AMERICAN UNIVERSITY OF BEIRUT

EXPLORING URBAN TRANSITIONAL SPACES AS CONTRIBUTORS TO URBAN GREENING – BEIRUT CASE STUDY

by
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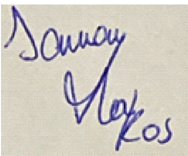
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ABSTRACT
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Trees are considered as the lungs of the city as they help mitigate air pollution. In dense urban areas, however, trees are non-existent and there is a need to explore the potential contribution of plants in alternative spaces such as vegetated transitional spaces, i.e. areas linking the inner and outer urban spaces. Most studies that report the beneficial impact of plants on urban air quality focus on assessing tree canopies while very few studies have attempted to explore the contribution of vegetated balconies to improved urban air quality. This study aims to assess the extent to which transitional spaces, specifically private balconies in residential areas, can mitigate air pollution.

The study was performed in Beirut, Lebanon. A total of 150 vegetated balconies were selected following purposeful sampling to capture examples of successfully maintained green balconies in the city of Beirut. The balconies were photographed from the street, and the number and types of plant species were deduced from the images. The mature size of each recorded plant species was estimated based on local expertise of typical container grown plant sizes in Beirut assuming that herbaceous plants are grown in 30 cm containers and woody plants in 50 cm containers. The canopy volume contributed by each plant species was then calculated following the formula by Thorne et.al, 2002 which is based on height and width of the plant. The small tree canopy equivalent (150,000,000 cm3) of the 150 case study vegetated balconies was then calculated by assessing the potential contribution of 20 such balconies in a 10 floor apartment building. In addition, the small tree canopy equivalent of each recorded species was calculated assuming 10 plants per balcony and assessing the potential contribution of 20 such balconies in a 10 floor apartment building. The results revealed 10 vegetated balcony assemblages that contributed the equivalent of 2-5 small trees per building. With respect to individual plant species, maximum canopy volume contribution was obtained from the following woody plants species, *Trachelospermum jasminoides* (2,617,994 cm3), *Jasminum officinale* (2,356,194 cm3), *Olea europaea L.* (2,120,575 cm3) and herbaceous plant species *Strelitzia sp.* (2,144,661 cm3), *Araucaria heterophylla (1,047,198 cm3), Musa acuminata Colla* (1,769,764 cm3). Results of this study provide quantitative estimates that shed light on the potential role that residents of urban dense neighborhoods can play in contributing to urban greening and improving urban air quality by planting their balconies.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS………………………………….. 1

ABSTRACT……………………………………………….. 2

ILLUSTRATIONS……………………………………… 5

TABLES…………………………………………………… 6

INTRODUCTION……………………………………… 7

A.Plants mitigate air pollution…………………………………………………….. 7

B.Plant canopies and air pollution mitigation: case studies of street trees…………… 8

C.Alternatives to urban trees in narrow streets ……………………………..…….10

D.Balconies as transitional green spaces for mitigating air pollution……………… 11

E.Objective………………………………………………………………………… 11

F.Research question……………………………………………………………….12

METHODOLOGY……………………………….. 13

A.Study area……………………………………………………………………… 13

1. Neighborhood description……………………………………………………….. 13

B.Case study balconies…………………………………………………………… 14

C.Photo Documentation and data collection from case study balconies……………. 14

D.Calculation of plant canopy volumes contributed by case study balconies……….15

E.Data analysis…………………………………………………………………… 16

RESULTS…………………………………………… 17

A.Type of planters and size of case study balconies………………………………………17

B.Type (woody / herbaceous) and density of plants used in case study balconies………….. 19

C.Estimated plant canopy volume and small urban tree equivalent contribution by case study balconies…………………………………………………………………………………...25

D.Plant species used in case study balconies………………………………………………... 39

E.Estimated plant canopy volume and small urban tree equivalent contribution by species recorded in case study balconies…………………………………………………………….. 44

F.Estimated plant canopy volume and small urban tree equivalent extrapolation to 10 floor 20 balcony building…………………………………………………………………………….. 48

DISCUSSION……………………………………………………..52

CONCLUSION…………………………………………………… 59

APPENDIX……………………………………………………….. 61

REFERENCES…………………………………………………… 63

ILLUSTRATIONS

Figure

1. Percentage of plants grown in in-built planters and in pot in the case study balconies in Beirut, Lebanon……………………………………………..15

2. Balcony plants grown in pots or in in-built planters in case study balconies in Beirut, Lebanon…………………………………………………………...15

3. Percentage of large and small balconies in the case study data…………17

4. Percentage balconies planted with only woody plants, only herbaceous plants and the combination of both woody and herbaceous plants…………….. 18

5. Different balcony examples from the data collection in Beirut, Lebanon..36

6. Percentage of herbaceous and woody plant species in the case study balconies in Beirut, Lebanon…………………………………………………………. 37

TABLES

Table

1. The number of woody plants on large or small balconies with only woody plants…………………………………………………………………..19

2. The number of plants available on balconies with both woody and herbaceous plants…………………………………………………………………..21

3. The number of herbaceous plants available on balconies with herbaceous plants only……………………………………………………………………..23

4. Balcony plant composition, estimated canopy volume, and number of small tree equivalents contributed by 150 case study vegetated balconies in Beirut, Lebanon. Canopy volume was calculated following Thorne, 2002………24

5. The number of woody species available on the balconies in Beirut, Lebanon…………………………………………………………………38

6. The number of herbaceous species available on the balconies in Beirut, Lebanon………………………………………………………………. 40

7. Most frequently recorded plant species in case study balconies in Beirut, Lebanon………………………………………………………………..41

8. Plant species recorded in only one of the 150 case study balconies in Beirut, Lebanon………………………………………………………………. 41

9. Estimated Canopy volume of herbaceous plants (by species) (estimated pot size 30 cm diameter) on selected balconies (150) in Beirut, Lebanon. Canopy volume was calculated following Thorne, 2002………………………………….42

10. Estimated canopy volume of woody plants and herbaceous plants with a woody appearance (e.g bamboos and palms) (by species) (estimated pot size 50 cm) on selected balconies in Beirut, Lebanon. Canopy volume was calculated following Thorne, 2002………………………………………………………. 44

11. Estimated number of small tree canopy equivalent contributed by a building that has 20 large apartment balconies each planted with 15 woody plants. Canopy volume was calculated following Thorne, 2002………………………… 47

CHAPTER I

INTRODUCTION

A. Plants mitigate air pollution

In 2020, the American Heart Association supported the association between areas with high greenness and a low rate of deaths from heart diseases. The Association reported that for "every 0.1 unit increase in greenness, deaths from heart diseases decreased by 13 deaths per 100,000 adults, while "for every 1 microgram increase in particulate matter per cubic meter of air, death from heart disease increased roughly by 39 deaths per 100,000 adults." (ScienceDaily, 2020). Plants have positive effects on air quality in urban areas; they intercept, modify, and reduce air pollution. Air pollution mitigation by plants occurs through the deposition of solid pollutants on the leaf surface and the absorption of gaseous pollutants by the stomata (Mori, 2018). Plants intercept pollutants before they reach people, they contribute to their dispersion by changing their speed and the distance traveled, and reduce exposure to air pollutants by diluting them with cleaner air (Greater London Authority, 2019).

Urban trees provide several ecosystem services at both the building and the urban scale (Prihatmanti, 2018). The use of plants as a nature based approach to mitigate air pollution is discussed by Jayasooriya (2017) and by Kumar (2019), while Hewitt (2020) indicates that the use of plants is a win–win solution to urban air pollution, reducing ground-level concentrations without imposing restrictions on traffic and other polluting activities. Although the effect of vegetation on air quality over large urban areas has been investigated using micrometeorological approaches and modeling at regional scale, there remains considerable uncertainty in the results obtained as these vary depending on the adopted model and on the considered variables (Mori, 2018). On the other hand, some reported interventions demonstrate the value of plants in reducing exposure to air pollution (Greater London Authority, 2019). Trees in cities can reduce air pollution levels significantly, by the removal of pollutant gases such as SO2, NOx, CO, and O3 through leaf stomata, and through the dry deposition of suspended particulate matter on leaf surfaces. A study in two cities in the UK reported that a 34% increase in tree cover would lead to an overall reduction of 18-20% in PM10 (Mori, 2018). Urban trees also contribute indirectly to air pollution mitigation by reducing through microclimate amelioration the urban heat island effect, and thus decreasing the need for air conditioning, which in turn reduces fossil-fuel generated air pollution (Vailshery, 2013).

B. Plant canopies and air pollution mitigation: case studies of street trees

The ability of street trees to modify the local microclimate varies according to the tree species, canopy and leaf characteristics such as leaf size, angle, canopy architecture and canopy density (Sanusi, 2017). According to Kumar et al. (2013), key characteristics that make plants efficient dust scavengers and pollutants absorbers are pollution resistant trees that are evergreen, with large leaves, a rough bark, that are native or ecologically compatible and agro-climatically suitable, and requiring little water and minimum care (Kumar, 2013).

