VERTICAL GREENING IN COMPACT CITIES
APPLYING VERTICAL LANDSCAPE IN DOWNTOWN CHICAGO WITH INTEGRATED ANALYSIS AND DESIGN APPROACHES

BY

JINGYI LI

THESIS

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Advisers:

Professor Brian Deal, Chair
Associate Professor Scott Murray
Professor Theresa Meers, Parkland College

ABSTRACT

Compact cities as the globally norm are suffering green space insufficiency. Vertical greening (VG) including a green roof, living wall system and green façade is proposed as an effective solution for that. Benefits of VG are well-known, however, the success rate for its application is still low. To improve VG's viability, plants selection, as one of the critical components of VG's success, is mainly focused in this research—there are nine criteria proposed for plants suitability. Downtown Chicago is served as a pilot site in this research to apply VG. After the calculation for more suitable sites in downtown Chicago, three prototypes were proposed based on the building's attributes, major users and common expectations. Planting fee information for each prototype has been provided at the same time. This research aims to improve VG's viability by providing a theoretical guideline for suitable plants and VGs decision.

To My Family and Professors

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CHAPTER 1: INTRODUCTION

Compact cities and vertical greening

As a high density urban settlement, compact cities are identified with these characters: 1) central area revitalization, 2) high-density and contiguous development patterns, 3) mixed-use development, and 4) efficient public transportation system (Bullard, 2018). Compared with sprawling cities, compact cities that concentrate social services and facilities in a certain area—mostly in the city center—can increase overall accessibility, efficiency of infrastructure and reduce resource consumption (Jenks et al., 1996). To data, strong arguments are emerging that compact city is the most sustainable urban form (Fertner & Große, 2016).

However, urban sustainability is not just about energy efficiency or economic viability, but also a better ecological revitalization and social livability, in other words, it should care more about people by qualifying their life and improving their health. Undoubtedly, green space has such a powerful effect on human health and life quality that people should have a priority to access it at all times (Schertz & Berman, 2019). However, insufficient green spaces in compact cities are making that priority barely achievable. As the competition for ground space increases in compact cities (and ground prices go up), the green space essential for human health and well-being, gets squeezed out. Physical and mental health suffers (Velarde et al., 2007). Then qualities and planning methods for green space could make differences. How to find spaces to add green infrastructure is demanded.

In this situation, "green up" instead of "green out" will be much more achievable. Vertical greening (VG) - greening a roof garden, a façade or a living wall system has been proposed as a potential solution (Haaland & van den Bosch, 2015). Not only does it save the land use and building's energy consumption but also brings more aesthetic and therapeutic values to human life. Although owning outstanding benefits such as cooling down the environment, insulating noise, purifying air, managing rainwater and reintroducing biodiversity, the success rate of vertical greening projects has been low and it has not been applied broadly especially in Asia, with the biggest number of compact cities around the world (Tian et al., 2012; Chan, 2018). Reasons include that VG requires unique technical support to build (structural support and irrigation) (Wong et al., 2010) and depend on ideal site conditions (e.g. height, direction and materials of a façade) (Tian & Jim, 2012). For some types of VG, they also require long-term

and intensive maintenance and therefore can be costly to establish. Failure to select appropriate plants is another key factor making VG unsuccessful (Tian & Jim, 2011). With the increasing ubiquity of compact urban areas there is an urgent need to study the design and application of vertical greening in order to improve its viability and sustainability.

Research question and methods

My research question is how to improve VG's viability in compact cities and find suitable places to apply different types of VG?

Literature review and practical design will be my research methods. Literature review contains successful case studies of VG's application, VG's cognition and plant suitability. Practical design includes identification of the most suitable sites, site analyses, site visit, proposal for prototypes, design phase, and total plant fee calculations.

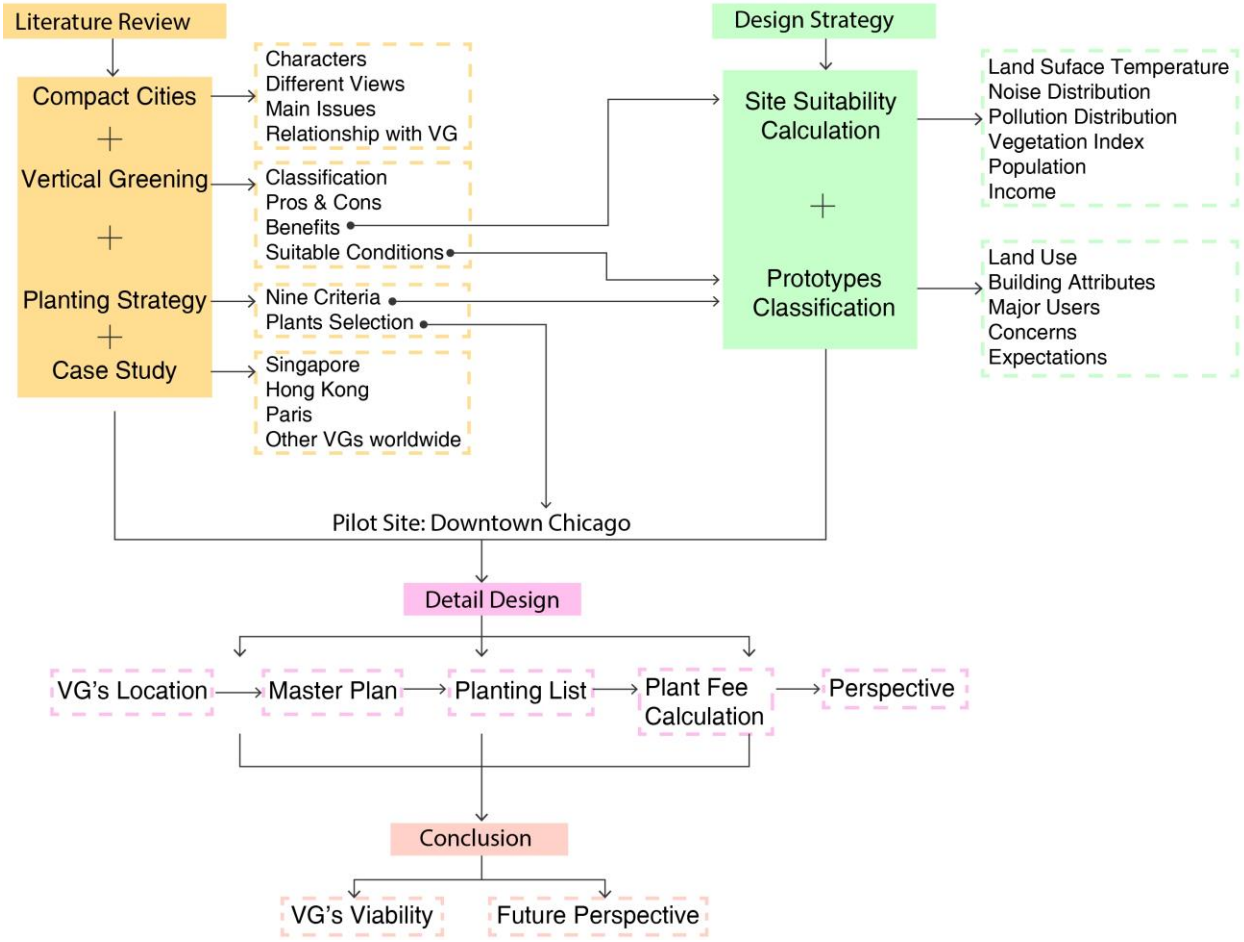

Figure 1.1: Research methods and process

Significance

Briefly speaking, this research aimed to redefine the relationship between nature and metropolitan environments. To be specific, it provided a further verification that VG is viable to alleviate issues caused by greenspace insufficiency especially in compact cities. This research could be used as a theoretical guide to help designers make better choices to choose appropriate VG types and suitable plants for VG projects based on the plant-select criteria. Strategies for proposed prototypes can be adopted for similar situations broadly.

References

[1] Bullard, E. (2018). Compact City. In *Salem Press Encyclopedia*. Salem Press.

[2] Chan, C. T. W. (2018). Promoting Vertical Greening in High-rise Residential Buildings within Urban Areas. *Pacific International Journal*, *1*(2), 29–38.

[3] Fertner, C., & Große, J. (2016). Compact and Resource Efficient Cities? Synergies and Trade-offs in European Cities. *European Spatial Research and Policy*, *23*(1), 65–79. https://doi.org/10.1515/esrp-2016-0004

[4] Haaland, C., & van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening*, *14*(4), 760–771. https://doi.org/10.1016/j.ufug.2015.07.009

[5] Jenks, M., Burton, E., & Williams, K. (Eds.). (1996). *The Compact city: A sustainable urban form?* (1st ed). E & FN Spon.

