the municipality of Beirut requires the robust collaboration between the concerned departments of the municipality. Given that the Committee of Parks, Health, and Environment is the main entity responsible for the urban green spaces, increased efforts and cooperation with the other committees especially the Committee of Planning, Public Works, Properties, and Expropriation and the Committee of Traffic and Transportation since green infrastructure projects are directly related to and affected by the city planning schemes and the transportation infrastructure. To enhance the communication between the different entities within the municipality, a separate committee that includes representatives from all the municipal departments could be formed. Specializing in planning for green infrastructure in the city, this committee serves to eliminate any barriers that might interfere in implementing green infrastructure projects, assign the roles and responsibilities of each department, and reduce the risk of work duplication and contradiction.

ii. Geographic Information Division

A distinct departmental division responsible for compiling all the data that the municipality has on Beirut and entering them into GIS in order to generate modifiable spatial data. Part of the data will definitely include the location and information on green infrastructure practices the city. Such geospatial data can also assist in incorporating future green infrastructure strategies and plans in Beirut.

b. Suggested Adjustments to the Lebanese Regulations

The implementation of green infrastructure in Beirut necessitates the presence of laws and regulations that support their development, encourage or obligate citizens to incorporate green infrastructure practices on their properties. The Lebanese laws explored in Chapter II are directly connected to the issue of green infrastructure, and if revised accordingly they can have a major effect on the promotion of green infrastructure in Beirut.

The concept of green infrastructure as a whole is not evident in any of the laws reviewed. By examining the Urban Planning Law and the Building Law, very few articles clearly state as a mandatory issue, that urban greening practices are an obligation. What is visible that the articles in these laws confine urban greening practices to planting a few trees around the buildings only. Additionally, the building law does mention that the owner might be obliged to construct a tank for rainwater harvesting. However, it does not explain the reasoning behind this statement, and what are the conditions that should be available so that the owner will have to consider rainwater harvesting.

The property law on the other hand, does not mention that landowners should reduce the amount stormwater generated from their properties, and it also does not mention the need for rainwater harvesting or extensive planting for other ecosystem benefits.

Moreover, from an environmental point of view, the current Environment law (Law no. 444/2002) does not mention as well the aspect of urban greening and impacts arising from their absence on the environment and human health.

The following are the suggested amendments to the pertinent laws as presented in Table 23:

Table 21 Suggested adjustments to the Lebanese regulations

Regulation	**Adjustments**
Urban Planning Law (Legislative Decree 1983/69)	- Specify detailed design standards for urban greening. - Require the development of open green spaces of a certain area in the city.
Building Law 646/2004	- Adopt the changes as proposed in the Green Plan for Beirut that assigns the area to be planted (not less than 50% of free area), planted and increased setback distance, as well spacing between trees (2.3m) (Région Île-de-France & Bureau CGLU-BTVL, 2012)
Property Law 3339/1930	- Oblige the management of generated stormwater runoff on site using green infrastructure practices when applicable.
Environment Protection Law 444/2004	- Acknowledging the importance and benefits of urban greenery in terms of the ecosystem services they provide. - Devise the necessary application decrees to conserve existing urban green spaces and the tools to increase their surface area.

c. Suggested Municipal Policy Programs

Adopting and implementing certain policy programs is an important aspect in green infrastructure planning. As a tool that can promote the development of green infrastructure in Beirut, the municipality can use the following policies:

i. Technology Standards

Technology standard-based policies could be implemented by the municipality, whereby it requires private property owners to use a certain green infrastructure practice such as using green roofs or permeable pavement for parking lots for instance. In this sense, properties that are found to be highly suitable for green infrastructure (such as green walls, green roofs, permeable pavement) after assessment could be obliged to invest in developing them. Furthermore, the municipality can enforce this policy on all new building designs in order to acquire a building permit.

Technology standard policies work best if mandated at first for governmental buildings to serve as an example to the public and encourage them to apply different green infrastructure practices, and they can be applied in certain neighborhoods in the city to achieve certain environmental targets such as reducing stormwater runoff or urban heat island effects (Carter & Fowler, 2008).

ii. Tax System

Small financial charges could be added on the annual municipal tax paid by private households and commercial units. The revenues from these fees will be used exclusively for investing in future green infrastructure projects. Another option would be to allocate a small percentage of the taxes currently being paid by the public for green infrastructure projects, in this way the people will be spared from paying additional charges.

iii. Direct and indirect financial incentives

Direct and indirect financial incentives can be used to encourage the private sector to invest in green infrastructure at the site scale. Direct financial incentives include municipal financial rewards given to private entities that implement a green infrastructure practice or as financial reimbursements for those who already invested in green infrastructure. Direct incentives also encompass subsidizing green infrastructure, thus reducing the costs of purchasing or installing green infrastructure practices on the public community (EPA, 2010a). This can achieved via agreements between the municipality and private companies that deal with supplying green infrastructure related material and other companies specialized in installing green roofs or green walls for example.

Indirect financial incentives include discounts on some municipal taxes for those who invest in green infrastructure. Another type of an indirect financial incentive is the provision of development incentives when applying for a building permit, this entails the incorporation of green infrastructure practices in building designs to obtain extra density credits. (EPA, 2010a)

iv. Pilot projects

Pilot projects are considered an excellent tool to introduce the green infrastructure concept in Beirut and increase community awareness and approval to support new related policies. Small scale pilot projects are generally implemented as a replication of what is intended for execution across the neighborhood or city. Such projects allow the municipality to gain on site experience related to the design, construction, and maintenance of green infrastructure. They also help in monitoring the performance of green infrastructure (capturing runoff, reducing air pollution…) and evaluate it on a trial and error basis. As a result of pilot testing a significant amount of unnecessary costs can be saved. (EPA, 2010a)

v. Education and outreach programs

Education and outreach programs also play an important role for green infrastructure policy application by explaining the concept of green infrastructure to the general public and educating them on the importance of green infrastructure and their benefits. Outreach programs can also focus on highlighting existing green infrastructure projects in different city neighborhoods, thus encouraging people to apply green infrastructure at home and within their neighborhood boundaries. (EPA, 2010a)

d. Changing Municipal Action: Transdisciplinarity

The Development of green infrastructure requires the collaboration between different stakeholders and disciplines. The municipality will need to change its methods and approaches from an expert in-house focused (top-down) approach to one that is more inclusive of multiple stakeholders. As such it is important to have a transdisciplinary body of stakeholders, in partnership with the municipality, working on green infrastructure projects to share their ideas, the expected implementation scheme, and the expected outcomes of the projects. This body should include representatives of communities, NGOs, academic institutions, and private stakeholders. As such the following is proposed:

- Consulting the neighborhood communities on future green infrastructure projects in their area, involve them in planning, and adjusting the project based on their needs. Involving the public will give a sense of ownership of the project and thus they can play a major role in managing and maintaining the project in the future.
- Encourage and support local NGOs that are working for creating new green spaces in Beirut and improving existing ones.
- Involving the academic sector and utilize their expertise in identifying the goals, needs, and expected targets that the green infrastructure projects should accomplish.
- Inviting the private sector to get involved and invest in green infrastructure projects. This can also include supporting public-private partnership (PPP) projects.

Based on all the above municipal policy guidelines and tools that could be implemented in order to facilitate the development of green infrastructure in Beirut, Table 22 presents a summary of all the policy implementation tools specific to the green infrastructure typologies considered in urban case study area of this research. It can be comprehended from the table below that the suggested policy implementation tools target facilitating the development of green infrastructure on either public or private properties.

Policies directed towards public properties are mainly based on developing municipal green infrastructure plans in a transdisciplinary manner, as well as they should be developed after the municipality acquires sufficient and comprehensive baseline data on existing green infrastructure-related city features as is the case for greening sidewalks and municipality-owned lots in the city. On the other hand, policies directed towards private properties are mainly based on changes in the tax system (such as tax breaks), as well as incentives and technology standards in order to promote incorporating green infrastructure typologies such as green roofs or green walls on private properties.