Vailshery (2013) indicated that the results of their experiment proved that road segments with tree cover in Bangalore had lower ambient air temperature, road surface temperature humidity and air pollution. Mori (2018) found that tree or shrub 'roadside vegetation barriers' were effective against air pollution, they screened the flux of air pollutants generated by traffic and limited their diffusion to the areas behind the rows of vegetation. The author found that air mitigation is maximized when the height of vegetation is higher than the height of the dust plume produced by traffic and recommended a height between 2 and 6 meters. The author also indicated that species used for roadside vegetation should have considerable width, a minimum of 3 meters, a high LAI or leaf area density (LAD), and porosity of the canopy should be maintained to allow air to pass (Mori, 2018). The author further specified that evergreen species that have sticky leaves or leaves that have waxes, trichomes or hairs have a higher potential of air pollution interception and indicated that evergreen plants intercept particles year round including the winter season when concentration of air pollutants is generally high (Mori, 2018). Sanusi (2017) showed that trees with a large spherical and closed canopy shape reduced the night time cooling effect. The author compared three street trees namely Ulmus procera, Platanus x Acerifolia, and Eucalyptus scoparia and found that the microclimatic benefits to the streets planted with Eucalyptus were much less than the streets planted with the other two species which delivered more benefits to the street microclimate with regard to the air temperature, relative humidity, and wind speed. The individual influences of the height, width and porosity are relative not only to each other but to external factors (Barwise, 2020). For example, the weather, climate and environmental conditions affect the porosity of different vegetation types in different ways; according to several studies, under high wind velocity, broadleaved and coniferous vegetation exhibit a decrease and an increase in porosity, respectively.

Barwise (2020) explored the difference between high and low-level vegetation hedges in urban areas in terms of their effect on air quality. The author found that high level vegetation can improve pedestrian-side air quality and recommended the planting of tall vegetation with an optimal thickness of 10 m or more and with low porosity. The author also indicated that similar criteria applied to low-level vegetation which should form a continuous barrier of at least 2 m however this type is not recommended in deep street canyons. (Barwise, 2020)

With respect to leaf size, Barwise (2020) reported that species with smaller leaves tend to be more effective in mitigating air pollution, partly due to the higher perimeter/surface area ratio of smaller leaves. The author found that leaf size is inversely correlated with accumulation and capture of traffic-related PM (PM1, PM2.5 and PM10) while there were no leaf surface characteristics that showed a clear correlation with PM accumulation across species. The author concluded that the needles of Juniperus chinensis were the most effective leaves in mitigating air pollution and indicated that this result was supported by other similar studies, which found that coniferous species generally offer higher deposition velocities than broadleaf species. (Barwise, 2020).

C. Alternatives to urban trees in narrow streets

The 21st century is known as the “Urban Century" because it is facing an increase of two billion people in cities globally and by 2050, the majority of people will live in cities, towns, and other urban areas (The Nature Conservancy et al., 2016; Birpinar, 2020). This expansion of cities, especially in developing countries, is accompanied by the loss of open spaces to accommodate the rapid increase in urban population by increasing built areas and expanding the supporting infrastructure (Prihatmanti, 2018). As green spaces become a rarity in the city, especially dense neighborhoods, developers are incorporating vegetation on rooftops, and building façades because they are a key selling point to promote the sustainable design for buildings through aesthetically pleasing elements that contribute to climate modification (Taib, 2019; Mladenovic, 2017; Prihatmanti, 2017). The integration of greeneries in buildings in densely populated areas in Malaysia and Singapore is considered as a key element of urban transformation and the most innovative and rapidly developing features of city planning, architecture, and ecological landscaping (Prihatmanti, 2017).

D. Balconies as transitional green spaces for mitigating air pollution

Additional spaces that could be explored and optimized for greening opportunities of limited spaces are the transitional spaces or the buffer spaces between the outdoor and indoor, these transitional spaces include sky courts, atriums, lobbies, corridors, and balconies (Prihatmanti, 2017; Prihatmanti, 2018). Although transitional spaces, or transient spaces, occupy a significant space in a building ranging between 10% to 40% of the total volume of buildings depending on building types (Mladenovic, 2017) there are no studies to our knowledge that explore if the vegetation in these spaces contribute to air pollution mitigation. Mladenovic (2017) explored the value of balconies in Serbia as urban gardens. The author defined the typology of the case study balconies and identified the species grown on the balconies but their intent was not to address the contribution of these balconies to air pollution mitigation.

E. Objective

The objective of the study is to assess the extent to which vegetated urban transitional spaces, specifically balconies in residential areas of Beirut, mitigate air pollution.

F. Research question

Considering that most studies focus on the contribution of urban trees to air pollution mitigation in the city the present study asks: What is the urban tree canopy volume-equivalent volume of vegetated urban balconies in Beirut?

CHAPTER II

METHODOLOGY

A. Study area

The study was conducted in the city of Beirut, Lebanon, in neighborhoods that lie within walking proximity to the researchers namely Hamra, Ashrafieh, and the Downtown area. Beirut's climate is mediterranean with hot summers and mild winters, an average temperature of 18.6 celsius with a difference around 15.7 celsius between the summer and winter, and a rainfall around 726 mm/year (Data.org).

1. Neighborhood description:

The three neighborhoods consisted of residential areas.

1. Hamra: The area is near shopping centers, hospitals, churchs, and schools. The streets were considered narrow and cars were parked along both sides of the streets. The sideways were narrow as well, limited to pedestrians passing by. The area is full of traffic mainly during the day and working hours.
2. Ashrafieh: The area is calmer than Hamra. Only one shopping center was near, however, the area had small shops, churches, an army center, and a military hospital. The street was even narrower than Hamra in certain places and cars were parked on both sides.
3. Downtown: The area is near a commercial or business area, however the buildings in the data collected were based on residential buildings. The area had banks, night life restaurants, a highway, and wider streets. The buildings in the sample were near churches and mosques, in addition to shopping centers.

In all areas of the neighborhood, the buildings create a shade all over the street that varies in length and direction throughout the day and from season to another (Avenue of the Starts Project, 2002).The only open space in the neighborhood is the parking lots available that were mostly shaded due to the high buildings. The case study areas did not have any available empty spaces.

B. Case study balconies

The selection of the case study balconies was done through purposeful sampling to capture examples of successfully maintained green balconies in the city of Beirut. Purposeful sampling is a type of non-probability sampling where the selected sites are defined by the researchers based on the purpose of the study (Etikan, 2016; Humanitarian response, 2014). Purposeful sampling is applied for the most effective use of limited resources, the sampling scheme is efficient and practical, and seeks to identify and select information-rich cases while being consistent with the aims and assumptions inherent in the use of the method which include a sampling method that comes from the research question addressed by the study, a sample size that generates a thorough database on the type of phenomenon under study, and allows the possibility of drawing clear inferences and credible explanations from the data, a sampling plan that allows the researcher to transfer/generalize the conclusions of the study to other settings or populations (Palinkas, 2015).

C. Photo Documentation and data collection from case study balconies

The balconies were photographed from the street, and the number and types of plant species were deduced from the images. Image-based identification of species has been previously reported and considered as a promising approach for species identification. Plants in the photographed case study balconies were first identified using an online plant identification resource such as https://plant.id/ and https://identify.plantnet.org/ which helped the researcher identify the species or to receive a list of possible species if a single match was not impossible (Waldchen, 2018; Kalafi, 2018). The list of species and matching balcony images were then revised and confirmed by a horticulture expert (M. Fabian). Once identification was completed, a short profile was created for each species such as the growth form as herbaceous or woody, and the typical height and width of these plants when grown in containers in Beirut.

D. Calculation of plant canopy volumes contributed by case study balconies

The green area contributed by the balconies was calculated using the Canopy volume equation by Thorne et. al (2002) which is derived from the basic ellipsoid volume formula:

CV= 2/3 p H (A/2xB/2) where:

H: Height from the base to the top of photosynthetically active material

A and B: diameter readings are taken at 50% of the plant height across the plane of photosynthetically active material. (Thorne, 2002). The canopy height of the reference small urban tree size reported by 89,000,000 cm3 was assumed according to the live canopy ratio for urban trees at 60% of estimated tree height (Raising the crown).

Estimates of typical plant height and canopy diameter of the identified species grown in containers in Beirut were acquired from literature and adjusted by a local horticulture expert at the American University of Beirut (M. Fabian). The species were grouped as either herbaceous or woody and herbaceous plants with a woody appearance (e.g bamboos and palms). The size estimates of herbaceous species was considered for plants grown in 30 cm diameter pots while the size of woody species and herbaceous plants with a woody appearance was estimated for plants grown in 50 cm diameter pots.

E. Data analysis

The tree canopy equivalent contributed by the balcony plants was estimated by comparing the calculated canopy volume of plants with the estimated canopy volume of a small tree derived from urban tree size categories shown in table Tree table 1.

Tree Table 1: Reference canopy volume for small, medium, and large trees (source: Head et al., 2001)

Tree size	Height of tree	Live crown ratio (60% of Height of tree)*	Diameter	Estimated Canopy Volume *
	cm	cm	cm	cm^3
Small	< 762	<457	609	< 89,000,000
Medium	762 – 1219	457 - 731	914	89,000,000 - 320,000,000
Large	1219 - 3048	731 - 1,829	1219	> 320,000,000

*canopy volume was calculated following Thorne, 2002

CHAPTER III

RESULTS

A. Type of planters and size of case study balconies

The study explored 150 planted balconies in the case study area in Beirut. Almost sixty percent of the balconies included plants grown in pots while the remaining balconies had built-in planters (Figure 1 and figure 2).

Figure 1: Percentage of plants grown in in-built planters and in pot in the case study balconies in Beirut, Lebanon.