[6] Schertz, K. E., & Berman, M. G. (2019). Understanding Nature and Its Cognitive Benefits. *Current Directions in Psychological Science*, *28*(5), 496–502. https://doi.org/10.1177/0963721419854100

[7] Tian, Y., & Jim, C. Y. (2011). Factors influencing the spatial pattern of sky gardens in the compact city of Hong Kong. *Landscape and Urban Planning*, *101*(4), 299–309. https://doi.org/10.1016/j.landurbplan.2011.02.035

[8] Tian, Y., & Jim, C. Y. (2012). Development potential of sky gardens in the compact city of Hong Kong. *Urban Forestry & Urban Greening*, *11*(3), 223–233. https://doi.org/10.1016/j.ufug.2012.03.003

[9] Tian, Y., Jim, C. Y., & Tao, Y. (2012). Challenges and Strategies for Greening the Compact City of Hong Kong. *Journal of Urban Planning and Development*, *138*(2), 101–109. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000076

[10] Velarde, Ma. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, *6*(4), 199–212. https://doi.org/10.1016/j.ufug.2007.07.001

[11] Wong, N. H., Tan, A. Y. K., Tan, P. Y., Sia, A., & Wong, N. C. (2010). Perception Studies of Vertical Greenery Systems in Singapore. *Journal of Urban Planning and Development*, *136*(4), 330–338. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000034

CHAPTER 2: CITIES THAT ARE RENOWNED WITH OUTSTANDING VGS

Abstract

Cities that are doing great of VG applications are all worthy to be learned. Singapore, Hong Kong and Paris as pioneers that have famous VG projects are researched in this chapter. Several symbolic VGs are introduced in detail, while for each city I made a map that marked all other well-known VGs using different colors for different types of VG (VG on walls, VG on roofs and combined VG). Besides, there are other famous VGs around the world mentioned to show how various VGs we already achieved in urban areas. With more developments on VG's acceptance as well as technology, we can fairly believe the green-insufficient issue is about to be solved in the future.

Singapore

In congruence with much of the fast urbanizing Asia and Middle East, the island nation of Singapore has evolved into a high-density, vertical "city in a garden". It is one of the most densely populated countries on the planet. Singapore's over 5 million people are crowded into only 269 square miles of land. That's 18,500 people per square mile, compared with 83 people per square mile in the U.S (Emmett, 2015). At the same time, it is also the greenest city in Asia. The green cover (public parks and gardens) ratio is 47% based on the resource of 2011 National Parks Board (Senthilingam, 2016). Even, it has outshone 16 cities from all around the world since 2017, such as Sydney (25.9%), Vancouver (25.9%), and Sacramento (23.6%) (Tan, 2017).

Singapore with the reputation of "A City in A Garden" is always chasing to be the world's greenest city. Indeed, Singapore is making impressive progress on that promise. How did Singapore become such a green city? The dense urban context in Singapore has seen an emergence and increase in elevated spaces in the form of sky-gardens, sky-bridges and sky-courts in a range of building types, seemingly seeking to tie together the different horizontal and vertical components of the city (Samant, 2019). In little more than a decade since the idea of vertical greening was actively promoted in the city (Wong et al., 2008), numerous vertical greenery installations now dot the city's landscapes. Currently, there are around 100 hectare of high-rise greenery islandwide (Sen & Charles, 2017), which is equivalent to more than 100 football fields. To date, the push to go green extends to a fundamental awareness—green

building has been mandatory since 2008 (Amy Kolczak, 2017). New developments must include plant life, in the form of green roofs, cascading vertical gardens, and verdant walls. For example, in Marina Bay, all developments comply with a 100 percent greenery replacement policy (Ooi, 2014). The Pinnacle@Duxton has seven 50-story buildings connected by gardens on the 26th and 50th floors (Yuen, 1996). People can jog around a track on these levels, which are also equipped with exercise stations.

Figure 2.1: The Marine Bay (left) and The Pinnacle@Duxton (right). Image source: http://worldbeautifullplaces.blogspot.com

Another impressive stretch can be seen in a series of parks called the Southern Ridges, where much of the connector is in the form of an elevated walk through the forest canopy, providing striking vistas and perspectives on both the natural and the built setting only a few hundred meters from extensive high-rise development. The bridge system connects the major housing areas and population centers to the parks in an ecological way. The goal is to eventually expand the network to three hundred kilometers (Emmett, 2015). This system offers Singaporeans a remarkable opportunity to walk, stroll, and hike the city, with dramatic pedestrian bridges, such as the Henderson Waves, that save walkers from having to cross busy roadways.

Figure 2.2: The Southern Ridges. Image source: https://www.lonelyplanet.com/

Besides public vertical greening projects conducted by government, private enterprises have also cultivated a green awareness in their commercial domain. A symbolic case is the PARKROYAL on Pickering, a renowned hotel that embodies Singapore's vision of "city in a garden". With a total of 15,000 square meters of sky gardens, reflecting pools, waterfalls, planter terraces and green walls, a 200% green coverage (Y-Jean, 2017), PARKROYAL shows how greenery can be conserved in a space starved in dense urban area while being both sustainable and unique, not only catering to the users of the building but to the neighboring community as well. The primary concept was to demonstrate how greenery can be conserved in a way that integrates harmoniously with the form and function of a business hotel and office development while seamlessly combining different aspects of design including architecture, landscape architecture and interior design (Warren, c2000.). These four-story-high sky gardens are the city's first zero-energy sky terraces (Newman, 2010), carefully planted with low-maintenance flora that is not only aesthetically important but also functionally critical in mitigating thermal gain on the west-facing wall and improving indoor air quality.

Figure 2.3: PARKROYAL on Pickering. Image source: https://timelessbeauty.wordpress.com

There are various VGs in Singapore indoor and outdoor. I divided other famous outdoor VGs into three categories: vertical walls on buildings, green roof and public green space with a combination of various types of VG.

1) Vertical walls on buildings:

Westgate; Lee Kong Chian Natural History Museum; The Oliv; Skyterrace @ Dawson; Skyville @ Dawson; Oasia Hotel Downtown; Kent Vale; Khoo Teck Puat Hospital; Singapore's Institute of Technical Education; The Olive Cove; National Museum of Singapore; Helios Residences; The Heeren; Tree House; Orchard Central; The Scala; 158 Cecil St; Gaia Residence; Eco Sanctuary; Sky Habitat

2) Green roof:

Nanyang Technological University; Ocean Financial Centre

3) Public green space (combination):

Gardens by The Bay; Jurong Central Park; Lakeview Estate; HortPark; Savannah Condopark; Changqi Park

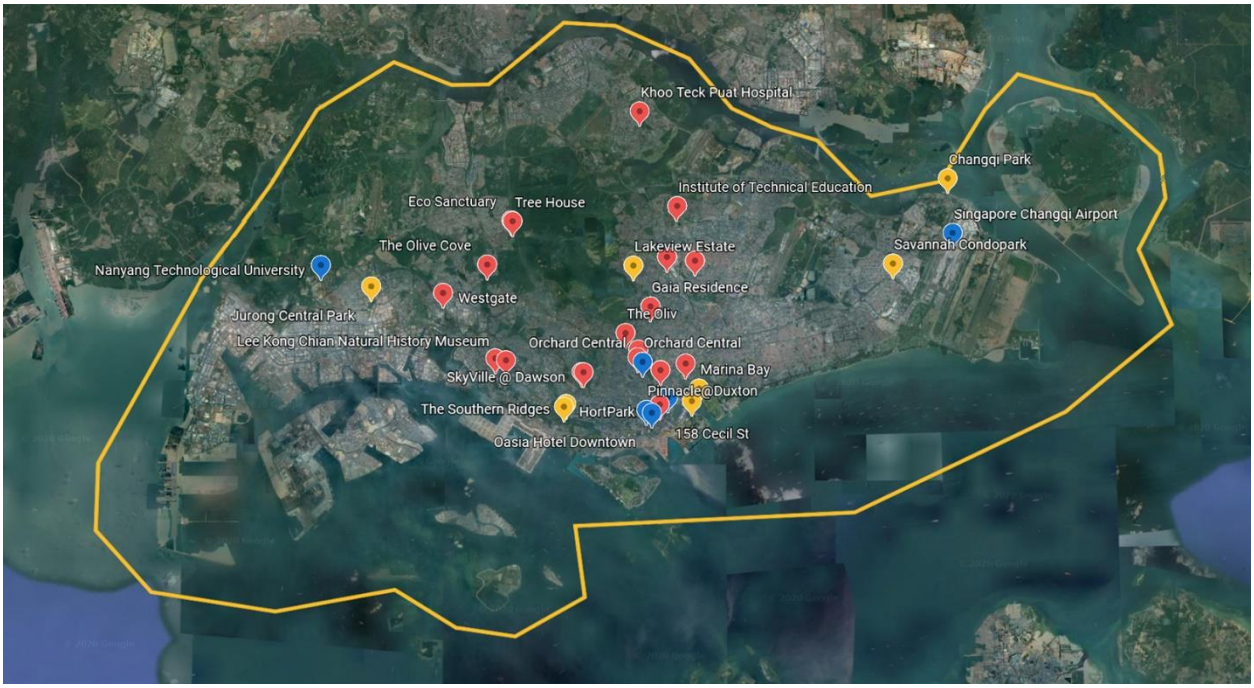

Figure 2.4: Locations of different VGs in Singapore: Vertical walls on buildings (red), Green roof (blue), and Combined VGs (yellow). Yellow line is an approximate boundary of Singapore.

Hong Kong

As one of the densest cities in China, Hong Kong is owning a population density of 17552 persons per sq mi based on the 2016 Population Census by Hong Kong Census and Statistics Department (2016 Population Census Results.pdf, n.d.), a similar density as Singapore. Consequently, Hong Kong has to develop high urban-density development to meet population growth, which contributes to severe urban heat island and lack of greenery space. Even with a 51.21% green cover (2004) of the whole Hong Kong area (Mahtab-uz-Zaman, 2003), there was an extreme lack of green space in its urban area—the ratio of open green space to total area was about 10% and the average area of open space per capita did not exceed 32.3 square feet (Tian et al., 2012). This was far from providing a comfortable living environment based on the Garden

City Standard (World Tourism Organization)—percentage of urban green spaces should be at least 40% (Senanayake, 2013).