Table 22 Summary of specific green infrastructure policy implementation tools

Morphology	**Typology**	**Green Infrastructure Opportunity Ranking**	**Suitable Standard / Urban Morphology**	**Suggested Municipal Implementation Tools**
Roofs	Extensive Green Roof	High	Buildings with free roof space > 1000m^2 (economically feasible) Buildings with free roof space < 1000m^2 (less economically feasible)	- Tax breaks - Technology standard for new buildings - Subsidized green roofs programs - Education and outreach - Pilot projects on municipal buildings
Walls	Direct Green Walls	Medium	Available soil, non-glass façade, non-north oriented (high success rate) Available soil, glass façade, north oriented (less success rate)	- Tax breaks - Technology standard for new buildings - Subsidized green walls programs - Education and outreach - Pilot projects on municipal buildings
Sidewalks	Street Trees	High	-At least 2.5m sidewalk width	- City baseline data on street trees

			-Bare or minimally planted sidewalks	- Developing wide sidewalks (2.7m wide) - Municipal street greening plans (long term) - Transdisciplinary planning and action
	Planter Boxes		-At least 2.7m sidewalk width -Bare or minimally planted sidewalks	
Unbuilt Open Space	Various	Low	Unbuilt private lot (aggressive municipal action: land purchase or PPP)	- Tax breaks - Technology standard for green parking lots - Subsidized green infrastructure programs - Education and outreach
			Unbuilt municipal lot (municipality willingness, economic feasibility)	- City baseline data on open spaces - Municipal green infrastructure plans - Pilot projects - Transdisciplinary planning and action

It is important to note that the green infrastructure opportunity ranking presented in table above reflect the results from the case study area, whereby the green infrastructure typologies that could be most implemented given the amount of suitable spaces for each. Therefore, given the numerous options where green roofs and sidewalk greening practices are suitable, they were given the highest opportunity, followed by green walls, and finally the applicability of green infrastructure in open unbuilt spaces.

This ranking was proved in the case study area examined, and it is expected that the ranking followed will be more or less similar in other neighborhoods in Beirut.

D. Opportunities of Stakeholders' Involvement

After discussing the potential policy guidelines and tools that could be implemented by the Municipality of Beirut to realize the green infrastructure opportunities in the urban neighborhood of this research, changing municipal action to include different stakeholders in planning and implementation of green infrastructure was presented as a necessary component that can facilitate efficient implementation. However, assuming that the municipal structure and processes in planning and executing urban developmental projects, including a green infrastructure program, resumes similar to what the current situation in Beirut is nowadays, an assessment of the stakeholders' opportunities in developing green infrastructure in the study area is presented in Table 23. This is presented to make the results of this research more pragmatic, reflecting the current situation in Beirut and Lebanon in general.

Table 23 Opportunities for stakeholders' Involvement

Stakeholders		**Capabilities**			**Willingness to support**	**Opportunity**
		Technical	Financial	Political		
Public Sector	**Municipality**	x	x	x		High
	National Government	x	x	x		High
Private Sector and Civil Society	**Residents**				x	Low
	Building Committees		x		x	Medium
	Landowners				x	Low
	Merchants Associations		x		x	Medium
	Universities	x	x		x	High
	Schools				x	Low
	NGOs	x	x		x	High

The different stakeholders presented in Table 23 above, include the public sector, private sector, and the civil society since they can all play a vital role in preparing and implementing a comprehensive green infrastructure program. High opportunity stakeholders (those who meet at least three criteria), include the representatives of the public sector that directly deal with green infrastructure. These governmental administrations can afford hiring the required technical expertise needed for conducting studies and master plans for green infrastructure on a neighborhood scale, or even city scale. They also have the financial capabilities to invest in green infrastructure, and the political power needed for implementation and eliminating barriers that can hinder implementation. However, since governmental and municipal administrations in Beirut still lack defining a clear vision and target objectives to execute developmental projects their willingness to support and implement green infrastructure initiatives is low.

On the other hand universities and specialized NGOs in Lebanon, always strive to develop and participate in initiatives that improve the human wellbeing and the environment. Examples of which are the Neighborhood Initiative Program at the American University of Beirut (AUB) and NGOs like Nahnoo that works for increasing public open spaces in urban areas. Such academic institutions and NGOs currently boast many researchers that have the technical expertise to present master plans for urban greening and urban planning, and can secure funding from local or international donors to implement small scale green infrastructure projects in an urban neighborhood. However, universities and NGOs can only advocate for realizing holistic green infrastructure projects, whereby they lack the political power to force governmental institutions to execute such projects and develop green infrastructure programs.

To a lesser extent, other important community stakeholders are the merchants' associations, like the Hamra Merchant Association, that can support developing green infrastructure projects along commercial streets to beautify them and improve them aesthetically. Such projects can boost the area economically and attract more visitors and shoppers. Associations similar to the one in Hamra, can also develop a fund to finance the development of street green infrastructure typologies such as street trees and planters. Likewise, local building committees in the neighborhood can support and finance incorporating green infrastructure typologies on their properties in an attempt to beautify the building exterior landscape, or improve the building's energy saving by installing green roofs or green walls for example.

Finally, low opportunity stakeholders include residents, landowners, and schools. These components of the community, can surely support neighborhood greening initiatives using green infrastructure however, they lack the technical know-how, financial capabilities, and the political power to generalize and enforce implementation across the neighborhood.

CHAPTER VI

CONCLUSION

Although urban greening is widely discussed in Lebanon, this research contributes to introduce the concept of urban green infrastructure as an urban landscape planning and management layer for the city of Beirut. The concept is based on multifunctionality and the provision of ecosystem services. North American and European cities have well-established green infrastructure programs that target improving their environment, communities, and economies. A similar and applicable program in space-limited Beirut, will be faced with regulatory and legislative challenges resulting from the absence of awareness and fiscal deficits.

Thus, this research explored the opportunities for developing urban green infrastructure in a neighborhood in Beirut and suggested evidence-based municipal guidelines and tools that can facilitate implementation. The opportunities were based on the financial feasibility for extensive green roofs, the success rate of direct green walls, the contribution to enhancing urban greenery using street trees and infiltration planter boxes; and finally the susceptibility of change and land tenure of the vacant lots. Moreover, other green infrastructure practices that do not require space were also considered.

Furthermore, this research went on to suggest and recommend certain municipal reforms that allow the Municipality of Beirut to introduce a holistic green infrastructure program to realize the urban greening opportunities identified. The primary benefit of this approach is its utility in planning a green infrastructure system at the municipal scale without having to conduct in-depth analysis beyond the physical constraints. Such an approach provides decision makers and planners with a rapid assessment tool to decide on possibilities, and develop budgets for an urban green infrastructure plan which then are detailed in further steps.

This will empower the municipality's capabilities to implement and develop neighborhood or even city-wide green infrastructure projects in the future. Such projects can improve the urban landscape of Beirut on multiple levels, by ameliorating the overall urban environment, creating new green spaces that enhance the communities' wellbeing and interactions, and by boosting the local economy (new jobs, lowering indirect costs of environmental impacts, attracting tourist etc.…). Thus, green infrastructure in Beirut can serve as one of the stepping stones in creating a sustainable city.

The research was also limited by several factors that could have yielded more accurate and comprehensive results if eliminated. These limitations include:

- Data on the buildings' age, roof conditions, and structural stability were not considered when assessing the suitability of buildings to extensive green roofs. However, these are significant indicators that, if considered, could have reduced the total pool of applicable buildings.
- Data on soil health and quality available at this fine scale was not considered. Given the urban context of the case study area, the soil most likely is compact and polluted thus greatly affecting the growth of the proposed street-level green infrastructure practices. While not considered here, it is a significant factor for green infrastructure implementation.

- The urban greening practices discussed should rely on native drought tolerant plants, that require minimal maintenance so that to reduce costs and save water resources. However the scope of this research did not include identifying the suitable plant species to be planted.
- It was beyond the scope of this research to quantify the environmental benefits of the proposed urban green infrastructure practices in the case study area, such as the volume of stormwater runoff detained, amount of air pollutants absorbed, and extent of reducing the urban heat island effect.
- The study did not address the requirements for the formulation of a green infrastructure program on a national scale, the scope was only limited to municipal Beirut.

In conclusion, this research may be considered as a first step in an in-depth analysis of the possibilities of transforming, applying, and implementing a green infrastructure approach to semi-arid, and highly dense Mediterranean urban contexts in order to improve and stabilize the urban ecosystem and increase the generation of essential ecosystem services. Nevertheless, it was deduced from the results of this research that the implementation of urban green infrastructure typologies is highly dependent upon the overall urban morphology of the area. The characteristics of the urban morphology could be considered as factors that can either support or limit the introduction of green infrastructure in a certain urban neighborhood.

This research has also built on previous studies conducted on improving the urban landscape in Beirut and its walkability using urban greening practices, such as those conducted by AUB graduate students Mohamad El Mais's "Enhancing Walkability through open spaces: The Case of Hamra, Beirut" (2014), Dana Balaa's

“Enhancing Walkability through Urban Connectivity: The Case of Hamra, Beirut” (2014), and Sandrine Samaha’s “Legalizing Nature: Sustainable Urban Greening Strategies for Corniche al Mazraa” (2011).