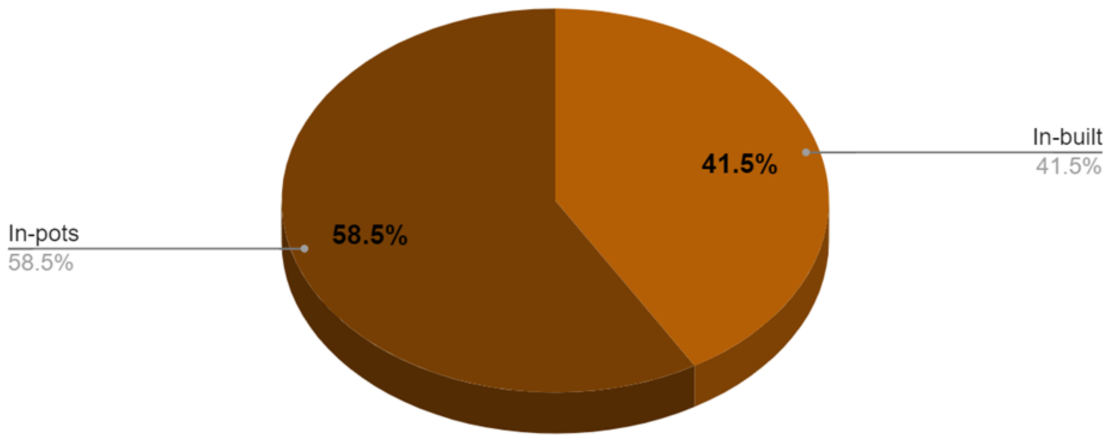
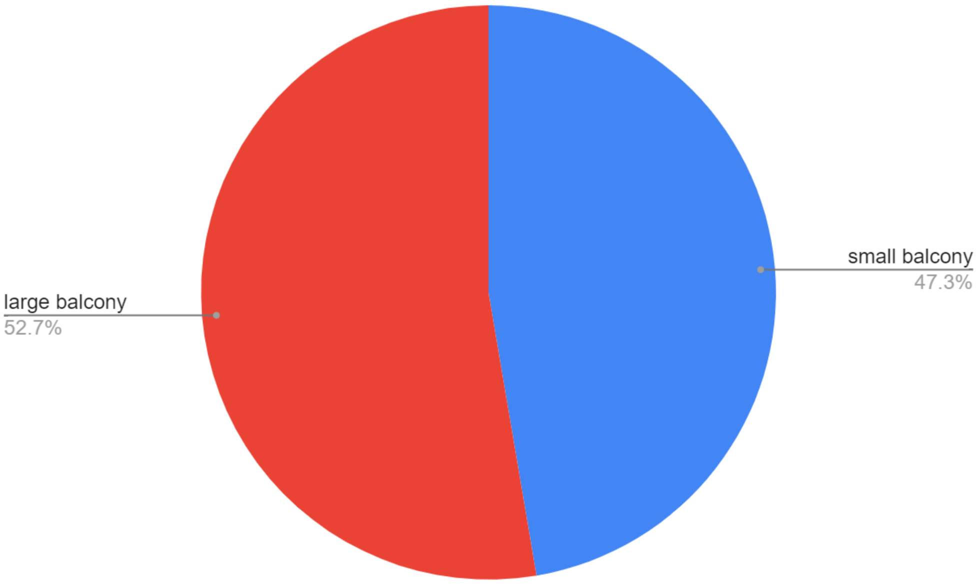


Figure 2: Balcony plants grown in pots or in in-built planters in case study balconies in Beirut, Lebanon.

In pot planters	In in-built planters

The case study balconies were categorized as small and large with estimated sizes of 3 m2 and more than 3 m2 respectively and constituted almost half the data each (Figure 3).

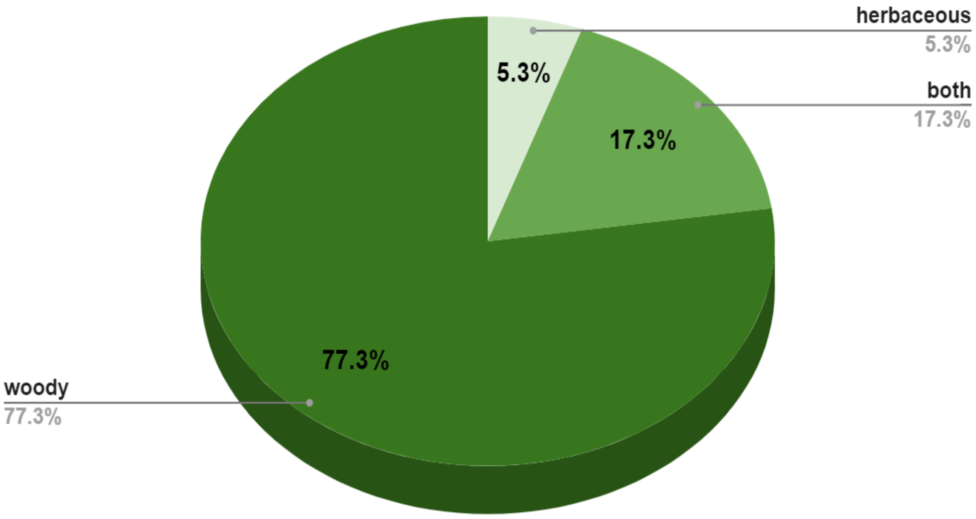
Figure 3: Percentage of large and small balconies in the case study data



B. Type (woody / herbaceous) and density of plants used in case study balconies

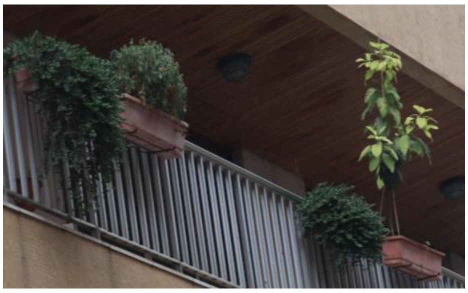
The balconies included only woody plants, or only herbaceous plants or both woody and herbaceous plants. The amount of balconies holding only woody plants was 77.3%, herbaceous balconies consisted of 5.3% and balconies containing both herbaceous and woody species consisted of 17.3% of the balconies in the data collected (Figure 4).

Figure 4: Percentage balconies planted with only woody plants, only herbaceous plants and the combination of both woody and herbaceous plants.



The number of plants per balcony was variable as some balconies included dense vegetation while others accommodated only few plants. For example densely planted balconies were recorded for balconies number 141 and 147 that consisted of 26 and 24 wooded plants respectively. On the other hand, examples of balconies that were sparsely planted included 123 and 117 which included one wooded plant each.

Sparsely planted	Densely planted

Balconies that included only woody plants ranged from 1 to 26 plants per balcony with densely planted large balconies averaging 15 plants per balcony (Table 1). Only two small balconies were densely planted and included 13 and 15 plants each.

Table 1: The number of woody plants on large or small balconies with only woody plants

Balcony number	Balcony size	Number of plants per balcony	Balcony number	Balcony size	Number of plants per balcony	Balcony number	Balcony size	Number of plants per balcony
2	L	2	98	L	4	33	S	1
3	L	3	101	L	2	36	S	2
4	L	4	103	L	4	39	S	4
6	L	15	104	L	15	40	S	1
8	L	12	115	L	2	41	S	3
9	L	8	121	L	3	42	S	2
14	L	5	122	L	2	44	S	3
22	L	1	123	L	1	46	S	4
23	L	8	124	L	2	48	S	2

34	L	6	125	L	4	50	S	2
37	L	5	126	L	3	54	S	3
38	L	1	127	L	4	57	S	13
43	L	5	128	L	3	58	S	4
47	L	1	129	L	7	67	S	1
49	L	4	131	L	11	73	S	4
51	L	4	134	L	15	74	S	3
52	L	3	139	L	4	82	S	3
53	L	13	140	L	15	90	S	4
59	L	8	141	L	26	91	S	2
61	L	8	142	L	1	92	S	6
62	L	3	143	L	4	96	S	2
68	L	2	144	L	9	100	S	15
69	L	5	145	L	7	105	S	2
70	L	4	5	S	5	106	S	3
71	L	6	10	S	2	107	S	2
72	L	5	12	S	4	108	S	4
76	L	1	13	S	2	111	S	1
77	L	6	16	S	2	113	S	1
78	L	2	17	S	3	116	S	5
79	L	1	18	S	1	117	S	1
80	L	2	19	S	2	132	S	3
81	L	4	21	S	3	136	S	2
84	L	3	24	S	2	137	S	2
87	L	2	25	S	3	138	S	4

88	L	3	26	S	4	146	S	4
89	L	4	27	S	2	148	S	3
93	L	4	28	S	5	149	S	1
95	L	4	29	S	1	150	S	2
97	L	2	32	S	1			

Balconies that included both herbaceous and woody plants had a number of plants that ranged from 2 to 24 plants per balcony with an average of five plants per balcony. The highest number of plants was for balcony number 147 that consisted of 16 *Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drude* plants and 8 *Ficus benjamina* plants. The least amount of plants on both balcony number 35 and 83 were each held a single herbaceous and a single woody plant (Table 2). Large mixed planting balconies averaged 6 plants per balcony, with only one large densely planted balcony (balcony 147) which was planted with 24 plants (Table 2). Small mixed planting balconies averaged 4.5 plants per balcony (Table 2).

Table 2: The number of plants available on balconies with both woody and herbaceous plants

Balcony number	Balcony size	Number of woody plants per balcony	Number of herbaceous plants per balcony	Total number of plants per balcony
20	L	2	2	4
60	L	5	2	7
64	L	2	1	3
85	L	2	2	4

86	L	4	1	5
94	L	3	1	4
114	L	7	1	8
118	L	2	1	3
119	L	1	2	3
120	L	2	3	5
135	L	2	1	3
147	L	8	16	24
1	S	3	2	5
7	S	1	7	8
15	S	2	2	4
30	S	3	1	4
31	S	4	1	5
35	S	1	1	2
45	S	2	1	3
56	S	2	1	3
63	S	1	4	5
83	S	1	1	2
99	S	4	2	6
109	S	4	1	5
112	S	3	2	5
130	S	3	3	6

The number of plants on balconies consisting of only herbaceous plants ranged from 1 to 8 plants per balcony with an average of 3 plants per balcony. The highest number of plants was for balcony number 75 that consisted of six *Agave americana* and two *Ocimum basilicum* (Table 3). The least amount of herbaceous plants was on both balcony number 66 and 110 with a single plant.