Luckily, especially after the mid-1970s, more attention was paid to these problems. The city council, highways office, and housing department began to figure out new city greenery plans that green open spaces should be generously allocated for landscaping and planting in newly reclaimed areas and government housing developments (Jim, 1987). Up to 2006, numerous studies had assessed the value of a three-dimensional green space system that forms a comparatively connected comprehensive green network by introducing skyscraper farms, and sky gardens could be considered as a novel strategy for creating urban green space in compact cities (Haaland & van den Bosch, 2015). In 2014 Green Roofs and Vertical Greening Technical Seminar in Hong Kong, experts reclaimed the promotion of vertical greening to achieve social livability and urban sustainability (Hui, 2014). With this efficient green space planning, Hong Kong has achieved a 30% green cover in urban area by the end of 2017 (GOHKSAR, 2017).

18 Kowloon East Hotel is the first of ground clearance up to 134.5 feet skyrise outdoor vertical green in Hong Kong, the whole project total green area at 8611 square feet (Aedas, 2011), showing the professionalism of vertical greening in Hong Kong. With the building located in a community with dense industrial blocks, instead of providing another office tower entirely wrapped in a coolly glazed skin, the design investigates the possibility of providing an environmentally sustainable design in such an industrial area. This project won the silver award in private development projects at Skyrise Greenery Awards 2012 by Development Bureau (ArchDaily, 2011).

Figure 2.5: 18 Kowloon East Hotel. Image source: Designbloom

Another impressive project is Hong Kong Jockey Club Shatin Racecourse - Energy Centre. It's the first vertical green project with total 260 sqm greening area include automatic data control recycled water system in Hong Kong (Milestones Stories, 2012). Approximately 25.7% annual energy savings are achieved in the SCTC building by reducing the demand through passive means—vertical greening, followed by efficient mechanical and electrical system design, and minimal use of renewable energy (BEAM Plus, 2016). The rooftop garden serves as an outdoor recreational space where fitness and well-being classes can be conducted and social events can be held.

Figure 2.6: Hong Kong Jockey Club's new Communications & Technology Centre. Image source: https://www.burohappold.com

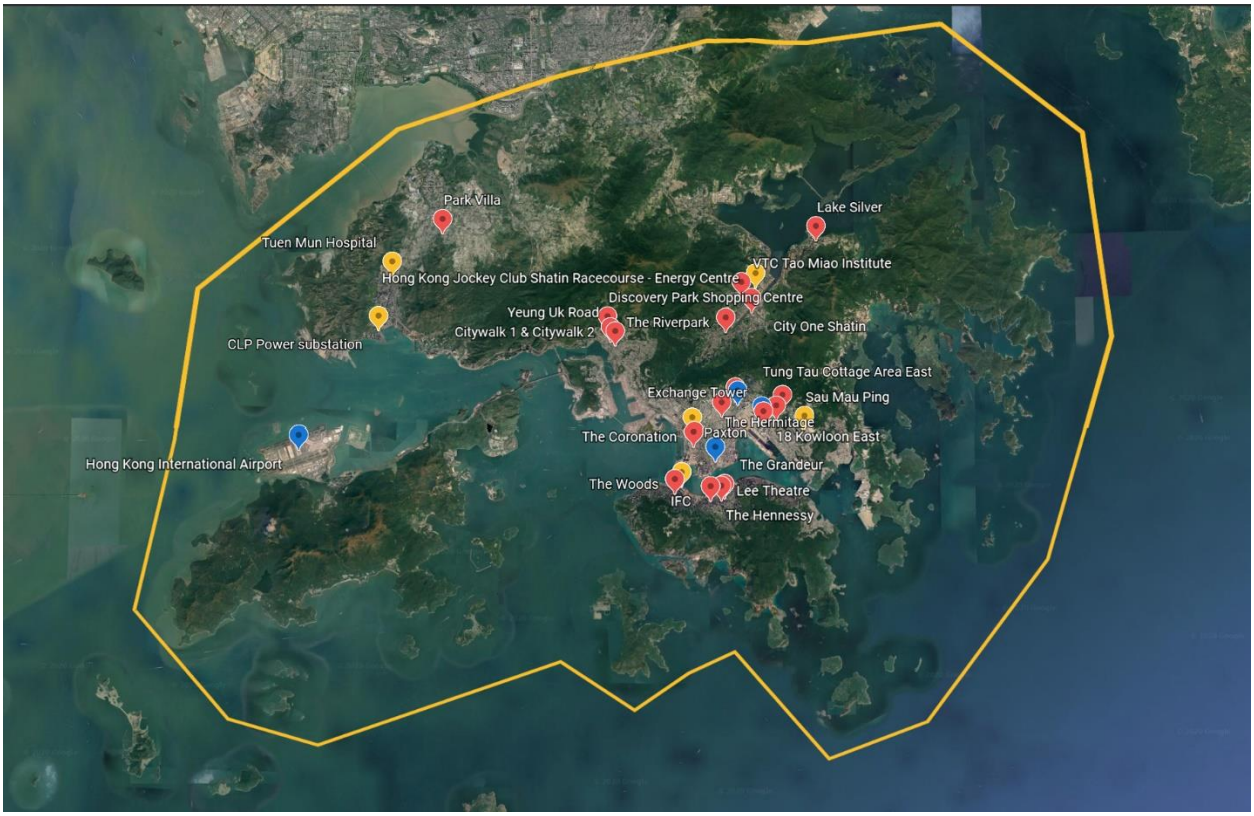

Figure 2.7: Locations of different VGs in Hong Kong: Vertical walls on buildings (red), Green roof (blue), and Combined VGs (yellow). Yellow line is an approximate boundary of whole Hong Kong.

Paris

A growing number of living walls around Europe are helping to make the busy urban centers of its cities much greener. This growing trend in European cities, with sustainability, function and aesthetics all contribute to a push to mix nature with concrete and glass jungles. Paris, as one of the most motivated cities to adopt VG as many as possible, has been proud of numerous worldwide-famous VGs. Starting from 2014 when Anne Hidalgo was selected to be the city's mayor, Paris government has been achieving a goal that the city's rooftops and walls should be covered with 100 hectares of vegetation by 2020. One third of the green space, according to its plan, should be dedicated to urban farming (Wong, 2018). Paris not only intends to produce fruit and vegetables but also invent a new urban model in which citizens can explore new ways to get involved in the city's invention and nature (Masson et al., 2013).

Another reason that made Paris perform outstandingly in VG application is Patrick Blanc, a French botanist who is the pioneer in greening architecture and ecological urban design. He invented the concept of the vertical garden and has been on a quest to green walls across the planet with his plant-based creations for the last 25 years (Gandy, 2010). In 2009, his concept of

vertical greening was on the annual list of the “Best 50 Great Inventions in the World” by Time magazine of the United States (Greening Solution, 2018), which caught the attention of the whole world. He has designed more than 300 vertical gardens around the world so far (Blanc, 2008).

When it comes to vertical greening in Paris, L’Oasis d’Aboukir may be the first one that comes in mind. This vertical garden blankets 2,700 square feet of an 82-foot-tall wall with 236 different kinds of plants (Gandy, 2010). The plant wall is designed in a verdant wave pattern on a formerly drab southwest-facing Parisian street corner. It’s one of Blanc’s masterpieces that turned the ordinary building facade into a gorgeous green space. This is what he firmly believes can greatly improve the quality of urban space. Plants are arranged in a diagonal-like mode to create a unique vibrancy and movement. This project also infers the evolution of Blanc’s idea: from a preliminary geometric frame pattern to a checkerboard pattern where each plant is carefully placed in a specific position (Hohenadel, 2013).

Figure 2.8: L’Oasis d’Aboukir, a VG on the side of a residential building. Image source: https://slate.com

Probably Blanc’s most famous work in Paris is the mur végétal on the façade of Quai Branly Museum, which came into use in June 2006. This is his collaboration with architect Jean Nouvel, which combines nature and architecture through the art of plant-made environmental installations. This VG is about 8611 square feet with approximately 15,000 plants of 150 different species (Travel France, 2020). There are about 200 plants per square feet. Indeed, it’s a

perfect vertical natural ecosystem. Besides its undeniable aesthetic appearance, it is an excellent refuge for biodiversity and an important element of urban ecology by providing nesting sites and food for birds and insects and ameliorating the quality of ambient air. The City of Paris plans to introduce dozens of these vertical green walls across the city in the coming years.

Figure 2.9: Mur vegetal on the façade of Quai Branly Museum. Image source: https://www.verticalgardenpatrickblanc.com

Figure 2.10: Locations of different VGs in Paris: Vertical walls on buildings (red), Green roof (blue), and Combined VGs (yellow). Yellow line is an approximate boundary of Paris.