However, a complete green infrastructure approach should also consider prioritizing and phasing which green infrastructure typologies should be implemented and developed first based on their need and cumulative benefit to the environment and the community. Whereby the development of open green spaces such as parks, by the municipality, amongst the urban fabric might be more important than subsidizing or enforcing green roofs given the minimal presence of open green spaces in Beirut.

On the other hand, a holistic green infrastructure approach should also focus on creating an interconnected green infrastructure network in urban centers, as well as a network that goes beyond the juridical boundaries of the cities to also include the suburban and rural areas. The acquired multi-level benefits from having such green infrastructure systems must act as the drivers for crafting the political will and developing necessary political tools required for implementation.

APPENDIX I

GIS DATA FOR STREET TREES AND PLANTER BOXES

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
0	Polyline	3.4	Applicable	10	6	1	2	1	1	Medium	Medium
1	Polyline	3.5	Applicable	89	6	6	15	1.5	9	High	High
2	Polyline	6	Applicable	42	6	3	7	1.33	4	High	High
3	Polyline	2	Not Applicable	74	6	5	0	0	0		
4	Polyline	1.45	Not Applicable	31	6	1	0	0	0		
5	Polyline	1.1	Not Applicable	53	6	1	0	0	0		
6	Polyline	1	Not Applicable	75	6	7	0	0	0		
7	Polyline	1.1	Not Applicable	83	6	1	0	0	0		
8	Polyline	1.1	Full Capacity	77	6	12	13	0	1		
9	Polyline	3.3	Applicable	69	6	5	12	1.4	7	High	High
10	Polyline	3.4	Applicable	60	6	3	10	2.33	7	High	High
11	Polyline	2.1	Not Applicable	27	6	1	0	0	0		
12	Polyline	2	Not Applicable	27	6	1	0	0	0		
13	Polyline	1.4	Not Applicable	35	6	1	0	0	0		
14	Polyline	2.6	Applicable	121	6	1	20	19	19		High
15	Polyline	2.6	Applicable	52	6	1	9	8	8		High
16	Polyline	2.3	Not Applicable	118	6	1	0	0	0		
17	Polyline	3.3	Applicable	38	6	1	6	5	5	High	High
18	Polyline	2.85	Applicable	264	6	1	44	43	43	High	High
19	Polyline	2.3	Not Applicable	283	6	1	0	0	0		
20	Polyline	2.4	Not Applicable	115	6	3	0	0	0		

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
21	Polyline	2.3	Not Applicable	106	6	1	0	0	0		
22	Polyline	3	Applicable	30	6	1	5	4	4	High	High
23	Polyline	1.1	Not Applicable	31	6	1	0	0	0		
24	Polyline	1.9	Not Applicable	77	6	2	0	0	0		
25	Polyline	1.65	Not Applicable	36	6	1	0	0	0		
26	Polyline	1.9	Not Applicable	45	6	1	0	0	0		
27	Polyline	3	Applicable	6	6	1	1	0	0	Low	Low
28	Polyline	1.9	Not Applicable	75	6	11	0	0	0		
29	Polyline	1.15	Not Applicable	40	6	2	0	0	0		
30	Polyline	1.2	Not Applicable	40	6	1	0	0	0		
31	Polyline	2.85	Applicable	25	6	1	4	3	3	High	High
32	Polyline	1.1	Not Applicable	103	6	1	0	0	0		
33	Polyline	1.15	Not Applicable	20	6	1	0	0	0		
34	Polyline	1.15	Not Applicable	18	6	1	0	0	0		
35	Polyline	1.15	Not Applicable	11	6	1	0	0	0		
36	Polyline	3.3	Applicable	24	6	1	4	3	3	High	High
37	Polyline	1.6	Not Applicable	18	6	1	0	0	0		
38	Polyline	2.7	Applicable	20	6	1	3	2	2	High	High
39	Polyline	1.35	Not Applicable	32	6	1	0	0	0		
40	Polyline	1.9	Not Applicable	89	6	1	0	0	0		
41	Polyline	1.2	Not Applicable	58	6	5	0	0	0		
42	Polyline	2.4	Not Applicable	21	6	1	0	0	0		
43	Polyline	1.8	Not Applicable	20	6	3	0	0	0		
44	Polyline	1.9	Not Applicable	80	6	6	0	0	0		
45	Polyline	1.2	Not Applicable	57	6	1	0	0	0		
46	Polyline	5.6	Applicable	30	6	3	5	0.67	2	Low	Low

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
47	Polyline	3.3	Applicable	59	6	5	10	1	5	Medium	Medium
48	Polyline	1.3	Not Applicable	30	6	2	0	0	0		
49	Polyline	1.9	Not Applicable	138	6	10	0	0	0		
50	Polyline	1.2	Not Applicable	45	6	1	0	0	0		
51	Polyline	1.9	Not Applicable	23	6	3	0	0	0		
52	Polyline	1.4	Not Applicable	40	6	1	0	0	0		
53	Polyline	1.9	Not Applicable	36	6	1	0	0	0		
54	Polyline	1.45	Not Applicable	13	6	1	0	0	0		
55	Polyline	1.45	Not Applicable	17	6	1	0	0	0		
56	Polyline	1.25	Not Applicable	34	6	1	0	0	0		
57	Polyline	2	Not Applicable	19	6	1	0	0	0		
58	Polyline	1.9	Not Applicable	64	6	1	0	0	0		
59	Polyline	1.85	Not Applicable	61	6	1	0	0	0		
60	Polyline	1.2	Not Applicable	14	6	1	0	0	0		
61	Polyline	3.2	Applicable	18	6	1	3	2	2	High	High
62	Polyline	1.4	Not Applicable	107	6	1	0	0	0		
63	Polyline	2.2	Not Applicable	36	6	4	0	0	0		
64	Polyline	1.9	Not Applicable	38	6	1	0	0	0		
65	Polyline	1.4	Not Applicable	52	6	1	0	0	0		
66	Polyline	1.1	Not Applicable	25	6	1	0	0	0		
67	Polyline	2.5	Not Applicable	29	6	3	0	0	0		
68	Polyline	1.1	Not Applicable	33	6	4	0	0	0		
69	Polyline	2.4	Not Applicable	102	6	1	0	0	0		
70	Polyline	1.3	Not Applicable	29	6	1	0	0	0		
71	Polyline	1.2	Not Applicable	22	6	1	0	0	0		
72	Polyline	1.8	Not Applicable	52	6	1	0	0	0		

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
73	Polyline	1.8	Not Applicable	61	6	1	0	0	0		
74	Polyline	1.15	Not Applicable	47	6	2	0	0	0		
75	Polyline	1.2	Not Applicable	17	6	1	0	0	0		
76	Polyline	1.2	Not Applicable	87	6	7	0	0	0		
77	Polyline	1.1	Not Applicable	21	6	1	0	0	0		
78	Polyline	1.65	Not Applicable	17	6	1	0	0	0		
79	Polyline	4.7	Applicable	41	6	2	7	2.5	5	High	High
80	Polyline	2.7	Full Capacity	29	6	5	5	0	0	Low	Low
81	Polyline	3.25	Applicable	13	6	1	2	1	1	Medium	Medium
82	Polyline	4.3	Applicable	14	6	2	2	0	0	Low	Low
83	Polyline	3.25	Applicable	24	6	1	4	3	3	High	High
84	Polyline	3.4	Applicable	86	6	7	14	1	7	Medium	Medium
85	Polyline	3.25	Applicable	22	6	2	4	1	2	Medium	Medium
86	Polyline	5.1	Applicable	44	6	3	7	1.33	4	High	High
87	Polyline	3	Applicable	24	6	3	4	0.33	1	Low	Low
88	Polyline	3.7	Applicable	28	6	3	5	0.67	2	Low	Low
89	Polyline	3	Applicable	48	6	4	8	1	4	Medium	Medium
90	Polyline	2.8	Applicable	74	6	8	12	0.5	4	Low	Low
91	Polyline	3.1	Applicable	20	6	1	3	2	2	High	High
92	Polyline	3.3	Applicable	15	6	1	2	1	1	Medium	Medium
93	Polyline	3.3	Applicable	23	6	1	4	3	3	High	High
94	Polyline	3.6	Applicable	81	6	10	14	0.4	4	Low	Low
95	Polyline	4.7	Applicable	21	6	2	4	1	2	Medium	Medium
96	Polyline	3.6	Applicable	87	6	5	14	1.8	9	High	High
97	Polyline	1.85	Not Applicable	67	6	1	0	0	0		
98	Polyline	5.1	Applicable	34	6	4	6	0.5	2	Low	Low