Table 3: The number of herbaceous plants available on balconies with herbaceous plants only

Balcony number	Species	Quantity per balcony	Total number of plants per balcony
11	*Strelitzia reginae Banks*	5	5
65	*Strelizia regilea*	2	2
66	*Philodendron selloum*	1	1
75	*Agave* americana	6	8
	Ocimum basilicum	2	
102	*Strelizia regia*	1	4
	Ocimum basilicum	3	
110	*Strelizia regia*	1	1
133	*Strelitzia nicolai Regel & K.Koch*	2	2

C. Estimated plant canopy volume and small urban tree equivalent contribution by case study balconies

The estimated canopy volume is a measure of greening contributed by balconies that depends on plant size rather than number of plants per balcony although it is related to the latter within a plant species. The case study balconies contributed a canopy volume that ranged between 39,270 cm^3 for balcony number 113 including a single *Rosmarinus officinalis Prostata* and 39,269,908 cm^3 for balcony number 134 including 15 plants of *Trachelospermum jasminoide*s. The average canopy volume was 4,763,998 cm^3 (Table 4). Another example of a balcony that contributes a high canopy volume includes balcony number 140 which holds around 15 container grown *Eugenia* *thymifolia* and contributes a canopy volume of 27,227,136 cm^3 (Figure 5). In contrast, an example of a balcony that contributes a small canopy is shown in balcony number 75 containing two species planted in pots namely six *Agave americana* and two *Ocimum basilicum* and contributing a volume of 427,257 cm^3 (Figure 5). Balcony number 100 contributed a canopy volume of 15,565,544 cm^3 and included one *Pittosporum tobira* and 14 *Eugenia thymifolia* (Figure 5) grown in an in-built planter. Balcony number 77 holds 2 different plant species; four *Olea europaea L.* and two *Gardenia sp.* planted in pots and contributing a canopy volume of 11,355,810 cm^3 (Figure 5). Balcony number 14 included 5 plants of the same species grown in pots and contributing a canopy volume of 6,544,985 cm^3 (Figure 5). Balcony number 90 included 4 plants of the same species grown in in-built planters and contributing a canopy volume of 8,042,477 cm^3 (Figure 5).

Table 4: Balcony plant composition, estimated canopy volume, and number of small tree equivalents contributed by 150 case study vegetated balconies in Beirut, Lebanon. Canopy volume was calculated following Thorne, 2002

Case study balconies	**Species used in case study balconies**	**Number of plants per species in case study balconies**	**Estimated combined plant canopy volume per case study balcony in cm3**	**Estimated number of small tree canopy equivalent contributed by case study vegetated balconies if applied to a 20 apartment building**
1	*Agave attenuata*	2	2,781,357	0.6
	Pittosporum tobira	3		
2	*Bougainvillea*	2	2,617,994	0.6
3	*Nandina domestica*	1	4,385,140	1.0
	Bougainvillea	1		

	Bougainvillea	1		
	Bougainvillea	1		
	Russelia	2		
	Olive	1		
4	*Jasminum officinale*	1	7,293,731	1.6
5	*Ficus benjamina*	5	6,785,840	1.5
6	*Viburnum lucidum*	15	10,210,176	2.3
	Metrosideros	1		
7	*Dracaena marginata*	7	4,574,159	1.0
	Schefflera actinophylla	8		
8	*Metrosideros*	4	18,380,411	4.1
	Phoenix roebelenii	3		
9	*Yucca aloifolia L.*	5	8,966,629	2.0
	Carissa grandiflora	1		
10	*Hibiscus rosa-sinensis L.*	1	1,418,429	0.3
11	*Strelitzia reginae Banks*	5	1,340,413	0.3
12	*Metrosideros excelsa*	4	4,222,301	0.9
13	*Trachelospermum jasminoides*	2	5,235,988	1.2
14	*Bougainvillea spectabilis*	5	6,544,985	1.5
	Strelitzia reginae Banks	2		
	Bougainvillea spectabilis Willd.	1		
15	*Gardenia sp.*	1	4,521,799	1.0
16	*Carissa grandiflora*	2	536,165	0.1
	Olea europaea	1		
	Metrosideros excelsa	1		
17	*Hibiscus rosa sinensis*	1	4,326,497	1.0

18	*Bougainvillea spectabilis*	1	1,308,997	0.3
19	*Bougainvillea spectabilis*	1	1,577,080	0.4
	Carissa grandiflora	1		
20	*Yucca aloifolia*	1	3,405,486	0.8
	Ficus benjamina	1		
	Araucaria heterophylla	1		
	Strelitzia reginae	1		
21	*Yucca aloifolia*	3	2,199,115	0.5
22	*Schefflera arborea*	1	733,038	0.2
23	*Rosmarinus officinalis" Prostata"*	3	5,353,797	1.2
	Eugenia mythifolia	5		
24	*Metrosideros excelsa*	1	2,492,330	0.6
	Gardenia sp	1		
25	*Ficus benjamina*	3	4,071,504	0.9
26	*Murraya paniculata*	4	2,722,714	0.6
27	*Murraya paniculata*	2	1,361,357	0.3
28	*Polygala myrtifolia*	2	3,455,752	0.8
	Schefflera arborea	3		
29	*Podocarpus macrophyllus*	3	6,361,725	1.4
	Nandina domestica	2		
30	*Bougainvillea spectabilis*	1	4,098,731	0.9
	Asparagus setaceus	1		
	Ficus benjamina	2		
31	*Washingtonia filifera*	3	3,903,952	0.9
	Agave attenuata	1		
	Ficus benjamina variegata	1		

32	*Gardenia*	1	1,436,755	0.3
33	*Hibiscus rosa sinensis*	1	1,150,347	0.3
	Bougainvillea spectabilis	1		
	Citrus sp.	1		
	Murraya paniculata	2		
34	*Ligustrum lucidum*	2	4,817,109	1.1
	Asparagus setaceus	1		
35	*Gardenia.*	1	1,512,153	0.3
36	*Schefflera arborea*	2	1,466,077	0.3
	Bougainvillea spectabilis	1		
	Phoenix roebelenii	3		
37	*Schefflera arborea ' variegata'*	1	7,343,473	1.7
38	*Carissa grandiflora*	1	268,083	
	Olea europaea	1		0.7
39	*Carissa grandiflora*	3	2,924,823	0.0
40	*Carissa grandiflora*	1	268,083	0.1
41	*Rosmarinus officinalis" Prostata"*	3	117,810	0.0
42	*Bougainvillea spectabilis*	2	2,617,994	0.6
43	*Rosmarinus officinalis" Prostata"*	5	196,350	0.0
44	*Bougainvillea*	3	3,926,991	0.9
	Polygala myrtifolia	1		
	Nerium oleander	1		0.5
45	*Strelitzia reginae*	1	2,027,374	
	Plumeria acutifolia	1		
	Cycads	1		0.9
46	*Gardenia*	1	4,192,979	

	Duranta erecta	1		
47	*Ficus benjamina*	1	1,357,168	0.3
48	*Carissa grandiflora*	2	536,165	0.1
	Eugenia mythifolia	2		
49	*Eugenia mythifolia*	2	4,188,790	0.9
50	*Plumeria acutifolia*	2	2,714,336	0.6
	Olea europaea	1		
	Yucca gloriosa L.	1		
	Ficus binnendijkii Alii	1		
51	*Ficus benjamina*	1	5,567,949	1.3
	Ficus binnendijkii Alii	1		
	Ficus benjamina	1		
52	*Codiaeum variegatum*	1	3,183,481	0.7
53	*Ficus benjamina L.*	13	17,643,184	4.0
54	*Olea europaea L.*	3	6,361,725	1.4
55	*Strelitzia nicolai Regel & K.Koch*	2	4,289,321	1.0
	Trachelospermum jasminoides	1		
	Olea europaea L.	1		
56	*Pennisetum setaceum*	1	5,006,651	1.1
	Trachelospermum jasminoides	7	21,199,467	
57	*Gardenia*	2		4.8
58	*Chamaerops humilis*	4	8,482,300	1.9
	Trachelospermum jasminoides	5	17,451,547	
	Yucca gloriosa L.	1		
	Olea europaea L.	1		
59	*Phyllostachys viridis imma*	1		3.9
	Olea europaea L.	1	13,321,400	3.0

60	*Strelitzia reginae*	1		
	Bougainvillea	1		
	Trachelospermum jasminoides	3		
	Musa acuminata Colla	1		
	Bougainvillea spectabilis Willd.	2	5,241,224	
	Olea europaea L.	1		
61	*Carissa grandiflora " Prostata"*	5		1.2
62	*Ficus benjamina L.*	3	4,071,504	0.9
	Yucca aloifolia L.	1		
	Dracaena marginata hort.	2		
	Aloe arborea	1		0.5
63	*Strelitzia reginae*	1	2,039,941	
	Bougainvillea	1		
	Strelitzia reginae	1		
64	*Rosmarinus officinalis*	1	1,642,529	0.4
65	*Strelitzia reginae*	2	536,165	0.1
66	*Philodendron selloum*	1	282,743	0.1
67	*Ficus benjamina L.*	1	1,357,168	0.3
68	*Phoenix dactylifera*	2	3,694,513	0.8
	Ficus benjamina L.	4		1.5
69	*Bougainvillea glabra Choisy*	1	6,737,669	
	Tradescantia purpurea	1		0.9
70	*Bougainvillea spectabilis Willd.*	3	3,960,501	
	Ficus elastica	2		
71	*Hibiscus rosa chinensis*	1	5,967,455	1.3