Other famous VGs around the world

Bosco Verticale (Vertical Forest), Milan, Italy. Designed by Boeri Studio

This splendid VG appears on a pair of residential towers which have a height of 364 feet and 249 feet (Rozza, 2012). The VG is basically balcony garden or roof garden therefore plants are still planted horizontally. Each tower houses 900 trees and 5000 shrubs on 96,000 square feet of terraces, and 11,000 perennials and groundcover on its façades (Boeri, 2018). With the reputation of "vertical forest", it helps mitigate smog and produce oxygen. These tree-packed high rises help cities built for density in a nature-friendly way, while improving the air quality. The 20,000 trees and perennial plants in the buildings will convert approximately 44,000 pounds of carbon each year (Chronicle, 2012). With more than 90 species, the buildings' biodiversity is expected to attract new bird and insect species to the city. It is also used to moderate nearby temperatures by shading buildings from the sun and blocking harsh winds. The vegetation also protects the interior spaces from noise pollution and dust from street-level traffic. On 12 November 2015, Bosco Verticale was admitted as the overall "2015 Best Tall Building Worldwide" at the 14th Annual CTBUH International Best Tall Building Awards Symposium (Ruta, 2019).

Figure 2.11: Bosco Verticale in Milan, Italy. Image source: https://www.lifegate.com

One Central Park, Sydney, Australia. Designed by Patrick Blanc and Jean Nouvel

As the surface of the world's largest vertical garden covered building, it is also the tallest of the vertical gardens Patrick Blanc has ever built (Gandy, 2010). This project is also comprised of residential apartments while a big difference between it and Bosco Verticale, its VGs are made up of living wall system and green façade in which plants are planted vertically. More than

350 Australian plant species, 35,000 green wall plants and 85,000 façade plants in total (WATPAC, 2014) are planted and climbed on the building, from the ground floor to the top floor, making the building a green tree of the new century and redefining the Sydney skyline. It has 23 separated green walls which take up about 13,000 square feet. Among them, the largest green wall is in the East Tower about 2100 square feet. Up to 2015, One Central Park has received numerous accolades and awards that have recognized both its structural ingenuity and sustainability measures (Tan, 2014).

Figure 2.12: One Central Park in Sydney, Australia. Image source: https://www.greenroofs.com and https://www.murvegetalpatrickblanc.com

Conclusion

Increasing impressive VGs are pouring into urban areas nowadays which bring people not only visual satisfaction but also indeed benefit urban ecology. VG's type in urban area has been developing from roof garden, at the starting point, to living wall system and green façade then to a combination of all kinds of VG. Buildings applicable for VGs have also been varying through this process—no matter what the materials of facades are, how high buildings are and what land use that buildings belong. As more and more VGs dot cities, the green-insufficient issue is likely to be solved in the future.

References

[1] *2016 Population Census Results.pdf*. (n.d.). Retrieved April 17, 2020, from https://www.bycensus2016.gov.hk/data/16bc-main-results.pdf

[2] Aedas. (2011, November 7). *Aedas: 18 kowloon east*. Designboom | Architecture & Design Magazine. https://www.designboom.com/architecture/aedas-18-kowloon-east/

[3] Amy Kolczak. (2017, February 28). *This City Aims to Be the World's Greenest*. National Geographic. https://www.nationalgeographic.com/environment/urban-expeditions/green-buildings/green-urban-landscape-cities-Singapore/

[4] ArchDaily. (2011, November 5). *18 Kowloon East / Aedas*. ArchDaily. http://www.archdaily.com/181332/18-kowloon-east-aedas/
[5] BEAM Plus. (2016). *Shatin Communications & Technology Centre—BEAM Plus Online Exhibition*. http://greenbuilding.hkgbc.org.hk/projects/view/60
[6] Blanc, P. (2008). *The vertical garden: From nature to the city /*. W.W. Norton,.
[7] Boeri, S. (2018). *Il Bosco Verticale*. *81*, 77–84.
[8] Chronicle, M. (2012). *Prime piante sul «Bosco verticale»—Milano*. https://milano.corriere.it/milano/notizie/cronaca/12_giugno_14/bosco-verticale-alberi-piante-catella-grattacielo-boeri-201596388512.shtml
[9] Emmett. (2015, January 13). *Urban Jungle: Singapore Leads the Way on Green Space*. https://www.conservation.org/blog/urban-jungle-singapore-leads-the-way-on-green-space
[10] Gandy, M. (2010). The Ecological Facades of Patrick Blanc. *Architectural Design*, *80*(3), 28–33. https://doi.org/10.1002/ad.1071
[11] GOHKSAR. (2017). Hong Kong Planning Standards and Guidelines Summary.
[12] Greening Solution. (2018). *Patrick Blanc & His Vertical Garden Designs*. https://www.greening-solution.com/patrick-blanc-his-vertical-garden-designs/
[13] Haaland, C., & van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening*, *14*(4), 760–771. https://doi.org/10.1016/j.ufug.2015.07.009
[14] Hohenadel, K. (2013, September 18). *Replanting the World's Concrete Jungles, One Wall at a Time*. Slate Magazine. https://slate.com/human-interest/2013/09/patrick-blanc-s-newest-vertical-garden-greening-urban-walls-around-the-world.html
[15] Hui, D. S. (2014). Green Roofs and Vertical Greening in Hong Kong. Hong Kong Institute of Surveyors (HKIS) Young Surveyors Group Technical Seminar.
[16] Jim, C. Y. (1987). Land use and amenity trees in urban Hong Kong. *Land Use Policy*, *4*(3), 281–293. https://doi.org/10.1016/0264-8377(87)90028-7
[17] Mahtab-uz-Zaman, Q. M. (2003). Hong Kong: A review of density, urban form and sustainable development. *Journal of Research in Architecture and Planning*, *2*, 33–39.
[18] Masson, V., Lion, Y., Peter, A., Pigeon, G., Buyck, J., & Brun, E. (2013). "Grand Paris": Regional landscape change to adapt city to climate warming. *Climatic Change*, *117*(4), 769–782. https://doi.org/10.1007/s10584-012-0579-1
[19] Milestones Stories. (2012). *Eco-Green Group*. http://www.hk-egg.com/en/milestone.aspx?Id=11
[20] Newman, P. (2010). Green Urbanism and its Application to Singapore. *Environment and Urbanization ASIA*, *1*(2), 149–170. https://doi.org/10.1177/097542531000100204
[21] Ooi, N. M. G. and C.-S. (2014, July 25). *Manufacturing Green Consensus: Urban Greenspace Governance in Singapore*. Urban Forests, Trees, and Greenspace; Routledge. https://doi.org/10.4324/9781315882901-13
[22] Rozza, G. (2012). *Luogo di incontro—Corriere.it*. https://www.corriere.it/cultura/eventi/2012/made-expo/notizie/rozza-luogo-incontro_d95716f2-183d-11e2-a20d-0e1ab53dafde.shtml
[23] Ruta, M. (2019). *Bosco Verticale in Milan by Stefano Boeri, Gianandrea Barreca, Giovanni La Varra*. *"Milan in Detail," supplemento speciale ad "ArKetipo," n. 134 (December 2019)*, 8–23.
[24] Samant, S. (2019). Cities in the Sky: Elevating Singapore's Urban Spaces. 국제초고층학회논문집, *8*(2), 137–154. https://doi.org/10.21022/IJHRB.2019.8.2.137
[25] Sen, & Charles. (2017, November 9). *More green spaces in high-rise buildings targeted for Singapore's concrete jungle* [Text]. The Straits Times. https://www.straitstimes.com/singapore/environment/more-green-spaces-in-high-rise-buildings-targeted-for-singapores-concrete

[26] Senanayake, I. P. (2013). *Assessment of Green Space Requirement and Site Analysis in Colombo, Sri Lanka—A Remote Sensing and GIS Approach*. *4*(12), 6.

[27] Senthilingam, B. M. S., for. (2016, July 21). *How did Singapore become such a green city?* CNN. https://www.cnn.com/travel/article/singapore-greenest-city/index.html

[28] Tan. (2017, February 23). *Not a concrete jungle: Singapore beats 16 cities in green urban areas* [Text]. The Straits Times. https://www.straitstimes.com/singapore/environment/not-a-concrete-jungle-singapore-beats-16-cities-in-green-urban-areas

[29] Tan, M. (2014). *Sydney's One Central Park wins international best tall building award | Architecture | The Guardian*. https://www.theguardian.com/artanddesign/2014/nov/11/sydneys-one-central-park-wins-international-best-tall-building-award

[30] Tian, Y., Jim, C. Y., & Tao, Y. (2012). Challenges and Strategies for Greening the Compact City of Hong Kong. *Journal of Urban Planning and Development*, *138*(2), 101–109. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000076

[31] Travel France. (2020). *Quai Branly Museum Vertical Garden—Paris*. Https://Www.Travelfranceonline.Com/. https://www.travelfranceonline.com/quai-branly-museum-vertical-garden-paris/

[32] Warren, W. (c2000.). *Singapore, city of gardens /*. Periplus Editions,.

[33] WATPAC. (2014). One Central Park a landmark project for Watpac.

[34] Wong. (2018). *Paris to turn a third of its green space into urban farms*. CNN. https://www.cnn.com/style/article/urban-farms-in-paris/index.html

[35] Wong, T.-C., Yuen, B. K. P., & Goldblum, C. (Eds.). (2008). *Spatial planning for a sustainable Singapore*. Springer.

[36] Y-Jean. (2017, May 1). *Parkroyal On Pickering In Singapore Is Designed As A Hotel And Office In A Garden*. https://www.forbes.com/sites/yjeanmundelsalle/2017/03/01/parkroyal-on-pickering-in-singapore-is-designed-as-a-hotel-and-office-in-a-garden/#3dc42c667dfc

[37] Yok, T. P. (2013). Vertical garden city, Singapore.