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
99	Polyline	4	Applicable	24	6	3	4	0.33	1	Low	Low
100	Polyline	1.9	Not Applicable	125	6	6	0	0	0		
101	Polyline	1.9	Not Applicable	25	6	1	0	0	0		
102	Polyline	1.9	Not Applicable	95	6	10	0	0	0		
103	Polyline	3.9	Applicable	15	6	1	2	1	1	Medium	Medium
104	Polyline	2	Not Applicable	20	6	2	0	0	0		
105	Polyline	1.9	Not Applicable	30	6	1	0	0	0		
106	Polyline	2.3	Not Applicable	23	6	1	0	0	0		
107	Polyline	3.9	Applicable	28	6	1	5	4	4	High	High
108	Polyline	2.3	Not Applicable	27	6	1	0	0	0		
109	Polyline	1.9	Not Applicable	32	6	3	0	0	0		
110	Polyline	1.75	Not Applicable	34	6	1	0	0	0		
111	Polyline	2.3	Not Applicable	33	6	1	0	0	0		
112	Polyline	4	Full Capacity	18	6	4	3	0	-1	Low	Low
113	Polyline	6.4	Full Capacity	14	6	4	2	0	-2	Low	Low
114	Polyline	4.1	Applicable	23	6	1	4	3	3	High	High
115	Polyline	1.8	Not Applicable	38	6	1	0	0	0		
116	Polyline	1.8	Not Applicable	59	6	1	0	0	0		
117	Polyline	2.1	Not Applicable	73	6	3	0	0	0		
118	Polyline	1.55	Not Applicable	189	6	6	0	0	0		
119	Polyline	1.45	Not Applicable	51	6	1	0	0	0		
120	Polyline	1.45	Not Applicable	51	6	1	0	0	0		
121	Polyline	2	Not Applicable	16	6	1	0	0	0		
122	Polyline	2.1	Not Applicable	15	6	1	0	0	0		
123	Polyline	1	Not Applicable	19	6	1	0	0	0		
124	Polyline	2	Not Applicable	82	6	1	0	0	0		

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
125	Polyline	1.9	Not Applicable	98	6	1	0	0	0		
126	Polyline	3	Applicable	19	6	1	3	2	2	High	High
127	Polyline	2.8	Applicable	21	6	1	4	3	3	High	High
128	Polyline	2.8	Applicable	44	6	2	7	2.5	5	High	High
129	Polyline	1.9	Not Applicable	91	6	1	0	0	0		
130	Polyline	3	Applicable	24	6	1	4	3	3	High	High
131	Polyline	3.2	Applicable	21	6	2	4	1	2	Medium	Medium
132	Polyline	3.25	Applicable	44	6	5	7	0.4	2	Low	Low
133	Polyline	1.4	Not Applicable	32	6	1	0	0	0		
134	Polyline	3	Applicable	32	6	1	5	4	4	High	High
135	Polyline	1.1	Not Applicable	48	6	1	0	0	0		
136	Polyline	1.1	Not Applicable	98	6	2	0	0	0		
137	Polyline	1.1	Not Applicable	60	6	1	0	0	0		
138	Polyline	1.8	Not Applicable	39	6	1	0	0	0		
139	Polyline	2.15	Full Capacity	38	6	7	6	0	-1		
140	Polyline	1.8	Not Applicable	63	6	1	0	0	0		
141	Polyline	3	Applicable	27	6	1	4	3	3	High	High
142	Polyline	1.2	Full Capacity	66	6	11	11	0	0		
143	Polyline	1.1	Not Applicable	18	6	1	0	0	0		
144	Polyline	3.5	Applicable	49	6	1	8	7	7	High	High
145	Polyline	1.1	Not Applicable	17	6	1	0	0	0		
146	Polyline	3.1	Applicable	52	6	1	9	8	8	High	High
147	Polyline	3.4	Full Capacity	24	6	4	4	0	0	Low	Low
148	Polyline	2	Not Applicable	33	6	4	0	0	0		
149	Polyline	1.9	Not Applicable	55	6	1	0	0	0		
150	Polyline	2	Not Applicable	38	6	5	0	0	0		

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
151	Polyline	2	Not Applicable	57	6	2	0	0	0		
152	Polyline	1.9	Not Applicable	41	6	1	0	0	0		
153	Polyline	1.7	Not Applicable	34	6	1	0	0	0		
154	Polyline	1.6	Not Applicable	39	6	2	0	0	0		
155	Polyline	3.5	Applicable	50	6	1	8	7	7	High	High
156	Polyline	7.9	Applicable	22	6	1	4	3	3	High	High
157	Polyline	2.2	Not Applicable	49	6	1	0	0	0		
158	Polyline	2	Not Applicable	109	6	1	0	0	0		
159	Polyline	1.9	Not Applicable	51	6	3	0	0	0		
160	Polyline	1.9	Not Applicable	53	6	1	0	0	0		
161	Polyline	2	Not Applicable	86	6	1	0	0	0		
162	Polyline	1.6	Not Applicable	11	6	1	0	0	0		
163	Polyline	2.5	Not Applicable	18	6	1	0	0	0		
164	Polyline	2.25	Not Applicable	41	6	2	0	0	0		
165	Polyline	1	Not Applicable	23	6	1	0	0	0		
166	Polyline	2.3	Not Applicable	22	6	1	0	0	0		
167	Polyline	1.1	Not Applicable	12	6	1	0	0	0		
168	Polyline	2.8	Applicable	43	6	1	7	6	6	High	High
169	Polyline	1.5	Not Applicable	12	6	1	0	0	0		
170	Polyline	1.5	Not Applicable	24	6	1	0	0	0		
171	Polyline	1.15	Not Applicable	13	6	1	0	0	0		
172	Polyline	1.6	Not Applicable	22	6	1	0	0	0		
173	Polyline	1.6	Not Applicable	23	6	1	0	0	0		
174	Polyline	3.1	Applicable	45	6	1	8	7	7	High	High
175	Polyline	1.7	Not Applicable	11	6	1	0	0	0		
176	Polyline	3	Full Capacity	26	6	4	4	0	0	Low	Low

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
177	Polyline	1.1	Full Capacity	12	6	2	2	0	0		
178	Polyline	1.4	Not Applicable	16	6	1	0	0	0		
179	Polyline	1.4	Not Applicable	17	6	1	0	0	0		
180	Polyline	1.5	Not Applicable	139	6	1	0	0	0		
181	Polyline	1.4	Not Applicable	48	6	1	0	0	0		
182	Polyline	1.9	Not Applicable	15	6	1	0	0	0		
183	Polyline	2.9	Applicable	19	6	1	3	2	2	High	High
184	Polyline	1	Not Applicable	49	6	6	0	0	0		
185	Polyline	1.9	Not Applicable	49	6	3	0	0	0		
186	Polyline	1.9	Not Applicable	42	6	1	0	0	0		
187	Polyline	4	Applicable	23	6	1	4	3	3	High	High
188	Polyline	1.45	Not Applicable	40	6	1	0	0	0		
189	Polyline	1.6	Not Applicable	55	6	1	0	0	0		
190	Polyline	3.15	Applicable	50	6	1	8	7	7	High	High
191	Polyline	3.95	Applicable	24	6	3	4	0.33	1	Low	Low
192	Polyline	0.8	Not Applicable	26	6	1	0	0	0		
193	Polyline	1.2	Not Applicable	26	6	2	0	0	0		
194	Polyline	2.7	Applicable	35	6	1	6	5	5	High	High
195	Polyline	1.65	Not Applicable	23	6	2	0	0	0		
196	Polyline	2.55	Applicable	34	6	1	6	5	5		High
197	Polyline	1.5	Not Applicable	14	6	1	0	0	0		
198	Polyline	1.5	Not Applicable	38	6	1	0	0	0		
199	Polyline	1.9	Not Applicable	44	6	1	0	0	0		
200	Polyline	1.35	Not Applicable	10	6	1	0	0	0		
201	Polyline	2.1	Not Applicable	45	6	1	0	0	0		
202	Polyline	3.4	Applicable	41	6	1	7	6	6	High	High