	Schefflera arboricola	3		
72	*Ficus benjamina L.*	4	6,865,427	1.5
	Gardenia sp.	1		
73	*Hibiscus rosa-sinensis L.*	1	5,173,680	1.2
	Bougainvillea spectabilis Willd.	1		
	Ficus benjamina	2		
74	*Bougainvillea spectabilis Willd.*	3	3,926,991	0.9
75	*Agave americana*	6	427,257	0.1
	Ocimum basilicum	2		
76	*Ficus benjamina L.*	1	1,357,168	0.3
77	*Olea europaea L.*	4	11,355,810	2.6
	Gardenia sp.	2		
78	*Ficus benjamina L.*	2	2,714,336	0.6
79	*Olea europaea L.*	1	2,120,575	0.5
80	*Eugenia mythifolia*	2	2,094,395	0.5
81	*Bougainvillea spectabilis Willd.*	4	5,235,988	1.2
82	*Bougainvillea spectabilis Willd.*	3	3,926,991	0.9
83	*Agave attenuata*	1	1,800,656	0.4
	Phoenix roebelenii	1		
84	*Eugenia mythifolia*	3	3,141,593	0.7
85	*Bougainvillea spectabilis Willd.*	1	2,630,560	0.6
	Dracaena marginata	1		
	Agave attenuata	1		
	Euphorbia tirucalli	1		
86	*Ficus benjamina L.*	1	6,894,749	1.5
	Erythrina caffra	3		

	Strelitzia nicolai	1		
	Bougainvillea glabra Choisy	1		
87	*Citrus sp.*	1	2,094,395	0.5
88	*Bougainvillea glabra Choisy*	3	9,355,663	2.1
89	*Ficus benjamina L.*	4	5,428,672	1.2
90	*Carissa grandiflora " Prostatus"*	4	402,124	0.1
	Yucca aloifolia	1		
91	*Carissa grandiflora " Prostatus"*	1	833,569	0.2
	Eugenia mytrhifolia	4		
92	*Carissa grandiflora " Prostatus"*	2	4,389,852	1.0
	Eugenia mytrhifolia	2		
93	*TRachelospermum jasminoides*	2	7,330,383	1.6
	Ficus benjamina.	1		
	Yucca aloifolia	1		
	Strelitzia sp.	1		
94	*Cymbopogon*	1	3,665,191	0.8
	Schefflera actinophylla (Endl.) Harms	2		
95	*Ficus benjamina*	2	4,180,413	0.9
	Bougainvillea glabra Choisy	1		
96	*Trachelospermum jasminoides*	1	3,926,991	0.9
97	*Olea europaea L.*	2	4,241,150	1.0
	Olea europaea L.	2		
	Bougainvillea glabra Choisy	1		
98	*Gardenia*	1	6,986,902	1.6

99	*Pittosporum tobira*	4	4,155,280	0.9
	Pennisetum setaceum	2		
100	*Pittosporum tobira*	1	15,565,544	3.5
	Eugenia mythifolia	14		
101	*Bougainvillea glabra Choisy*	1	2,042,035	0.5
	Yucca aloifolia	1		
102	*Strelitzia reginae*	1	607,375	0.1
	Ocimum basilicum	3		
103	*Muraya paniculata*	4	2,722,714	0.6
104	*Gardenia sp.*	9	20,261,178	4.6
	Bougainvillea glabra Choisy	5		
	Euphorbia tirucalli	1		
105	*Ficus benjamina L.*	2	2,714,336	0.6
106	*Bougainvillea glabra Choisy*	3	3,926,991	0.9
107	*Nerium oleander L.*	1	1,759,292	0.4
	Polygala myrtifolia	1		
108	*Lantana camara*	4	1,526,814	0.3
109	*Nandina domestica*	1	1,951,976	0.4
	Rosmarinus officnalis ' Prostata"	3		
	Cymbopogon	1		
110	*Strelitzia reginae*	1	268,083	0.1
111	*Russelia equisetiformis Schltdl. & Cham.*	1	753,982	0.2
112	*Gaura lindheimeri Engelm. & A.Gray*	2	653,975	0.1
	Rosmarinus officnalis ' Prostata"	3		
113	*Rosmarinus officnalis ' Prostata"*	1	39,270	0.0

114	*Metrosideros excelsa*	7	7,657,108	1.7
	Strelitzia reginae	1		
115	*Bougainvillea glabra Choisy*	1	2,666,165	0.6
	Plumeria rubra L.	1		
116	*Rosmarinus officnalis ' Prostata"*	3	1,022,590	0.2
	Pittosporum tobira	2		
117	*Ficus nitida*	1	1,357,168	0.3
118	*Thuja sp.*	1	2,073,451	0.5
	Dracaena marginata	1		
	Yucca gigantea	1		
119	*Dracaena marginata*	1	2,021,091	0.5
	Yucca gigantea	1		
	Dracaena fragrans	1		
120	*Yucca gloriosa L.*	2	2,065,074	0.5
	Agave attenuata	1		
	Philodendron selloum	2		
121	*Plumeria acutifolia*	2	4,023,333	0.9
	Bougainvillea	1		
122	*Ficus benjamina L.*	2	2,714,336	0.6
123	*Carissa grandiflora Prostrata*	1	100,531	
124	*Yucca aloifolia*	2	1,466,077	0.3
125	*Ficus benjamina L.*	4	5,428,672	1.2
126	*Bougainvillea*	1	3,947,935	0.9
	Phyllostachys viridis	1		
	Ficus australis	1		
127	*Bougainvillea*	1	3,868,348	0.9
	Codiaeum variegatum	1		
	Yucca aloifolia	1		

	Ficus benjamina" Variegata"	1		
128	*Citrus sp.*	1	3,353,127	0.8
	Eriobotrya japonica	1		
	Gardenia sp.	1		
129	*Buxus sempervirens L.*	4	4,482,006	1.0
	Eugenia mythifolia	3		
130	*Cycas revoluta*	1	739,845	0.2
	Carpobrotus edulis	1		
	Geranium sp.	1		
	Strelitzia reginae	1		
	Rosmarinus officnalis	2		
131	*Buxus sempervirens L.*	8	6,607,817	1.5
	Bougainvillea	3		
132	*Schefflera arboricola (Hayata) Merr.*	1	4,162,610	0.9
	Chamaerpos humilis	1		
	Bougainvillea	1		
133	*Strelitzia nicolai Regel & K.Koch*	2	4,289,321	1.0
134	*Trachelospermum jasminoides*	15	39,269,908	8.8
135	*Ficus benjamina*	2	4,858,997	1.1
	Strelitzia nicolai Regel & K.Koch	1		
136	*Bougainvillea spectabilis Willd.*	2	2,617,994	0.6
137	*Ficus benjamina variegata L.*	1	2,666,165	0.6
	Bougainvillea spectabilis Willd.	1		
138	*Ficus benjamina L.*	2	5,332,330	1.2
	Bougainvillea spectabilis Willd.	2		

139	*Ficus benjamina L.*	4	5,428,672	1.2
140	*Eugenia mythifolioa*	15	15,707,963	3.5
141	*Eugenia mythifolioa*	26	27,227,136	6.1
142	*Olea europaea L.*	1	2,120,575	0.5
	Pittosporum tobira	1		
	Duranta erecta Variegata	1		
143	*Phoenix roebelenii*	2	5,570,044	1.3
	Duranta erecta Variegata	2		
	Carissa grandiflora	4		
144	*Metrosideros*	3	6,501,002	1.5
	Howea sp.	1		
	Metrosideros	5		1.7
145	*Schefflera arboricola (Hayata) Merr.*	1	7,518,878	
	Bougainvillea spectabilis Willd.	2		
146	*Pittosporum tobira*	2	4,427,551	1.0
	Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drude	16		
147	*Ficus benjamina*	8	23,423,715	5.3
148	*Ficus benjamina Variegata*	3	2,714,336	0.6
149	*Ficus benjamina Variegata*	1	2,714,336	0.6
150	*Ficus benjamina*	2	2,714,336	0.6

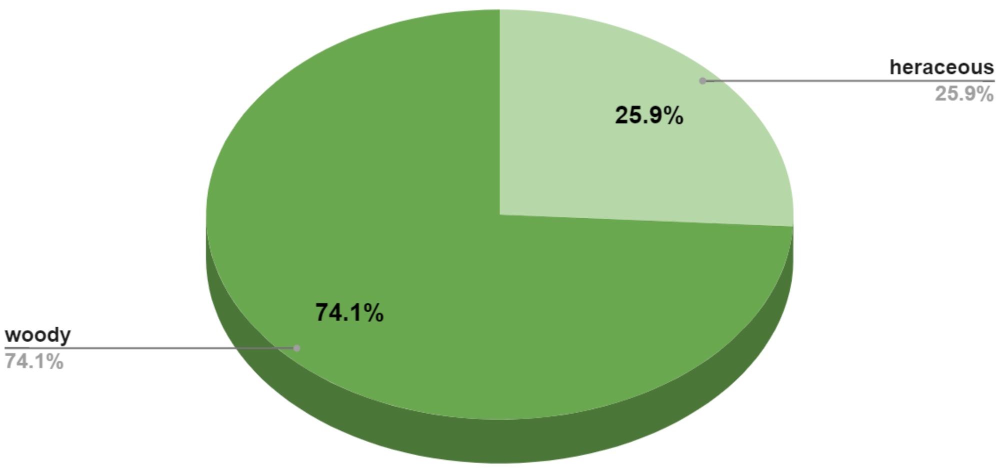
Figure 5: Different balcony examples from the data collection in Beirut, Lebanon

	
Picture 1: Balcony number 140	Picture 2: Balcony number 75
	
Picture 3: Balcony number 100	Picture 4: Balcony number 77
	
Picture 5: Balcony number 14	Picture 6: Balcony number 90

D. Plant species used in case study balconies

With respect to species used in the 150 case study balconies, the recorded number was 81 species and included 21 (25.9%) herbaceous species and 60 (74.1%) woody species or herbaceous species with woody stems (Table 7, Table 8, and Figure 6).

Figure 6: Percentage of herbaceous and woody plant species in the case study balconies in Beirut, Lebanon.