[38] Yuen, B. (1996). Creating the Garden City: The Singapore Experience. *Urban Studies*, *33*(6), 955–970. https://doi.org/10.1080/00420989650011681

CHAPTER 3: VERTICAL GREENING (VG)—A SYSTEMATIC REVIEW OF THEIR CHARACTERS AND ENVIRONMENTAL BENEFITS

Abstract

Dense urban environments are becoming the norm worldwide. As the competition for ground space increases in these cities (and ground prices go up) the green space essential for human health and well-being, gets squeezed out. Physical and mental health suffers. Vertical greening (VG)—living wall system, green façade, green roof and balcony garden—has been proposed as an effective solution.

Sustainable urban development demands a harmonious relationship between nature and metropolitan environment, which encourages combinations of architectures and plants. Numerous researches have proved VG's environmental functions, including relieving urban heat-island effects, reintroducing biodiversity, increasing buildings' property value, insulating against pollution and noises, purifying air and rainwater quality, and benefiting human health and well-being. This research studied different types of vertical greening and analyzed their opportunities and disadvantages as an approach for urban sustainability.

Introduction

The form of vertical greening has a long-time history. The first try recorded to connect building and green landscape dates back 2000 years ago, which were hanging gardens in Babylon (Kontoleon & Eumorfopoulou, 2010), one of the Seven Wonders of the World. It was a terraced garden with an elaborate irrigation system outside of modern-day Baghdad (Dalley, 2013). It is believed that the hanging gardens were built by a husband to satisfy his wife who missed the days they spent in a mountain area and was so passionate about natural surroundings(Reade, 2000). About 2000 years ago, people in Mediterranean areas used vines to plant the earliest form of vertical greening—green façade. Vine trees covered the whole façade, provided shades for people, cooled down the environment and some of them served as a vertical farm to produce fruits and vegetables (Medl, Stangl, & Florineth, 2017). In the 20th century, since brick façades were popular at that time, English and Boston Ivy which grew vigorously on those facades were included in the plant species for VG primarily(Köhler, 2008). More recently, VG has a considerable progress in technology advancement especially in the domain of wall

cladding (Manso & Castro-Gomes, 2015a). As Patrick Blanc invented the first green wall using a hydroponic system, there is another type of VG—living wall system becoming a norm worldwide. It gives plants selection much more diversities not just climbers but also groundcovers, even shrubs and trees. Since then, VG has more various aesthetic appearances and functions to urban ecology and human life.

Vertical greening is an integration of vegetation and vertical or elevated infrastructures which include building façades, walls, balconies and roofs(Timm, Dearborn, & Pomeroy, 2018; Dunnett, 2008; Snodgrass, 2006). It requires specific types of plants (climbers or groundcovers), technologies, irrigation systems, human maintenance and sometimes, additional structural supports (for plants growing). Coordinated with the ecological theories since 1866 which advocates a better awareness and actions on global concerns, vertical greening affects urban environment powerfully in saving building energy and benefiting our ecosystem. As a green infrastructure full of various plants, it promotes not only social and aesthetical value but also human well-being and healthier psychology. More important, VG is an efficient and effective ecological method to increase green areas in a dense urban environment which is becoming a common phenomenon all over the world.

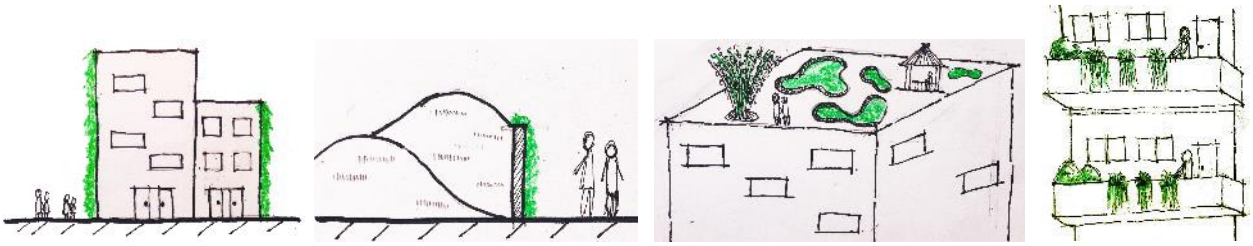

Figure 3.1: Vertical greening on a building façade (left 1); VG on a wall (left 2); VG on a building's roof (left 3); VG on a balcony (left 4)

Vertical greening can be applied inside or outside buildings but with different types of it. Inside VG is usually planted with modular panels attached to the walls which are called living wall systems, and its plants are mainly groundcovers. While outside VG usually lets plants grow in soil beneath or above the facades using climbing or cascading plants, which is another type of VG—green façade. Living wall system and green façade are the two main categories of VG. They are developed from two German terms—'fassadengebundene Begrünung' and 'bodengebundene Begrünung' (Leyshon, 2019), which are translated as "wall-based greening method" and "ground-based greening method". Green roof and balcony garden are also viewed as two types of vertical greenery. Frequently, they are combined with green wall together

applying on a building to form an integrated vertical landscape(Timm et al., 2018; (Boeri & Insulza, 2009), projects such as PARKROYAL on Pickering in Singapore and Bosco Verticale in Milan, Italy. This research stressed more on living wall system and green façade. For each category, they can be divided further in a detailed classification. From literature review, there are various existing classifications for VG. While, this research proposed a new classification based on the technical details and final appearances (see Figure 3.2). Having studied each of their pros and cons through reviewing 100 identified References (see Figure 3.3), we can have a knowledge of applying suitable vertical greening for specific outcomes.

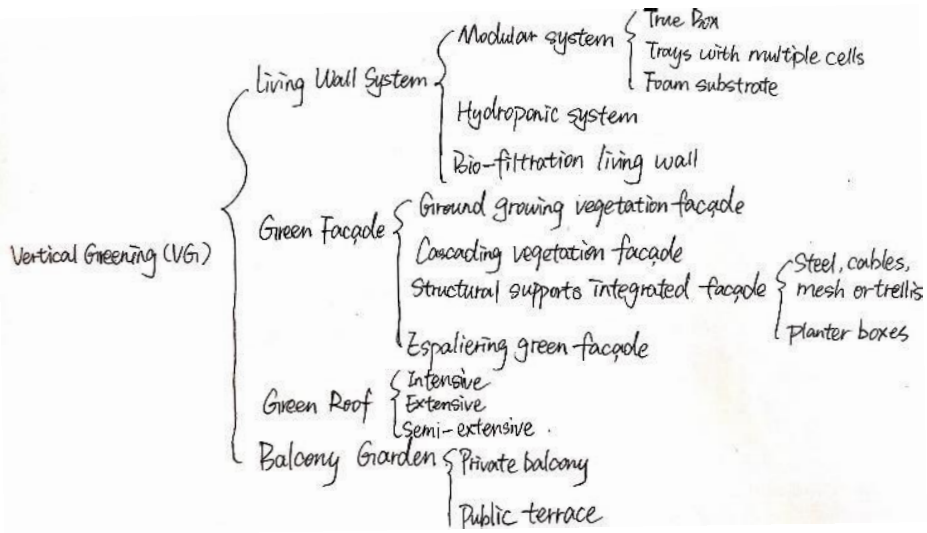

Figure 3.2: Classification of Vertical Greening based on their technical details and final appearances

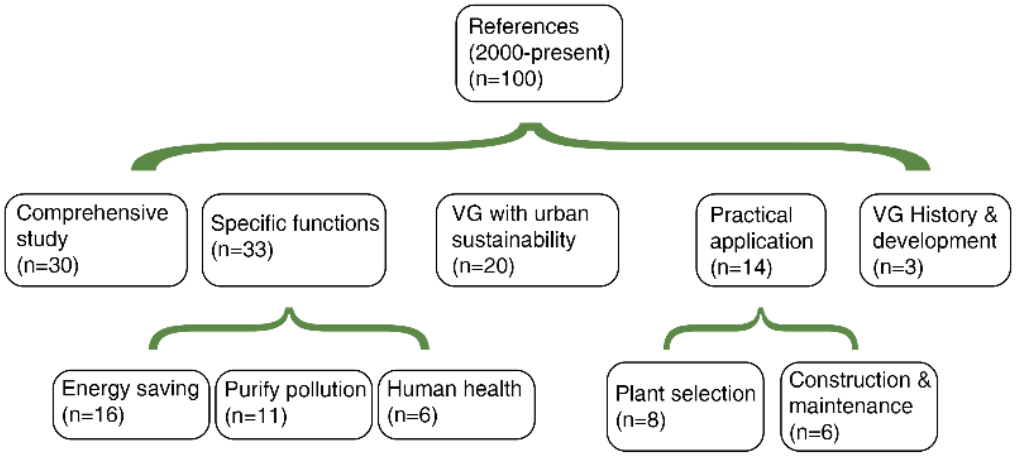

Figure 3.3: Overview of identified articles as References for this research

Living wall system

Living wall system is a type of VG that plants vegetation directly on the façade or other vertical surfaces—wall-based greening method—without having a connection with the natural ground necessarily. It is based on modular systems made by plastics, metal, fabrics or other materials which are connected vertically to a wall's surface. Each of the panel holds its own substrate and has a boundary with the other. The place of a panel is the whole growing space for the plants in it. It could be made up of various plant species and because of that, it can exhibit a creatively designed format and has more possibilities in the final appearance aesthetically. However, because of the same reason, it commonly requires more human maintenances to promise a good growing condition for abundant plants and the ecosystem it creates. Besides, since it is planted with mature plants, it doesn't take a long time to become the final expected appearance, and it basically can maintain the same appearance for a long time. Based on the technical details, living wall system could be divided into three categories—modular system (containing planter box and tray or foam basement), hydroponic system, and bio-filtration living wall.