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
203	Polyline	1.9	Not Applicable	46	6	1	0	0	0		
204	Polyline	2	Not Applicable	53	6	7	0	0	0		
205	Polyline	4.8	Applicable	53	6	1	9	8	8	High	High
206	Polyline	2.4	Not Applicable	71	6	1	0	0	0		
207	Polyline	3.8	Applicable	36	6	1	6	5	5	High	High
208	Polyline	1.5	Not Applicable	39	6	1	0	0	0		
209	Polyline	1.55	Not Applicable	62	6	1	0	0	0		
210	Polyline	1.35	Not Applicable	20	6	1	0	0	0		
211	Polyline	1.3	Not Applicable	37	6	1	0	0	0		
212	Polyline	2.1	Not Applicable	26	6	1	0	0	0		
213	Polyline	2	Full Capacity	24	6	4	4	0	0		
214	Polyline	2.4	Not Applicable	18	6	1	0	0	0		
215	Polyline	3.2	Full Capacity	21	6	4	4	0	0	Low	Low
216	Polyline	1.7	Not Applicable	36	6	5	0	0	0		
217	Polyline	3	Applicable	29	6	1	5	4	4	High	High
218	Polyline	2.1	Not Applicable	20	6	1	0	0	0		
219	Polyline	1.4	Not Applicable	73	6	1	0	0	0		
220	Polyline	1	Not Applicable	65	6	1	0	0	0		
221	Polyline	1.45	Not Applicable	61	6	1	0	0	0		
222	Polyline	1.9	Not Applicable	19	6	2	0	0	0		
223	Polyline	1.9	Not Applicable	83	6	8	0	0	0		
224	Polyline	2	Not Applicable	55	6	1	0	0	0		
225	Polyline	1.9	Not Applicable	75	6	3	0	0	0		
226	Polyline	1.9	Not Applicable	62	6	7	0	0	0		
227	Polyline	2.1	Not Applicable	16	6	1	0	0	0		
228	Polyline	1.45	Not Applicable	73	6	8	0	0	0		

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
229	Polyline	1.9	Not Applicable	19	6	1	0	0	0		
230	Polyline	4	Applicable	5	6	1	1	0	0	Low	Low
231	Polyline	1.4	Not Applicable	55	6	1	0	0	0		
232	Polyline	1.45	Not Applicable	59	6	1	0	0	0		
233	Polyline	2.8	Applicable	19	6	1	3	2	2	High	High
234	Polyline	2.6	Applicable	43	6	1	7	6	6		High
235	Polyline	1.7	Not Applicable	63	6	1	0	0	0		
236	Polyline	1.2	Not Applicable	66	6	1	0	0	0		
237	Polyline	1.2	Not Applicable	40	6	1	0	0	0		
238	Polyline	3.2	Applicable	26	6	1	4	3	3	High	High
239	Polyline	0.8	Not Applicable	44	6	1	0	0	0		
240	Polyline	1.8	Not Applicable	50	6	1	0	0	0		
241	Polyline	5.8	Applicable	22	6	3	4	0.33	1	Low	Low
242	Polyline	5.8	Applicable	19	6	1	3	2	2	High	High
243	Polyline	4.8	Applicable	16	6	1	3	2	2	High	High
244	Polyline	2.55	Applicable	15	6	1	2	1	1		Medium
245	Polyline	6	Applicable	19	6	1	3	2	2	High	High
246	Polyline	2.5	Not Applicable	18	6	1	0	0	0		
247	Polyline	0	Not Applicable	140	6	1	0	0	0		
248	Polyline	0	Not Applicable	65	6	1	0	0	0		
249	Polyline	0	Not Applicable	39	6	1	0	0	0		
250	Polyline	0	Not Applicable	13	6	1	0	0	0		
251	Polyline	0	Not Applicable	50	6	1	0	0	0		
252	Polyline	0	Not Applicable	7	6	1	0	0	0		
253	Polyline	0	Not Applicable	4	6	1	0	0	0		
254	Polyline	0	Not Applicable	92	6	1	0	0	0		

FID	Shape *	Width (m)	Applicable Width	Length (m)	Threshold	# of Trees	Length/Threshold	Ratio	Trees Difference	Opportunity for Planters	Opportunity for Trees
255	Polyline	0	Not Applicable	45	6	1	0	0	0		
256	Polyline	0	Not Applicable	42	6	1	0	0	0		
257	Polyline	0	Not Applicable	109	6	1	0	0	0		
258	Polyline	0	Not Applicable	68	6	1	0	0	0		
259	Polyline	0	Not Applicable	17	6	1	0	0	0		
260	Polyline	0	Not Applicable	18	6	1	0	0	0		
261	Polyline	0	Not Applicable	33	6	1	0	0	0		
262	Polyline	0	Not Applicable	128	6	1	0	0	0		
263	Polyline	0	Not Applicable	43	6	1	0	0	0		
264	Polyline	0	Not Applicable	18	6	1	0	0	0		
265	Polyline	0	Not Applicable	33	6	1	0	0	0		
266	Polyline	0	Not Applicable	19	6	1	0	0	0		
267	Polyline	0	Not Applicable	16	6	1	0	0	0		
268	Polyline	0	Not Applicable	20	6	1	0	0	0		
269	Polyline	0	Not Applicable	19	6	1	0	0	0		
270	Polyline	0	Not Applicable	37	6	1	0	0	0		
271	Polyline	0	Not Applicable	68	6	1	0	0	0		
272	Polyline	0	Not Applicable	67	6	1	0	0	0		
273	Polyline	0	Not Applicable	62	6	1	0	0	0		
274	Polyline	0	Not Applicable	62	6	1	0	0	0		
275	Polyline	2.1	Not Applicable	51	6	1	0	0	0		
276	Polyline	2	Not Applicable	25	6	1	0	0	0		
277	Polyline	0	Not Applicable	26	6	1	0	0	0		
278	Polyline	0	Not Applicable	6	6	1	0	0	0		
279	Polyline	0	Not Applicable	17	6	1	0	0	0		