With respect to woody species and or herbaceous species with woody stems the number of individual plants used in all the case study balconies ranged between one specimen for Cycas *sp.* and *Duranta sp.* to 78 specimens for *Eugenia myrtifolia* (Table 5). While the number of herbaceous species available in the case study balconies range from one specimen in the case of several species such as *Aloe arborea* and *Araucaria heterophylla* and 16 specimens for *Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drude* (Table 6).

Table 5: The number of woody species available on the balconies in Beirut, Lebanon

Name of woody species	Number of woody species available on the balconies in Beirut, Lebanon
Bougainvillea	17
Bougainvillea spectabilis Willd.	22
Bougainvillea glabra Choisy	17
Bougainvillea spectabilis	8
Buxus sempervirens L.	12
Carissa grandiflora	15
Carissa grandiflora " Prostata"	12
Chamaerops humilis	5
Citrus sp.	3
Codiaeum variegatum	2
Cycas	1
Cycas revoluta	1
Duranta erecta	1
Duranta erecta Variegata	3
Eriobotrya japonica	1
Erythrina caffra	3
Eugenia myrtifolia	78
Euphorbia tirucalli	2
Ficus australis	1
Ficus benjamina	73
Ficus benjamina Variegata	7
Ficus binnendijkii Alii	2
Ficus elastica	7
Ficus nitida	1
Gardenia	7
Gardenia sp	14

Hibiscus rosa chinensis	5
Howea sp.	1
Jasminum officinale	1
Lantana camara	4
Ligustrum lucidum	2
Metrosideros	13
Metrosideros excelsa	9
Murraya paniculata	12
Nandina domestica	4
Nerium oleander	2
Olea europaea L.	22
Phoenix dactylifera	2
Phoenix roebelenii	6
Phyllostachys viridis imma	2
Pittosporum tobira	13
Plumeria acutifolia	5
Plumeria rubra L.	1
Podocarpus macrophyllus	3
Polygala myrtifolia	4
Rosmarinus officinalis	3
Rosmarinus officinalis "Prostata"	16
Russelia equisetiformis Schltdl. & Cham.	2
Schefflera arboricola	3
Schefflera arboricola (Hayata) Merr.	2
Schefflera arborea	6
Schefflera arborea ‘ variegata’	1
Schefflera actinophylla	10
Thuja sp.	1
Trachelospermum jasminoides	34
Viburnum lucidum	15

Washingtonia filifera	3
Yucca aloifolia L.	11
Yucca gloriosa L.	3
Yucca gigantea	2

Table 6: The number of herbaceous species available on the balconies in Beirut, Lebanon

Name of herbaceous species	Number of herbaceous species available on the balconies in Beirut, Lebanon
Agave americana	8
Agave attenuata	4
Aloe arborea	1
Araucaria heterophylla	1
Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drude	16
Asparagus setaceus	2
Dracaena fragrans	1
Dracaena marginata	12
Carpobrotus edulis	1
Cymbopogon	2
Gaura lindheimeri Engelm. & A.Gray	2
Geranium sp.	1
Musa acuminata Colla	1
Ocimum basilicum	5
Pennisetum setaceum	3
Philodendron selloum	2
Philodendron selloum	1
Strelitzia nicolai Regel & K.Koch	5
Strelitzia nicolai	3
Strelitzia reginae Banks	12

Tradescantia purpurea	1

Ficus benjamina was the most frequently recorded plant species and was found in 25 out of 150 balconies. The next most frequently used species were *Bougainvillea spp 23 balconies*, *Olea europaea L*. which was recorded in 14 balconies, , and *Eugenia myrtifolia* which was recorded in 10 balconies (Table 7).

Table 7: Most frequently recorded plant species in case study balconies in Beirut, Lebanon

Plant species	**Number of balconies where the plant is grown**
Ficus benjamina	25
Bougainvillea sp.	23
Olea europaea L.	14
Euginia mythifolioa	10

Thirty four species were recorded in only one of the 150 case study balconies as shown in Table 8.

Table 8: Plant species recorded in only one of the 150 case study balconies in Beirut, Lebanon

Agave americana, Aloe arborea, Araucalia heterophylla, Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drude, Carbobrutus edulis, Cycas, Cycas revoluta, Dracaena fragrans, Durantha erecta, Eryobotriba japonica, Erytrina cafra, Ficus austalis, Ficus elastica, Ficus nitida, Gaura lindheimeri Engelm. & A.Gray, Geranium sp., Howea sp., Jasminum officinale, Lantana camara, Ligustrum lucidum, Musa acuminata Colla, Phoenix dactilifera, Plumeria rubra L., Podocarpus macrophyllus, Rosmarinum officinalis, Russelia, Russelia equisetiformis Schltdl. & Cham., Schefflera arboricola, Scheflerra arborea ' variegata', Sheflerra actinophylla, Strelizia nicolaii, Thuja sp., Tradescathia purpurea, Viburnum lucidum, Washingtonia filifera

E. Estimated plant canopy volume and small urban tree equivalent contribution by species recorded in case study balconies

Herbaceous plants such as *Agave sp*. and *Asparagus sp*. had a significantly low canopy volume, 33,510 cm^3 and 75,398 cm^3 respectively. The maximum canopy volume contributed by herbaceous plants is 2,144,661 cm3 for *Strelitzia nicolai*, the minimum canopy volume is 33,510 cm3 for *Agave attenuata*, and the average is around 524,372 cm^3 (Table 9).

Table 9: Estimated Canopy volume of herbaceous plants (by species) (estimated pot size 30 cm diameter) on selected balconies (150) in Beirut, Lebanon. Canopy volume was calculated following Thorne, 2002

Name of plant	**Family**	**Plant Height**	**Plant Spread**	**Estimated plant**

				Canopy Volume
		cm	cm	cm3
Agave americana	Agavaceae	40	40	33,510
Agave attenuata	Agavaceae	40	40	33,510
Aloe arborea	Xanthorrhoeaceae	40	40	33,510
Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drude	Arecaceae	150	100	785,398
Asparagus setaceus	Asparagaceae	40	60	75,398
Carpobrotus edulis	Aizoaceae	30	50	39,270
Cymbopogon	Gramineae/poaceae	80	40	67,021
Dracaena fragrans	Asparagaceae	150	100	785,398
Dracaena marginata	Asparagaceae	150	80	502,655
Gaura lindheimeri Engelm. & A.Gray	Onagraceae	80	80	268,083
Geranium sp.	Geraniaceae	40	40	33,510
Ocimum basilicum	Lamiaceae	60	60	113,097
Musa acuminata Colla	Musaceae	200	130	1,769,764
Pennisetum setaceum	Poaceae	80	80	268,083
Philodendron selloum	Araceae	150	60	282,743
Philodendron selloum	Araceae	150	60	282,743
Strelitzia nicolai Regel & K.Koch	Strelitziaceae	160	160	2,144,661
Strelitzia nicolai	Strelitziaceae	160	160	2,144,661
Strelitzia reginae Banks	Strelitziaceae	80	80	268,083
Tradescantia purpurea	*Commelinaceae*	40	40	33,510

The maximum canopy volume contributed by woody plants is 2,617,994 cm^3 for *Trachelospermum jasminoides*, the minimum canopy volume is 39,270 cm^ 3 for *Rosmarinus officinalis "Prostata"*, and the average is around 1,065,523 cm^3 (Table

10). The average canopy volume of woody species (1,065,523 cm^3) is around double the average of herbaceous (524,372 cm^3).

Table 10: Estimated canopy volume of woody plants and herbaceous plants with a woody appearance (e.g bamboos and palms) (by species) (estimated pot size 50 cm) on selected balconies in Beirut, Lebanon. Canopy volume was calculated following Thorne, 2002

Name of plant	**Family**	**Plant Height**	**Plant Spread**	**Estimated plant Canopy Volume**
		cm	**cm**	**cm3**
Araucaria heterophylla	Araucariaceae	200	100	1,047,198
Bougainvillea	Nyctaginaceae	250	100	1,308,997
Bougainvillea spectabilis Willd.	Nyctaginaceae	250	100	1,308,997
Bougainvillea glabra Choisy	Nyctaginaceae	250	100	1,308,997
Bougainvillea spectabilis	Nyctaginaceae	250	100	1,308,997
Buxus sempervirens L.	Buxaceae	100	80	335,103
Carissa grandiflora	Apocynaceae	80	80	268,083
Carissa grandiflora " Prostata"	Apocynaceae	30	80	100,531
Chamaerops humilis	*Arecaceae*	180	150	2,120,575
Citrus sp.	Rutaceae	150	100	785,398
Codiaeum variegatum	Euphorbiaceae	140	80	469,145
Cycads	Cycadaceae	80	80	268,083
Cycads revoluta	Cycadaceae	80	80	268,083
Duranta erecta	Verbenaceae	150	120	1,130,973
Duranta erecta Variegata	Verbenaceae	150	120	1,130,973
Eriobotrya japonica	Rosaceae	150	120	1,130,973
Erythrina caffra	Fabaceae	150	120	1,130,973