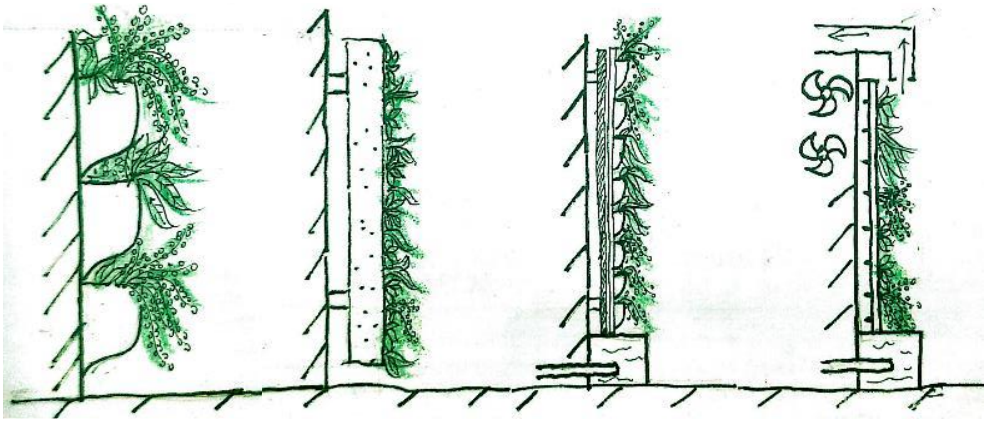

Figure 3.4: Living wall system: Modular system-planter box (left 1); Modular system-tray or foam basement (left 2); Hydroponic system (left 3); Bio-filtration system (left 4)

Modular system

A modular system is a system that uses modular panels, boxes or blankets with a rectangular or square shape as a planting medium for plants to grow. Plants are required to be pre-planted first in these mediums which then are attached side by side on a vertical surface. The modular system is inspired by a type of green roof which uses modules instead of soil to grow plants (Othman & Sahidin, 2016). Nutrients and soils for plant needs are provided separately in

each modular panel or box. Considered different materials of the modular system, there are two main divisions: one is the true box system, another is the utilization of plastic or metal trays containing multiple slanted cells (Weinmaster, 2009), also named continuous green wall (Medl et al., 2017).

For the planting box system, it uses square or rectangular boxes made by plastic, metal or fabric as separate growing environments for plants. Every box contains the individual substrate including coco-coir, mineral wool, peat, perlite, vermiculite or some similar substrate(Luckett, 2009). The plant species for this type of VG are mainly groundcovers, such as Creeping Jenny (Lysimachia nummularia), Stonecrop (Sedum rupestre) or plant species belonging to ferns. Commonly, a box can grow whatever from six to fifteen individual plants depends on how big the plant is and types of the box. And a box is usually about one square foot and few more inches thick even though the scales of walls it attached are various (Weinmaster, 2009).

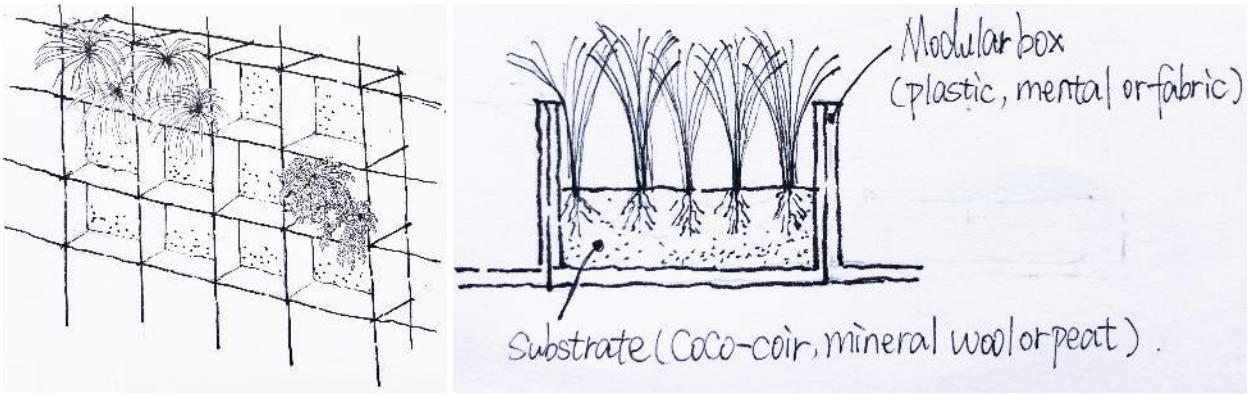

Figure 3.5: Modular box system (left), the section of a box (right)

Another type of modular system is to use trays or foam bulks with multiple slanted cells as the basement, and a frame to hold everything and prevent humidity from approaching the wall, which forms a continuous green wall just like a painting (see Figure 3.6 left). Why slanted cells? There are two main reasons. One is for better irrigation (Weinmaster, 2009). The slanted cell could form a little pond at the bottom of the planting box (see Figure 3.6 top right), and dripped water is collected in it to the roots because of the gravity. Another one is to keep plants in place. Plant' roots can be inserted into bulk foam and it can support plants firmly (see Figure 3.6 bottom right). This type of living wall system could be more complicated in construction technology because it is a combination of several different pots instead of a whole pot.

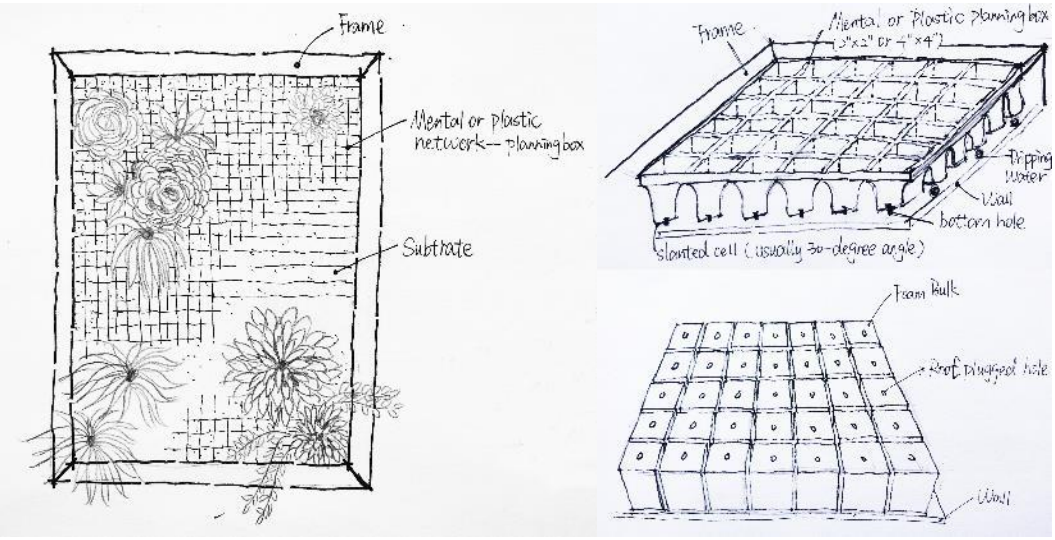

Figure 3.6: Trays' modular system (left), slanted metal or plastic planting box (right-up), foam-bulk planting box (right-bottom).

The most suitable application for it is a temporary green wall which needs an expected final appearance in a short amount of time and could be replaced easily a couple months later. That is, there are two main advantages. One is showing the final appearance as soon as the whole modular system is established. It doesn't need an extra time for plants to grow, compared with green façade that needs 1 to 3 years to reach a full coverage. Another is an easy replacement of each module. If the plants don't grow well, modules are easily purchased and are portable for transportation.

Whereas, its disadvantages are also outstanding. First, because the only space for plants to grow is a small box no larger than one square foot, plant roots can't grow deeply and firmly, which could lead to easily destruction by rainfall or wind. Second, also because of that, the plant selection is limited only to small groundcovers, reducing biodiversity to some extent. Third, as an aesthetical aspect, the whole wall will be barely anything but geometric square boxes and human-made signs, which is not natural to some people. Last, since different box systems should be planted manually then placed into their expected places, it could cost one to six months to establish the entire wall, which probably increases the price to build it.

Hydroponic system

Hydroponic system, by definition, is a system in which plants grow in a liquid-base and nutrient-rich substrate instead of soil. It is also called vegetated mat wall (Othman & Sahidin, 2016). Plants root will come in direct contact of the nutrient solution, at the same time are able to

obtain oxygen from the surrounding environment. It is first invented by Patrick Blanc who is reputable as the grandfather of the green wall (living wall system) and the primary advocator to apply it in the urban area broadly dating back to 1985 (Blanc, 2008). Blanc defined the term “Mur végétal" which is basically translated to “vertical garden”. He got an inspiration by observing nature and noticed that there are lots of plants growing without soil. Plants roots need substrates that are not necessarily soil but could be rocks, tree trunks or even water. Those plants he found were mostly moss, algae or ferns. While up to now, his vertical greening wall is a norm worldwide and it is found in his works that even trees and shrubs can thrive in this system as its technology grows more mature. During the design, he tried to imitate natural structural supports for plants growing vertically without soil. He figured out the best choice was synthetic fabrics such as nylon, plastic fabric or polyester because they were not easily broken by water washes or wind flows compared to natural fabrics. And they are qualified to hold humidity, let roots move freely, and serve as structural supports (Weinmaster, 2009; Manso & Castro-Gomes, 2015).