APPENDIX II

GIS DATA FOR GREEN ROOFS AND GREEN WALLS

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
0	Polygon	125	182	0	Not Applicable	Concrete with balcony		0	Low
1	Polygon	98	24	118	Low	Concrete with balcony		0	Low
2	Polygon	414	320	282	Low	Concrete with balcony		0	Low
3	Polygon	37	54	0	Not Applicable	Concrete with balcony		0	Low
4	Polygon	38	55	0	Not Applicable	Concrete with balcony		0	Low
5	Polygon	236	235	108	Low	Concrete with balcony		0	Low
6	Polygon	194	51	231	Low	Concrete	yes	182	High
7	Polygon	207	0	300	Low	Mixed (Concrete/ Balcony)		0	Low
8	Polygon	228	102	229	Low	Concrete with balcony	yes	1450	High
9	Polygon	543	0	790	Medium	Concrete with balcony		0	Low
10	Polygon	131	22	169	Low	Concrete with balcony		0	Low
11	Polygon	282	0	410	Low	Concrete with balcony		0	Low
12	Polygon	241	120	231	Low	Concrete		0	Low
13	Polygon	346	121	382	Low	Concrete		0	Low
14	Polygon	353	223	290	Low	Concrete with balcony		0	Low
15	Polygon	235	39	303	Low	Concrete		0	Low
16	Polygon	430	164	462	Low	Concrete with balcony		0	Low
17	Polygon	199	124	165	Low	Glass		0	Low
18	Polygon	424	73	544	Medium	Concrete with balcony		0	Low
19	Polygon	1576	223	2068	High	Mixed (Concrete/ Balcony)		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
20	Polygon	353	514	0	Not Applicable	Mixed (Concrete/ Balcony)		0	Low
21	Polygon	252	170	197	Low	Concrete with balcony		0	Low
22	Polygon	433	110	520	Medium	Concrete with balcony		0	Low
23	Polygon	355	321	196	Low	Concrete with balcony		0	Low
24	Polygon	199	183	107	Low	Concrete with balcony		0	Low
25	Polygon	305	68	376	Low	Concrete		0	Low
26	Polygon	207	0	301	Low	Existing Green Wall		0	Low
27	Polygon	229	334	0	Not Applicable	Concrete with balcony		0	Low
28	Polygon	261	57	322	Low	Concrete with balcony		0	Low
29	Polygon	404	356	231	Low	Concrete with balcony	yes	15	High
30	Polygon	415	307	297	Low	Mixed (Concrete/ Balcony)		0	Low
31	Polygon	274	285	114	Low	Concrete with balcony		0	Low
32	Polygon	425	56	562	Medium	Concrete with balcony		0	Low
33	Polygon	151	116	104	Low	Concrete with balcony		0	Low
34	Polygon	268	179	211	Low	Concrete with balcony		0	Low
35	Polygon	212	147	161	Low	Concrete with balcony		0	Low
36	Polygon	377	183	365	Low	Concrete with balcony		0	Low
37	Polygon	117	50	120	Low	Concrete with balcony		0	Low
38	Polygon	128	30	157	Low	Concrete with balcony		0	Low
39	Polygon	237	41	303	Low	Concrete with balcony		0	Low
40	Polygon	419	473	137	Low	Concrete with balcony		0	Low
41	Polygon	391	568	0	Not Applicable	Mixed (Glass and Balcony)		0	Low
42	Polygon	140	57	146	Low	Concrete with balcony		0	Low
43	Polygon	220	320	0	Not Applicable	Concrete with balcony		0	Low
44	Polygon	168	60	184	Low	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
45	Polygon	282	241	169	Low	Concrete with balcony	yes	32	Medium
46	Polygon	267	56	333	Low	Concrete with balcony		0	Low
47	Polygon	232	296	42	Low	Concrete with balcony		0	Low
48	Polygon	145	211	0	Not Applicable	Concrete		0	Low
49	Polygon	219	34	285	Low	Concrete with balcony		0	Low
50	Polygon	225	327	0	Not Applicable	Concrete	yes	233	Medium
51	Polygon	72	55	49	Low	Concrete	yes	233	Medium
52	Polygon	229	142	191	Low	Concrete	yes	86	High
53	Polygon	306	327	118	Low	Concrete with balcony		0	Low
54	Polygon	876	867	408	Low	Concrete		0	Low
55	Polygon	217	181	134	Low	Concrete with balcony	yes	0	Medium
56	Polygon	141	42	102	Low	Concrete with balcony	yes	233	High
57	Polygon	277	172	231	Low	Concrete with balcony		0	Low
58	Polygon	459	403	265	Low	Concrete		0	Low
59	Polygon	162	23	212	Low	Concrete with balcony		0	Low
60	Polygon	626	668	243	Low	Concrete with balcony		0	Low
61	Polygon	336	193	295	Low	Mixed (Concrete/ Balcony)		0	Low
62	Polygon	302	138	302	Low	Concrete with balcony		0	Low
63	Polygon	196	91	194	Low	Concrete with balcony		0	Low
64	Polygon	202	69	224	Low	Concrete with balcony		0	Low
65	Polygon	462	672	0	Not Applicable	Concrete		0	Low
66	Polygon	258	71	304	Low	Concrete with balcony		0	Low
67	Polygon	349	355	153	Low	Concrete with balcony		0	Low
68	Polygon	51	0	74	Low	Concrete		0	Low
69	Polygon	149	0	216	Low	Concrete		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
70	Polygon	315	41	418	Low	Concrete		0	Low
71	Polygon	205	69	229	Low	Concrete with balcony		0	Low
72	Polygon	294	333	95	Low	Concrete		0	Low
73	Polygon	204	53	243	Low	Concrete with balcony		0	Low
74	Polygon	149	0	217	Low	Concrete with balcony		0	Low
75	Polygon	195	200	83	Low	Concrete with balcony		0	Low
76	Polygon	292	280	145	Low	Concrete with balcony		0	Low
77	Polygon	206	54	245	Low	Concrete with balcony		0	Low
78	Polygon	248	0	361	Low	Concrete		0	Low
79	Polygon	465	294	382	Low	Concrete with balcony		0	Low
80	Polygon	961	422	976	Medium	Concrete	yes	899	High
81	Polygon	444	434	211	Low	Concrete		0	Low
82	Polygon	253	368	0	Not Applicable	Concrete		0	Low
83	Polygon	173	84	168	Low	Concrete with balcony		0	Low
84	Polygon	219	319	0	Not Applicable	Concrete with balcony		0	Low
85	Polygon	139	0	202	Low	Concrete with balcony		0	Low
86	Polygon	136	43	155	Low	Concrete with balcony		0	Low
87	Polygon	100	145	0	Not Applicable	Concrete with balcony		0	Low
88	Polygon	326	0	474	Low	Concrete		0	Low
89	Polygon	101	101	46	Low	Concrete with balcony		0	Low
90	Polygon	997	379	1070	High	Glass		0	Low
91	Polygon	312	143	311	Low	Concrete		0	Low
92	Polygon	47	0	69	Low			0	Low
93	Polygon	339	365	129	Low	Concrete		0	Low
94	Polygon	123	179	0	Not Applicable	Concrete		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
95	Polygon	240	109	240	Low	Concrete with balcony		0	Low
96	Polygon	1927	1181	1622	High	Glass		0	Low
97	Polygon	426	141	479	Low	Concrete		0	Low
98	Polygon	715	1040	0	Not Applicable	Concrete with balcony	yes	9	Medium
99	Polygon	539	405	379	Low	Glass		0	Low
100	Polygon	3002	933	3433	High	Concrete		0	Low
101	Polygon	3298	4797	0	Not Applicable	Concrete		0	Low
102	Polygon	1133	0	1648	High	Concrete	yes	899	Medium
103	Polygon	1502	426	1759	High	Concrete		0	Low
104	Polygon	441	641	0	Not Applicable	Glass		0	Low
105	Polygon	683	534	459	Low	Glass		0	Low
106	Polygon	111	162	0	Not Applicable	Concrete		0	Low
107	Polygon	478	482	214	Low	Concrete with balcony		0	Low
108	Polygon	542	389	399	Low	Concrete with balcony		0	Low
109	Polygon	595	100	766	Medium	Concrete with balcony		0	Low
110	Polygon	204	297	0	Not Applicable	Concrete	yes	15	High
111	Polygon	393	84	487	Low	Glass		0	Low
112	Polygon	320	283	182	Low	Glass		0	Low
113	Polygon	547	566	229	Low	Glass		0	Low
114	Polygon	696	0	1013	High	Concrete with balcony		0	Low
115	Polygon	330	90	389	Low	Concrete with balcony	yes	7	High
116	Polygon	700	1019	0	Not Applicable	Concrete		0	Low
117	Polygon	560	814	0	Not Applicable	Concrete		0	Low
118	Polygon	339	111	228	Low	Concrete		0	Low
119	Polygon	443	645	0	Not Applicable	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
120	Polygon	423	305	310	Low	Concrete with balcony		0	Low
121	Polygon	258	205	170	Low	Concrete with balcony		0	Low
122	Polygon	263	383	0	Not Applicable	Glass		0	Low
123	Polygon	255	57	314	Low	Concrete with balcony		0	Low
124	Polygon	264	383	0	Not Applicable	Concrete		0	Low
125	Polygon	166	114	128	Low	Concrete with balcony		0	Low
126	Polygon	409	45	550	Medium	Concrete		0	Low
127	Polygon	1311	704	1203	High	Existing Green Wall		0	Low