Eugenia thymifolia	Myrtaceae	200	100	1,047,198
Euphorbia tirucalli	Euphorbiaceae	150	100	785,398
Ficus australis	Moraceae	150	120	1,130,973
Ficus benjamina	Moraceae	180	120	1,357,168
Ficus benjamina Variegata	Moraceae	180	120	1,357,168
Ficus binnendijkii Alii	Moraceae	180	120	1,357,168
Ficus elastica	Moraceae	180	120	1,357,168
Ficus nitida	Moraceae	180	120	1,357,168
Gardenia	Rubiaceae	140	140	1,436,755
Gardenia sp	Rubiaceae	140	140	1,436,755
Hibiscus rosa chinensis	Malvaceae	130	130	1,150,347
Howea sp.	Arecaceae	200	120	1,507,964
Jasminum officinale	Oleaceae	200	150	2,356,194
Lantana camara	*Verbenaceae*	90	90	381,704
Ligustrum lucidum	Oleaceae	130	100	680,678
Metrosideros	Myrtaceae	140	120	1,055,575
Metrosideros excelsa	Myrtaceae	140	120	1,055,575
Murraya paniculata	Rutaceae	130	100	680,678
Nandina domestica	Berberidaceae	150	150	1,767,146
Nerium oleander	Berberidaceae	150	120	1,130,973
Olea europaea L.	Oleaceae	180	150	2,120,575
Phoenix dactylifera	Arecaceae	180	140	1,847,256
Phoenix roebelenii	Arecaceae	150	150	1,767,146
Phyllostachys viridis imma	Poaceae	200	120	1,507,964
Pittosporum tobira	Pittosporaceae	120	120	904,779
Plumeria acutifolia	Apocynaceae	180	120	1,357,168
Plumeria rubra L.	Apocynaceae	180	120	1,357,168
Podocarpus macrophyllus	Podocarpaceae	180	100	942,478
Polygala myrtifolia	Polygalaceae	120	100	628,319
Rosmarinus officinalis	Lamiaceae	50	50	65,450

Rosmarinus officinalis "Prostata"	Lamiaceae	30	50	39,270
Russelia equisetiformis Schltdl. & Cham.	Scrophulariaceae	100	120	753,982
Schefflera arboricola	Araliaceae	140	100	733,038
Schefflera arboricola (Hayata) Merr.	Araliaceae	140	100	733,038
Schefflera arborea	Araliaceae	140	100	733,038
Schefflera arborea ' variegata'	Araliaceae	140	100	733,038
Schefflera actinophylla	Araliaceae	200	130	1,769,764
Thuja sp.	Cupressaceae	160	100	837,758
Trachelospermum jasminoides	Apocynaceae	500	100	2,617,994
Viburnum lucidum	Viburnaceae	130	100	680,678
Washingtonia filifera	Arecaceae	160	100	837,758
Yucca aloifolia L.	Agavaceae	140	100	733,038
Yucca gloriosa L.	Agavaceae	140	100	733,038
Yucca gigantea	Asparagaceae	140	100	733,038

F. Estimated plant canopy volume and small urban tree equivalent extrapolation to 10 floor 20 balcony building

The balcony that contributed the most canopy volume, balcony number 134, is densely planted with woody plants and contributes a canopy volume of 39,269,908 cm3. The extrapolation of this balcony prototype to a 20 apartment 10 floor building would theoretically contribute the equivalent of 8.8 small urban trees. A similar extrapolation exercise to balcony that contributes an average canopy volume is balcony number 60, a balcony that has mixed planting and contributes to an equivalent of 3 small urban trees. Balcony number 75 which has a very low canopy volume has a negligible contribution amounting to 0.1 small urban trees.

An extrapolation of canopy volume findings to a 20 apartment balcony building planted with herbaceous plants was found negligible and contributed less than one small urban tree per building.

With respect to woody species, an extrapolation of findings revealed that a 20 balcony 10 floor building densely planted with *Trachelospermum jasminoides* contributes an equivalent of 8.8 small urban trees (Table 11). Other species that contribute a high canopy volume equivalent to up to 5 small urban trees include, Jasminum officinale, Chamaerops humilis, Olea europaea L., Phoenix dactylifera, Schefflera actinophylla, Nandina domestica, Phoenix roebelenii, Howea sp., and Phyllostachys viridis imma.

Table 11: Estimated number of small tree canopy equivalent contributed by a building that has 20 large apartment balconies each planted with 15 woody plants. Canopy volume was calculated following Thorne, 2002

Plant name	**Estimated Canopy Volume per plant cm3**	**Estimated Canopy volume in a building that has 20 apartment balconies each planted with 15 plants**	**Estimated number of small tree canopy equivalent in a building that has 20 apartment balconies each planted with 15 plants**
Trachelospermum jasminoides	2,617,994	785398200	8.8
Jasminum officinale	2,356,194	706858200	7.9
Chamaerops humilis	2,120,575	636172500	7.1
Olea europaea L.	2,120,575	636172500	7.1
Phoenix dactylifera	1,847,256	554176800	6.2
Schefflera actinophylla	1,769,764	530929200	6.0
Nandina domestica	1,767,146	530143800	6.0
Phoenix roebelenii	1,767,146	530143800	6.0

Howea sp.	1,507,964	452389200	5.1
Phyllostachys viridis imma	1,507,964	452389200	5.1
Gardenia	1,436,755	431026500	4.8
Gardenia sp	1,436,755	431026500	4.8
Ficus benjamina	1,357,168	407150400	4.6
Ficus benjamina Variegata	1,357,168	407150400	4.6
Ficus binnendijkii Alii	1,357,168	407150400	4.6
Ficus elastica	1,357,168	407150400	4.6
Ficus nitida	1,357,168	407150400	4.6
Plumeria acutifolia	1,357,168	407150400	4.6
Plumeria rubra L.	1,357,168	407150400	4.6
Bougainvillea	1,308,997	392699100	4.4
Bougainvillea spectabilis Willd.	1,308,997	392699100	4.4
Bougainvillea glabra Choisy	1,308,997	392699100	4.4
Bougainvillea spectabilis	1,308,997	392699100	4.4
Hibiscus rosa chinensis	1,150,347	345104100	3.9
Duranta erecta	1,130,973	339291900	3.8
Duranta erecta Variegata	1,130,973	339291900	3.8
Eriobotrya japonica	1,130,973	339291900	3.8
Erythrina caffra	1,130,973	339291900	3.8
Ficus australis	1,130,973	339291900	3.8
Nerium oleander	1,130,973	339291900	3.8
Metrosideros	1,055,575	316672500	3.6
Metrosideros excelsa	1,055,575	316672500	3.6
Araucaria heterophylla	1,047,198	314159400	3.5
Eugenia thymifolia	1,047,198	314159400	3.5

Podocarpus macrophyllus	942,478	282743400	3.2
Pittosporum tobira	904,779	271433700	3.0
Thuja sp.	837,758	251327400	2.8
Washingtonia filifera	837,758	251327400	2.8
Citrus sp.	785,398	235619400	2.6
Euphorbia tirucalli	785,398	235619400	2.6
Russelia equisetiformis Schltdl. & Cham.	753,982	226194600	2.5
Schefflera arboricola	733,038	219911400	2.5
Schefflera arboricola (Hayata) Merr.	733,038	219911400	2.5
Schefflera arborea	733,038	219911400	2.5
Schefflera arborea 'variegata'	733,038	219911400	2.5
Yucca aloifolia L.	733,038	219911400	2.5
Yucca gloriosa L.	733,038	219911400	2.5
Yucca gigantea	733,038	219911400	2.5
Ligustrum lucidum	680,678	204203400	2.3
Murraya paniculata	680,678	204203400	2.3
Viburnum lucidum	680,678	204203400	2.3
Polygala myrtifolia	628,319	188495700	2.1
Codiaeum variegatum	469,145	140743500	1.6
Lantana camara	381,704	114511200	1.3
Buxus sempervirens L.	335,103	100530900	1.1
Cycas	268,083	80424900	0.9
Cycas revoluta	268,083	80424900	0.9
Carissa grandiflora	268,083	80424900	0.9
Carissa grandiflora " Prostata"	100,531	30159300	0.3
Rosmarinus officinalis	65,450	19635000	0.2
Rosmarinus officinalis "Prostata"	39,270	11781000	0.1

CHAPTER IV

DISCUSSION

This study was conducted with a basic assumption that urban trees and street trees help mitigate air pollution in cities and that in dense cities it is not possible to plant street trees. Trees and other forms of vegetation may act as efficient sinks for particles, metals, and other gaseous compounds, inhibiting the spread of air pollution (Jung, 2011). Air pollution mitigation by trees occurs through the interception of incoming airflow by the canopy and the passing of the airflow through the canopy where a fraction of the PM is removed (McDonald). The ability of trees and tree canopies to trap air pollution was presented in several studies. Nowak indicated that small urban trees mitigate pollution by intercepting airborne particles, he stated that “an estimated 1,821 metric tons of air pollution is removed by trees in New York City, and that pollution removal per m2 of canopy cover was similar among cities (Nowak, 2002). King (2019) showed that small to medium size trees (Birch) removed tiny particles from diesel pollution in the air with a removal rate of 79% (King, 2019; Myers, 2021). The use of vegetation in open roads was shown to have an impact on the speed of air and at the same time on the rate of pollution spreading (Małyszko, 2019). Lower PM concentrations were recorded in areas of Sydney which had abundant tree vegetation (Paull, 2020). China's forest cover estimated at 22.96 % could absorb 40 million tons of air pollutants and 6.158 billion tons of dust per year with PM removal capacity being the highest in coniferous trees followed by evergreen and deciduous trees (Han, 2020). The effect of trees can vary depending if they are planted densely or distributed. Badach (2020) showed in broad street canyon geometry, “an overall improvement was obtained for dense trees, suggesting that they might serve as a mitigation strategy, while for sparse and tall trees in the same geometric conditions, a pollution trapping effect was observed." Additionally, it was observed that tree arrangement had little influence on flow structure and concentration distribution for the same tree volume and trunk height. The trunk height was the major factor influencing the air flow and pollution dispersion (Badach, 2020). According to Baldauf's study on dense and mixed roadside vegetation with full coverage from the ground to the top of the canopy, although the heights, thickness and species varied, it suggested that thicker and denser vegetation promotes increased pollution reductions (Baldauf, 2017).