Concluded from Blanc’s vertical greening works, hydroponic system requires an erected frame which could be a vertical beam or lattice structure. Non-rusting metal such as stainless steel or aluminum or wood can be used to make that structure. The most important element of hydroponic system is the waterproof layer. It plays a powerful role to decide whether this whole system will last long without manually fixing or not. It prevents the humidity reaching the wall so should cover every single part of the wall. As for the planting layer, it is basically a special mat with several “pockets” for plants to grow instead of an entirely flat mat (see Figure 3.7). Rather than nurtured by soil, plants absorb nutrient from the substrate, which is mostly a recycled synthetic fiber that is spun into a nonwoven matrix (Weinmaster, 2009). It holds water and liquid nutrient longer, relieving the irrigation burden. Then a drip irrigation system is functional enough to produce humidity and nutrients generally. For some living walls, there will be a water pump in the catchment tank which collects water and nutrient from the irrigation. Through that, water is re-circulated to the irrigation system, which helps to conserve water.

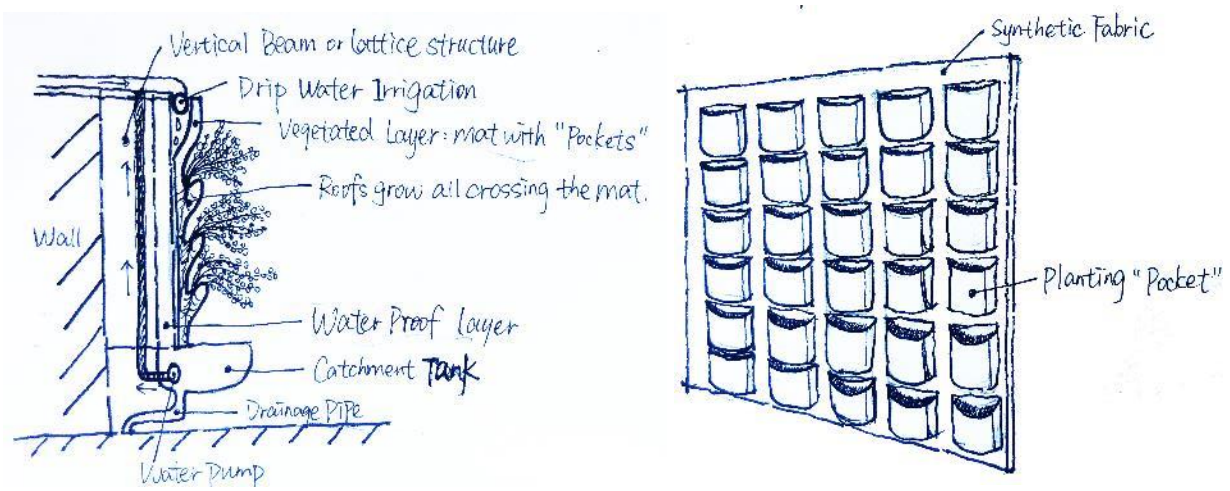

Figure 3.7: The section of a hydroponic system (left), the "pocket" planting mat (right)

The suitable application for this type of VG is a permanent wall since it's an integrated system compared with modular system with separate planting substrates. In addition, a hydroponic living wall can be applied as a small moveable green infrastructure indoors, which could be served as a decoration or division between different areas in an office (see Figure 3.8). It has been applied all over the world and indeed owns many advantages. From the aesthetical aspect, it provides more possibilities for design and aesthetic appearance since a large variety of plants can be applied. Because there is no habit boundary between each plant, plants' sizes or species are not rigorously required. Plant roots could grow through the whole mat and twist with each other becoming a network, which makes the root system extremely strong. It even can hold large plants such as shrubs or trees, which is another reason for higher biodiversity. As for the water consumption for irrigation, its substrate has a close-grained texture so can hold water longer. Besides, the dripping water is percolated directly in the area of plant roots. These two reasons help to save water extremely compared with irrigations for urban parks or other traditional landscapes. From the pest aspect, it's well known that higher biodiversity, lower percent for pest disaster. Pests cause disaster because they target one plant species and destroy them entirely. In a hydroponic system, even a square feet will have numerous plants so it would be a vivid ecosystem. Plants can also achieve mutualism and maintain the whole system with higher resistibility and resilience. From the weight aspect, it's about four times lighter than others because it lacks soil (Weinmaster, 2009).

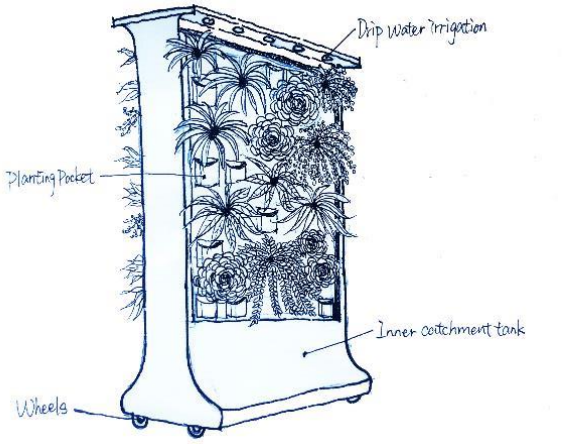

Figure 3.8: A moveable hydroponic living wall with wheels

The disadvantages are not too many compared to its advantages. It's not easy to replace plants or change planting format, not like modular system. It requires a time for plants to grow so not suitable for temporary exhibition. Besides, because of higher biodiversity, it requires more human maintenance at the beginning. So for saving the construction and management price, it's more economic to be applied indoors or outdoors with smaller scales.

Bio-filtration living wall

Living wall system owns plenty of benefits to the urban environment because of various plants. Besides, its aesthetical values and functional values are thought highly of by people especially since the theory of urban ecology has been accepted broadly (Ascott & Kenny, 2019). It serves as a bio-interlayer to cool down the building, purify the air conditions and filtrate the rainfall. Traditionally, living walls serve as "passive" biofilter, but this type of VG is an "active" biofilter (Pérez-Urrestarazu, Fernández-Cañero, Franco-Salas, & Egea, 2015). The bio-filtration living wall is a particular living wall that fosters and enhances its air cleaning functions for urban environment. There are two main mechanics of how it works. One is as a thermal regulation of surrounding area. This is an inherent function without other extra actions, as various plants it contained can shade the building and prevent dramatic temperature changes. Another one is as an air filtration. For this function, fans are required. The polluted air is forced to pass through the living wall through fans then get filtrated. Then air will be collected afterward and released inside a building since it is already clean, cool and humid. Its irrigation method is similar to the

hydroponic system, using a pre-vegetated mat as a planting basement and a water pump in the catchment tank to re-circulate nutrients.

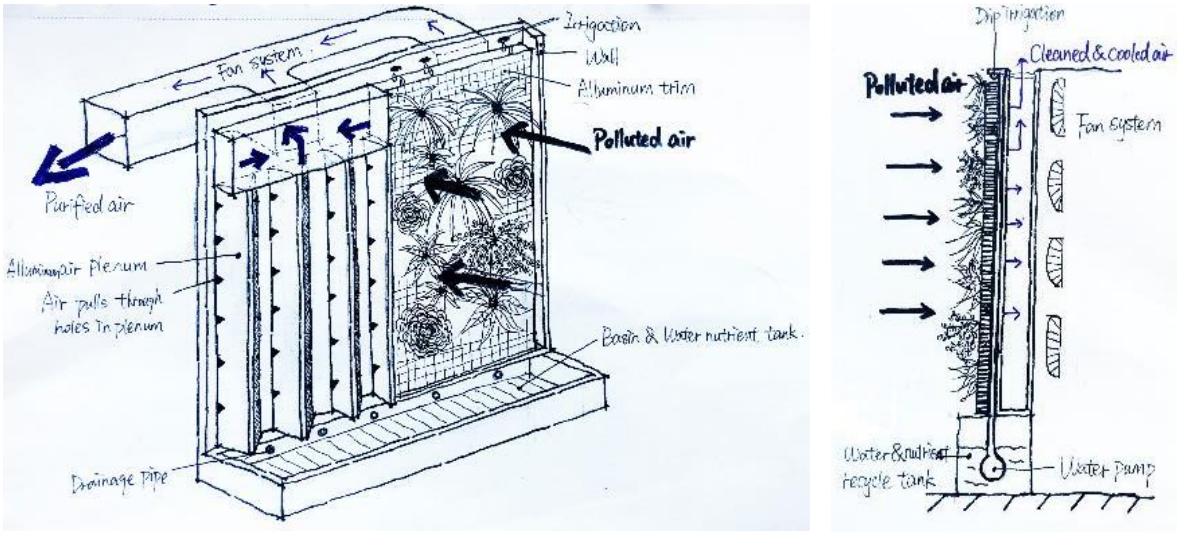

Figure 3.9: A bio-filtration living wall (left), the section of the bio-filtration system (right).

The suitable application for it is outside for which it can maximize its function in purifying the air. Also, because of its auxiliary facilities, fan system and aluminum plenums, more spaces behind this living wall are required. Applying it outdoor will take less indoor places which are essential for building's facilities such as air conditioners and electrical systems. Besides, it is encouraged to use it in heavy-polluted areas such as industrial districts and areas along the road system.