128	Polygon	61	89	0	Not Applicable	Concrete		0	Low
129	Polygon	104	72	80	Low	Concrete with balcony		0	Low
130	Polygon	453	324	335	Low	Concrete with balcony		0	Low
131	Polygon	761	109	998	Medium	Mixed (Concrete/ Balcony)	yes	6	High
132	Polygon	334	126	359	Low	Concrete with balcony		0	Low
133	Polygon	410	135	461	Low	Concrete with balcony		0	Low
134	Polygon	190	277	0	Not Applicable	Glass	yes	21	Low
135	Polygon	276	401	0	Not Applicable	Concrete		0	Low
136	Polygon	404	588	0	Not Applicable	Concrete with balcony		0	Low
137	Polygon	576	93	745	Medium	Concrete with balcony		0	Low
138	Polygon	498	202	522	Medium	Existing Green Wall		0	Low
139	Polygon	593	140	722	Medium	Glass		0	Low
140	Polygon	898	274	1033	High	Concrete		0	Low
141	Polygon	585	205	646	Medium	Concrete with balcony		0	Low
142	Polygon	200	291	0	Not Applicable	Concrete with balcony		0	Low
143	Polygon	197	94	192	Low	Concrete with balcony		0	Low
144	Polygon	329	277	202	Low	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
145	Polygon	463	591	83	Low	Concrete with balcony		0	Low
146	Polygon	166	125	117	Low	Concrete		0	Low
147	Polygon	391	569	0	Not Applicable	Concrete with balcony	yes	0	High
148	Polygon	199	290	0	Not Applicable	Concrete with balcony		0	Low
149	Polygon	213	100	210	Low	Concrete with balcony		0	Low
150	Polygon	208	302	0	Not Applicable	Concrete with balcony		0	Low
151	Polygon	111	113	49	Low	Concrete with balcony		0	Low
152	Polygon	152	221	0	Not Applicable	Concrete with balcony	yes	8	High
153	Polygon	336	250	239	Low	Concrete with balcony	yes	27	High
154	Polygon	350	145	364	Low	Concrete with balcony	yes	15	High
155	Polygon	191	90	188	Low	Concrete with balcony		0	Low
156	Polygon	189	51	224	Low	Existing Green Wall	yes	6	
157	Polygon	401	583	0	Not Applicable	Concrete with balcony		0	Low
158	Polygon	115	167	0	Not Applicable	Concrete with balcony		0	Low
159	Polygon	668	400	572	Medium	Mixed (Glass/ Concrete)		0	Low
160	Polygon	375	85	460	Low	Concrete		0	Low
161	Polygon	586	314	538	Medium	Concrete with balcony		0	Low
162	Polygon	366	149	384	Low	Concrete with balcony		0	Low
163	Polygon	249	362	0	Not Applicable	Concrete with balcony		0	Low
164	Polygon	179	260	0	Not Applicable	Concrete with balcony		0	Low
165	Polygon	387	103	460	Low	Concrete		0	Low
166	Polygon	294	427	0	Not Applicable	Concrete with balcony	yes	75	High
167	Polygon	373	101	442	Low	Concrete with balcony	yes	75	High
168	Polygon	613	409	204	Low	Concrete		0	Low
169	Polygon	287	35	383	Low	Glass		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
170	Polygon	461	323	138	Low	Existing Green Wall		0	Low
171	Polygon	425	229	390	Low	Existing Green Wall		0	Low
172	Polygon	513	496	250	Low	Glass		0	Low
173	Polygon	480	698	0	Not Applicable	Glass		0	Low
174	Polygon	331	280	201	Low	Glass		0	Low
175	Polygon	353	0	514	Medium	Glass		0	Low
176	Polygon	300	155	281	Low	Concrete		0	Low
177	Polygon	178	62	196	Low	Mixed (Concrete/ Balcony)		0	Low
178	Polygon	144	109	101	Low	Concrete		0	Low
179	Polygon	149	110	106	Low	Glass		0	Low
180	Polygon	242	127	225	Low	Concrete		0	Low
181	Polygon	137	135	64	Low	Concrete with balcony		0	Low
182	Polygon	67	25	72	Low	Glass		0	Low
183	Polygon	104	67	84	Low	Concrete with balcony		0	Low
184	Polygon	117	129	41	Low	Concrete with balcony		0	Low
185	Polygon	382	402	153	Low	Concrete with balcony		0	Low
186	Polygon	573	429	404	Low	Glass		0	Low
187	Polygon	327	417	58	Low	Concrete with balcony		0	Low
188	Polygon	345	26	307	Low	Concrete with balcony		0	Low
189	Polygon	255	107	264	Low	Concrete with balcony		0	Low
190	Polygon	179	175	86	Low	Concrete with balcony		0	Low
191	Polygon	487	424	284	Low	Glass		0	Low
192	Polygon	604	329	550	Medium	Glass		0	Low
193	Polygon	348	88	418	Low	Concrete with balcony		0	Low
194	Polygon	266	0	387	Low	Glass		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
195	Polygon	590	214	644	Medium	Concrete		0	Low
196	Polygon	537	696	84	Low	Concrete with balcony		0	Low
197	Polygon	811	215	965	Medium	Concrete		0	Low
198	Polygon	345	190	312	Low	Existing Green Wall		0	Low
199	Polygon	213	162	148	Low	Concrete with balcony		0	Low
200	Polygon	496	721	0	Not Applicable	Concrete with balcony	yes	12	Medium
201	Polygon	366	105	427	Low	Existing Green Wall		0	Low
202	Polygon	493	349	368	Low	Concrete with balcony		0	Low
203	Polygon	269	277	114	Low	Concrete with balcony		0	Low
204	Polygon	220	73	247	Low	Glass		0	Low
205	Polygon	269	312	79	Low	Glass		0	Low
206	Polygon	138	154	47	Low	Concrete with balcony		0	Low
207	Polygon	300	93	343	Low	Concrete		0	Low
208	Polygon	552	600	204	Low	Existing Green Wall		0	Low
209	Polygon	492	400	316	Low	Concrete with balcony		0	Low
210	Polygon	424	617	0	Not Applicable	Concrete with balcony		0	Low
211	Polygon	105	0	152	Low	Concrete	yes	233	High
212	Polygon	545	547	245	Low	Concrete with balcony	yes	9	High
213	Polygon	402	111	474	Low	Concrete with balcony		0	Low
214	Polygon	484	580	124	Low	Concrete with balcony		0	Low
215	Polygon	188	274	0	Not Applicable	Concrete with balcony		0	Low
216	Polygon	247	360	0	Not Applicable	Concrete with balcony		0	Low
217	Polygon	228	106	225	Low	Concrete with balcony		0	Low
218	Polygon	206	299	0	Not Applicable	Concrete with balcony		0	Low
219	Polygon	177	258	0	Not Applicable	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
220	Polygon	240	288	60	Low	Concrete with balcony		0	Low
221	Polygon	213	310	0	Not Applicable	Concrete with balcony		0	Low
222	Polygon	138	201	0	Not Applicable	Concrete		0	Low
223	Polygon	147	139	74	Low	Concrete with balcony		0	Low
224	Polygon	499	0	726	Medium	Glass		0	Low
225	Polygon	638	450	478	Low	Concrete with balcony	yes	0	
226	Polygon	449	53	600	Medium	Concrete with balcony	yes	2	High
227	Polygon	128	187	0	Not Applicable	Concrete		0	Low
228	Polygon	708	215	814	Medium	Concrete with balcony		0	Low
229	Polygon	235	164	178	Low	Concrete with balcony		0	Low
230	Polygon	361	525	0	Not Applicable	Concrete with balcony		0	Low
231	Polygon	938	1214	150	Low	Concrete with balcony		0	Low
232	Polygon	450	370	285	Low	Concrete with balcony	yes	40	Medium
233	Polygon	237	188	156	Low	Concrete		0	Low
234	Polygon	337	390	100	Low	Concrete with balcony		0	Low
235	Polygon	155	23	203	Low	Concrete with balcony	yes	1450	High
236	Polygon	370	539	0	Not Applicable	Glass		0	Low
237	Polygon	611	305	583	Medium	Concrete		0	Low
238	Polygon	472	247	439	Low	Concrete with balcony		0	Low
239	Polygon	243	145	209	Low	Concrete		0	Low
240	Polygon	806	117	1116	High	Concrete with balcony		0	Low
241	Polygon	592	342	520	Medium	Concrete with balcony		0	Low
242	Polygon	522	356	372	Low	Concrete with balcony		0	Low
243	Polygon	620	505	396	Low	Concrete with balcony		0	Low
244	Polygon	937	704	659	Medium	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
245	Polygon	433	555	75	Low	Concrete with balcony		0	Low
246	Polygon	588	619	237	Low	Concrete with balcony	yes	10	High
247	Polygon	119	39	134	Low	Concrete with balcony		0	Low
248	Polygon	333	109	375	Low	Glass		0	Low
249	Polygon	311	180	273	Low	Concrete with balcony		0	Low
250	Polygon	632	271	649	Medium	Concrete with balcony	yes	2	High
251	Polygon	441	345	297	Low	Concrete with balcony	yes	2	High
252	Polygon	111	104	57	Low	Concrete with balcony		0	Low