While the World Health Organization (WHO) recommends a minimum of 9 m2 of green space per capita (UN-HABITAT, 2018), Beirut has only 0.8 m2 (Nazzal, 2018). Dense neighborhoods have limited spaces for trees to mature and hence the option of considering trees in air pollution mitigation is not existent (Beer et al. 2003). In the case of Malaysia, urban green space per person in Kuala Lumpur decreased from 13 m2 in 2010 to 8.5 m2 in 2014. The high urbanization rate and the increase in densification will not allow the country to achieve the target set by the National Urbanization Policy (NUP) which is achieving 2 hectares per 1000 population by the year 2020. Malaysia is required to provide 112,100 hectares of green space to meet its planning standard but the total area of current urban green space is only 13,626 hectares, which is enough for 6.81 million and not 15.09 million, the actual urban population of Malaysia. The high urbanization rate has become the main obstacle in preventing the local authorities from achieving the standards (Maryanti, 2017). Similar to Malaysia, Fuller (2009) documented a drastic drop in per capita green space provision in cities with greater population densities. The development of infrastructure will always force urban green spaces to be less important in most high-density cities (Maryanti, 2017).

The study categorized the balconies as either in-built and in pot planters, or large and small balconies. The large balconies mainly consisted of in-pot planters while the small balconies consisted of in-built planters. Large balconies or in pot planters had a higher contribution to canopy volume since large balconies had an average of 15 plants per balcony that were mainly woody plants, while small or in pot planters had a maximum of 15 plants per balcony in only one of the case study samples. Through observation it can be deduced that large balconies were used as an escape since they included a seating place along with some plants.

Findings from this study revealed that a large beiruti balcony densely planted with woody plants contributes a canopy volume equivalent to 8.8 small urban trees if theoretically extrapolated to a 10 floor building with 20 balconies. Therefore this finding suggests that transitional spaces may play a significant role in urban greening and air pollution mitigation by contributing alternative vegetation canopies in dense neighborhoods. Furthermore, the impact of vegetated balconies on air quality is expected to be similar to that of green walls in mitigating air quality. Green walls have been shown to reduce the level of air pollution and indoor air quality by threefolds due to “settling/ sticking of solid particles to the leaf surface”, “absorption of gaseous pollutants", and the “passive accumulation of pollutants on the plant’s root-soil system” (Małyszko, 2019). PM reduction by green walls, and an overall improvement in local air quality has been noted in previous studies (Paull, 2020). A study by Srbinovska showed that the green wall areas mitigated the PM of 2.5 or less micrometers (PM2.5) on average by 25% and PM of 10 or less micrometers (PM10) on average by 37% compared to the areas lacking green walls. (Srbinovska, 2021). Moreover, balconies are able to mitigate the spread of harmful substances and modify the near-wall air flows, changing the characteristics of indoor air re-entry (Ribeiro, 2020). The contribution of vegetated balconies depends on which floor the balcony is located and the wind in that area. Since pollution is the highest near its source, balcony on the lower floors may have higher levels of air pollution emitted not only from traffic emissions, but also business-related emissions" (Jung, 2011). Abbaspour (2000) revealed that the average concentration of CO increases from the lowest point up to about 6 floors and then decreases irregularly. This may be due to the higher wind speed while moving upwards in floors causing the decrease in pollution intensity. He suggested that the difference in the distance from the primary source of pollution is not associated with the volume of pollution accumulated. Moreover, the main factor suggested is the local wind around the building which can cause pollution accumulation. The airflow around the building is more important than the pollution source while considering the variation in the amount of pollution dispersed. Kozlovtseva (2016) showed that the maximum diameter of particulate matter inside buildings ranges from 47 to 106 μm and that the value decreases with increasing building floors, with the smallest particles recorded on the highest floors. A study previously mentioned stated that the combination of low temperatures, high humidity and no, or low wind speed lead to high PM concentrations. (Srbinovska, 2021). One limitation of our study is the lack of information on the orientation of balconies and number of building floor per building in the samples because the impact of plants is more significant when taking into account both characteristics. An experiment by Wu (2013, 2014) showed that wind direction strongly influenced both particle number concentration (PNC) and PM2.5 mass concentration. In the experiment, wind comes from the southwest to northwest, or from the north, or from the east. The high concentrations of pollution in the evening profile were largely driven when the wind came from the east. PNC increased by a factor of two with north wind and a factor of four with east winds compared with days with west winds. PM2.5 increased fourfolds with eastern winds but a slight increase with northern winds (Wu, 2013, 2014). Since it was previously stated that planted balconies are similar to green walls in mitigating air pollution, a study revealed that the air quality improvement by green roofs and green walls depend on building height, surrounding urban infrastructure, vegetation cover and proximity to the pollutant source. The experiment results showed that 50%–75% of green roof coverage on low-rise buildings improved air quality at the pedestrian/commuter level. However, just a 25% coverage of the green wall yielded the highest PM2.5 capture. It was concluded that to decrease PM2.5 concentrations, priority should be given to install green roofs in buildings lower than 10 m in height. For green walls, the PM2.5 abatement was favorable in all cases of the experiment. (Viecco, 2021)

Plants in urban environments may perform multiple ecological functions and provide services to improve human well-being. Plants contribute to climatic regulation such as the uptake and reduction of CO2 and other GHGs, shading which reduces the heat island effects, and creating a cooling factor. In densely urbanized areas, plants act as a protection from environmental hazards such as torrential floods and strong winds. (Fineschi, 2020). Planted balconies can add life and colors making their use more appealing (Peters, 2021). Plants provide an opportunity for relaxing. They give a positive impact on human social relationships, and contribute to better life quality. (Fineschi, 2020)

Moreover, plants on balconies can protect from incident solar radiation making the space more comfortable. Plants have receptors that perceive light to which they are exposed to. They are very good filters of light. They absorb and use most of the red light available for photosynthesis (Runkle, 2022). Ardavani (2020) showed that the use of plants can contribute to the reduction of energy consumption, thus creating an enormous opportunity for a new state-of- the-art market and research that could potentially minimize CO2 emissions and light pollution, improve urban and suburban microclimate, mitigate the effects of climate change, as well as provide an alternative means of lighting affecting both outdoor lighting design and landscape planning in suburban and urban settings. (Ardavani, 2020)

Furthermore, balconies as transitional spaces have served as an escape for people during lockdown providing a social platform for reviving the collective spirit of the city when inhabitants played music, danced, sang the national anthem, or celebrated medical workers for their service (Vergis, 2021). In addition, urban residents found that "parks and gardens are an unexpected source of calm and joy" and took advantage of their rooftops and balconies to complement the sense of nature. The balcony acted as a "truncated version of nature" (UNSW, 2020). People's interest in planting after the consecutive covid lockdowns increased because a greener balcony is able to provide a similar feel to a park; the feeling of increasing stress relief, soothing mental illness, and increase in neighborhood satisfaction (Abrams, 2017). Balcony gardening also contributes to relieving stress by contributing to improved physical health of people that spend more active time outdoors (UNSW, 2020).

There were a total of 81 species used in the case study balconies in Beirut. Most of them are characterized as evergreen species and many as woody trees and shrubs that are drought tolerant (Aldrich, 2021). There are few studies that report balcony plants and their effects on the environment. One study by Krzymińska (2020) assessed the most used balcony species in the small Polish town of Sieraków and indicated that herbaceous plants namely *Pelargonium peltatum, Pelargonium zonale* and *Petunia × atkinsiana* were the most used and contributed to microclimate amelioration the most. However, according to our canopy calculations herbaceous plants do not contribute sizable canopy volumes. Geranium is a herbaceous plant and has a low canopy volume estimate of 33,510 cm3. In this study, the most popular recorded balcony plants in Beirut were all woody and included *Eugenia myrtifolia*, *Ficus benjamina*, and *Trachelospermum jasminoides* all which contributed sizable canopy volume. One should keep in mind however that the residents' choice of the types of balcony plants in different cities is not possible as species used on balconies are context-dependent and influenced by meteorological conditions (Barwise, 2020).

CHAPTER V

CONCLUSION

This study showed that a relatively small building in Beirut is equivalent to 1 to 8.8 small treeswhen contributing to air pollution mitigation. The findings revealed that the best balcony plant combination was based on woody species that contribute significant canopy volume such as *Trachelospermum jasminoides* and *Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drud*e and *Ficus benjamina, Jasminum officinale, Strelitzia nicolai Regel & K.Koch, Strelizia nicolaii, Chamaerops humilis, Olea europaea L.* (Table 3). These species could be planted as a single plant or as assemblages with other species that produce equal or less canopy volume thus, increasing the contribution of the balcony and the entire building to mitigate air pollution.

Based on the study, the benefits of the planted balconies are primarily for the people nearest to them, the apartment owners and then the microclimate, as the distance gets further from the balcony the benefits are reduced but the impact of the balcony on the pedestrians is still existent.. The more the balcony is planted, the more the environmental, aesthetic, and human benefits are. As the volume of the planted balconies increase, the more is the contribution to mitigating air pollution in the area.

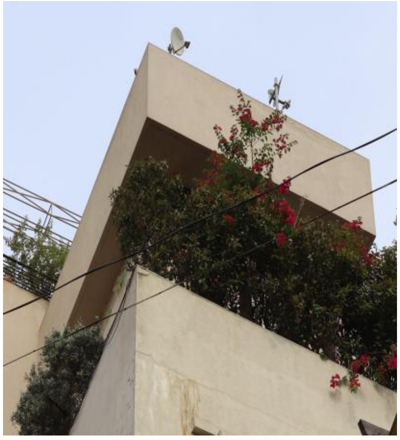
The research provides a proof on the capability of planted to balconies to contribute to urban greening in dense cities. The limitation of this study is that it assumes a relation between air pollution mitigation and canopy volume which does not have a solid proof on the case of the case study balconies. Further studies should be done concerning air pollution mitigation by specific species available in urban areas and the creation of a guideline indicating the best species to use and their management and maintenance practices to maximize their efficiency.

APPENDIX

Figure 7

Figure 8

Figure 9



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