253	Polygon	303	264	177	Low	Concrete with balcony		0	Low
254	Polygon	273	125	273	Low	Concrete with balcony		0	Low
255	Polygon	440	640	0	Not Applicable	Concrete	yes	2	High
256	Polygon	353	245	268	Low	Concrete		0	Low
257	Polygon	780	266	869	Medium	Concrete		0	Low
258	Polygon	302	439	0	Not Applicable	Concrete	yes	568	Medium
259	Polygon	559	260	552	Medium	Concrete with balcony	yes	568	High
260	Polygon	626	161	750	Medium	Concrete with balcony		0	Low
261	Polygon	330	166	315	Low	Concrete with balcony		0	Low
262	Polygon	372	345	196	Low	Concrete with balcony		0	Low
263	Polygon	272	79	316	Low	Concrete with balcony		0	Low
264	Polygon	430	66	560	Medium	Concrete	yes	4	High
265	Polygon	225	33	294	Low	Mixed (Glass/ Concrete)		0	Low
266	Polygon	237	142	202	Low	Concrete with balcony		0	Low
267	Polygon	253	298	69	Low	Concrete with balcony		0	Low
268	Polygon	195	35	248	Low	Concrete with balcony		0	Low
269	Polygon	324	149	322	Low	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
270	Polygon	306	251	194	Low	Concrete with balcony	yes	86	High
271	Polygon	327	157	319	Low	Concrete		0	Low
272	Polygon	244	92	262	Low	Concrete with balcony		0	Low
273	Polygon	470	100	584	Medium	Concrete with balcony		0	Low
274	Polygon	737	831	242	Low	Mixed (Concrete/ Balcony)	yes	46	High
275	Polygon	562	359	458	Low	Concrete with balcony		0	Low
276	Polygon	506	65	671	Medium	Concrete		0	Low
277	Polygon	949	0	1380	High	Concrete		0	Low
278	Polygon	327	390	86	Low	Mixed (Concrete/ Balcony)	yes	4	High
279	Polygon	241	0	351	Low	Concrete with balcony		0	Low
280	Polygon	202	293	0	Not Applicable	Concrete with balcony		0	Low
281	Polygon	819	1191	0	Not Applicable	Concrete with balcony		0	Low
282	Polygon	116	78	90	Low	Concrete with balcony		0	Low
283	Polygon	178	99	160	Low	Concrete with balcony		0	Low
284	Polygon	105	61	92	Low	Concrete with balcony		0	Low
285	Polygon	534	285	492	Low	Concrete with balcony		0	Low
286	Polygon	576	838	0	Not Applicable	Concrete with balcony	yes	1	High
287	Polygon	511	462	281	Low	Concrete with balcony		0	Low
288	Polygon	478	442	253	Low	Concrete with balcony		0	Low
289	Polygon	205	83	120	Low	Concrete with balcony		0	Low
290	Polygon	434	362	269	Low	Existing Green Wall		0	Low
291	Polygon	159	98	133	Low	Concrete with balcony		0	Low
292	Polygon	91	84	49	Low	Concrete with balcony		0	Low
293	Polygon	599	372	499	Low	Concrete with balcony		0	Low
294	Polygon	262	46	334	Low	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
295	Polygon	523	246	514	Medium	Concrete with balcony		0	Low
296	Polygon	178	111	148	Low	Concrete with balcony		0	Low
297	Polygon	273	178	219	Low	Concrete with balcony		0	Low
298	Polygon	246	171	186	Low	Concrete with balcony		0	Low
299	Polygon	120	0	175	Low	Concrete with balcony	yes	9	Medium
300	Polygon	159	53	179	Low	Concrete with balcony		0	Low
301	Polygon	48	70	0	Not Applicable			0	Low
302	Polygon	415	62	542	Medium	Concrete with balcony		0	Low
303	Polygon	283	203	262	Low	Concrete with balcony		0	Low
304	Polygon	349	84	424	Low	Concrete with balcony		0	Low
305	Polygon	696	337	675	Medium	Concrete with balcony		0	Low
306	Polygon	658	507	450	Low	Concrete		0	Low
307	Polygon	277	303	100	Low	Mixed (Glass and Balcony)		0	Low
308	Polygon	132	98	94	Low	Concrete with balcony		0	Low
309	Polygon	285	219	196	Low	Glass		0	Low
310	Polygon	678	545	442	Low	Mixed (Concrete/ Balcony)	yes	12	Medium
311	Polygon	514	537	210	Low	Concrete with balcony		0	Low
312	Polygon	186	186	84	Low	Concrete with balcony		0	Low
313	Polygon	204	107	190	Low	Concrete with balcony		0	Low
314	Polygon	583	190	659	Medium	Concrete with balcony		0	Low
315	Polygon	363	527	0	Not Applicable	Concrete with balcony		0	Low
316	Polygon	498	255	470	Low	Concrete with balcony		0	Low
317	Polygon	382	332	223	Low	Concrete with balcony		0	Low
318	Polygon	194	182	101	Low	Concrete with balcony		0	Low
319	Polygon	113	60	104	Low	Concrete		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
320	Polygon	146	152	60	Low	Concrete		0	Low
321	Polygon	229	104	229	Low	Concrete with balcony		0	Low
322	Polygon	236	102	241	Low	Concrete with balcony		0	Low
323	Polygon	406	281	310	Low	Concrete with balcony		0	Low
324	Polygon	107	0	156	Low	Concrete with balcony		0	Low
325	Polygon	68	0	99	Low	Concrete with balcony		0	Low
326	Polygon	257	38	336	Low	Mixed (Glass/ Concrete)		0	Low
327	Polygon	655	620	333	Low	Concrete with balcony		0	Low
328	Polygon	325	473	0	Not Applicable	Concrete	yes	620	High
329	Polygon	341	403	93	Low	Glass		0	Low
330	Polygon	517	155	597	Medium	Concrete with balcony		0	Low
331	Polygon	329	147	331	Low	Concrete with balcony		0	Low
332	Polygon	253	91	277	Low	Concrete with balcony		0	Low
333	Polygon	305	0	443	Low	Concrete with balcony		0	Low
334	Polygon	311	453	0	Not Applicable	Concrete with balcony	yes	5	High
335	Polygon	364	91	438	Low	Concrete with balcony		0	Low
336	Polygon	125	0	181	Low	Concrete with balcony		0	Low
337	Polygon	196	25	260	Low	Concrete with balcony		0	Low
338	Polygon	723	702	350	Low	Concrete		0	Low
339	Polygon	139	123	80	Low	Concrete with balcony		0	Low
340	Polygon	341	382	114	Low	Concrete with balcony		0	Low
341	Polygon	253	166	202	Low	Glass		0	Low
342	Polygon	298	273	160	Low	Existing Green Wall		0	Low
343	Polygon	322	351	117	Low	Concrete with balcony		0	Low
344	Polygon	221	188	134	Low	Concrete with balcony		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
345	Polygon	140	30	173	Low	Concrete with balcony		0	Low
346	Polygon	195	53	230	Low	Concrete with balcony		0	Low
347	Polygon	104	152	0	Not Applicable	Concrete		0	Low
348	Polygon	192	193	87	Low	Concrete		0	Low
349	Polygon	335	276	211	Low	Concrete		0	Low
350	Polygon	319	110	353	Low	Concrete with balcony		0	Low
351	Polygon	272	101	295	Low	Concrete with balcony		0	Low
352	Polygon	216	32	184	Low	Concrete		0	Low
353	Polygon	406	387	203	Low	Concrete with balcony		0	Low
354	Polygon	214	145	166	Low	Concrete with balcony		0	Low
355	Polygon	367	129	405	Low	Concrete with balcony	yes	336	High
356	Polygon	143	167	40	Low	Mixed (Concrete/ Balcony)	yes	336	High
357	Polygon	209	81	223	Low	Concrete with balcony		0	Low
358	Polygon	390	445	123	Low	Concrete	yes	336	High
359	Polygon	4255	5506	682	Medium	Concrete		0	Low
360	Polygon	405	307	282	Low	Concrete with balcony		0	Low
361	Polygon	264	137	246	Low	Concrete		0	Low
362	Polygon	1037	297	1211	High	Glass		0	Low
363	Polygon	302	120	319	Low	Glass		0	Low
364	Polygon	333	0	484	Low	Glass		0	Low
365	Polygon	1231	962	828	Medium	Glass		0	Low
366	Polygon	212	48	260	Low	Concrete		0	Low
367	Polygon	249	206	156	Low	Concrete		0	Low
368	Polygon	301	90	347	Low	Concrete with balcony		0	Low
369	Polygon	158	104	126	Low	Glass		0	Low

FID	Shape *	Roof Area	Occupied Roof Space	Free Roof Space	Green Roof Opportunity	Façade Material	Available Soil	Soil Area	Green Wall Opportunity
370	Polygon	0	0	0	Not Applicable	Concrete with balcony		0	Low
371	Polygon	261	71	190	Low	Concrete with balcony		0	Low
372	Polygon	732	732	0	Not Applicable	Existing Green Wall		0	Low
373	Polygon	267	51	216	Low	Glass		0	Low
374	Polygon	568	568	0	Not Applicable			0	Low
375	Polygon	391	246	145	Low	Concrete with balcony		0	Low
376	Polygon	112	0	112	Low	Concrete with balcony		0	Low

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