One unpleasant condition of it is that people may don't want to apply it as broadly as other types of living wall. For one thing, this type of living wall is a kind of extreme example to fully use the benefits of vegetated walls, so it is more applicable in the place which largely needs to purify air. After all, normal green walls can purify atmosphere too—just not as powerful as bio-filtration living wall. For another thing, it always will be combined with fan systems, pipes and aluminum plenums, which could negatively affect its aesthetic when there is no way to cover these facilities. Also because of that, it requires more techniques for the auxiliary facilities which could be costly, as well as take up a lot of space beside or behind the wall.

Green façade

Compared with living wall system, vegetation of green façades is rooted in ground soil or soil containers at any height and grows vertically, at the same time, horizontally on vertical surfaces (Weinmaster, 2009). They grow more natural even without any artificial assistants as

they get nutrients from ground soil rather than vertical surfaces, which also require less financial support relatively (Lin, Xiao, Musso, & Lu, 2019). Plants for green façade are mainly climbers, such as ivies, creepers, and vines, which are mainly shrubs even trees. Normally, 3-5 years for plants growing are required to reach full coverage (Chew, Conejos, & Azril, 2019). That contributes to one of disadvantages—it requires long time to grow fully or to make up the empty made by dead plants. Besides, some plants with aerial roots may destroy building façade which requires the original external surface to be strong. The last is the limitation of its aesthetical creation. Plants grow naturally and we probably can't force them to grow in specific shapes. So the final appearance would always be robust rather than elegant. As for the classification, this research proposed one focusing on the final appearance of green façade, which contains ground growing vegetation façade, cascading vegetation façade, structural supports integrated façade and espaliering green façade.

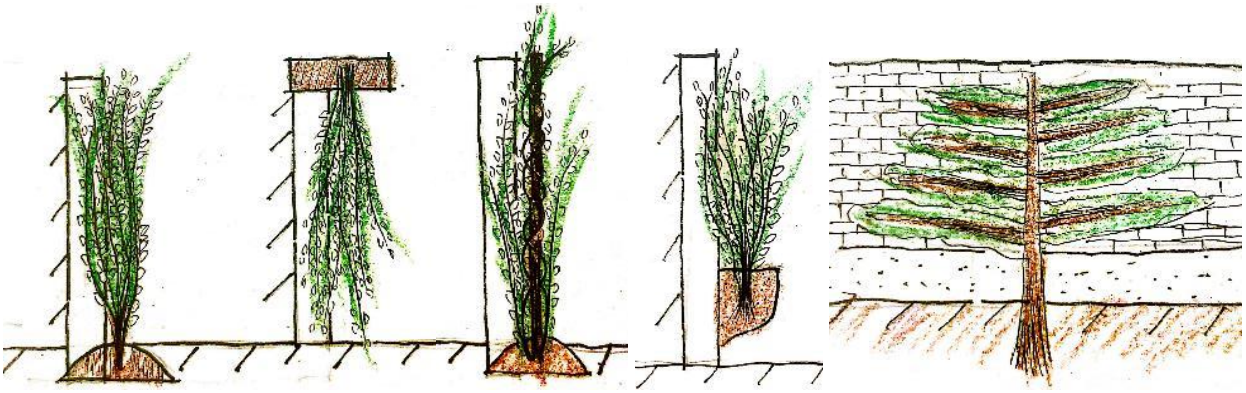

Figure 3.10: Green façade (from left to right): Ground growing vegetation façade; Cascading vegetation façade; Structural supports integrated façade—steel, cables, mesh or trellis; Structural supports integrated façade—planter box; Espaliering green façade

Ground growing vegetation façade

Vegetation for this type of façade is rooted in the ground and grow up along a vertical surface. There is no requirement for extra structural assistants because those plants usually have strong adventitious roots or self-adhesive pads which help them directly adhere to an external surface. This type of façade happens naturally even doesn't require to be planted first, which makes it be the most common green façade. For most people, it is their first cognition of vertical greening.

This green façade could be the most economical one compared to other vertical greening. Artificial planting as well as careful maintenance are not necessarily required. Plants could grow robustly by themselves. It is suitable for areas where people don't want to invest a lot in

construction and management (eg. industrial area or suburban), walls without windows would not need to be trimmed as frequently, and serve as green isolation belts around urban margins.

Plants for it are usually English Ivy and Parthenocissus. While, not all building facades are suitable to apply it because plants with aerial roots are so strong that could penetrate cracks or joints and destroy building's integration. For old buildings with fragile structures or light wooden structures, this type of façade may not be suitable. Compared to that, concrete or brick surface are encouraged to apply it. Another disadvantage of it, also because of plants, is that once plants have fully grown up, it's difficult to move them from the surface later. So it is not a good idea for temporary structures. While for Parthenocissus which are not supported by aerial roots but five to eight branched tendrils ending in cup-like adhesive tips, they could have less threats to the life of building façade (Weinmaster, 2009), leading them more utilizations compared to ivies in green façade.

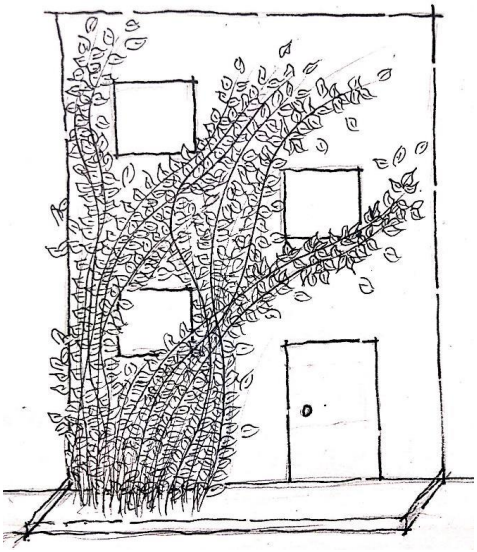

Figure 3.11: Ground growing vegetation façade on a residential building

Cascading vegetation façade

Cascading vegetation is used in this type of façade. They are planted in a substrate above a wall or they don't even need a substrate such as air plants. Plants for it are usually cascading groundcover such as *Aubrieta Superbissima*, snow-in-summer (*Cerastium sp.*), creeping jenny (*Lysimachia nummularia*), creeping rosemary (*Rosmarinus officinalis 'Prostratus'*), evergreen candytuft (*Iberis sempervirens*), stonecrop (*Sedum rupestre*).

It is frequently used in streetscapes or topographic retaining walls. Its final appearances are more attracting compared with ground growing façade since flowers of cascading plants are

usually condensed. Branches of plants are so soft that swaying with wind. It would form an exquisite landscape. The vertical surface should not be so large—usually human height or a little bit higher would be better—because groundcovers are usually with low height and can't cover fully if the wall are so large.

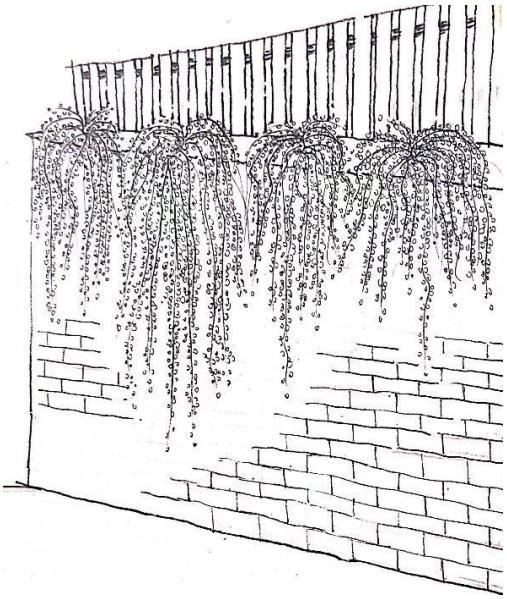

Figure 3.12: Cascading vegetation façade on a topographic retaining wall

Structural supports integrated green façade

Structural supports mainly contain two categories—one is like the second skin next to the building exterior: steel, cables, mesh or trellis and another is planter boxes. For the former support, they are prepared for plants such as *Campsis radicans, Japanese honeysuckle,* genera such as *Jasminum, Clematis and Lonicera*. They support plants to climb up without touching the building surface. Materials such as aluminum, plastic, wood and steel (stainless steel, coated steel, galvanized steel) could be used as supporters depending on expecting aesthetic, thickness, climbers' total weight, profile, cost and durability (Rakhshandehroo, Mohd Yusof, & Deghati Najd, 2015). For the latter one, they provide soil in containers at any level of the building, especially useful for planting small climbers in a large area of surface, which could be viewed as one kind of green wall system.

Adding structural supports makes plant selection more various, and final appearance is more aesthetical and creative. Structures could be any shape then climbers will grow up following that shape, such as arch, circle, rectangle, radial pattern even a tree-shape. In that case, VGs are not necessarily built against building façades anymore. They could be built in a public

square combined with shade structures or in a public park as a green sculpture. People can have more interactions with green façades such as touching and sitting instead of just watching. These structural supports together with plants could be moved easily so it's suitable for temporary utilizations.

Nevertheless, it could be expensive because heavy climbers such as Wisteria requires good quality of supporters. If the surface is large, there may be a large area of cable supporters required to cover it fully. For the façade with specific shape, frequent maintenance is indispensable to let plants grow as that shape.

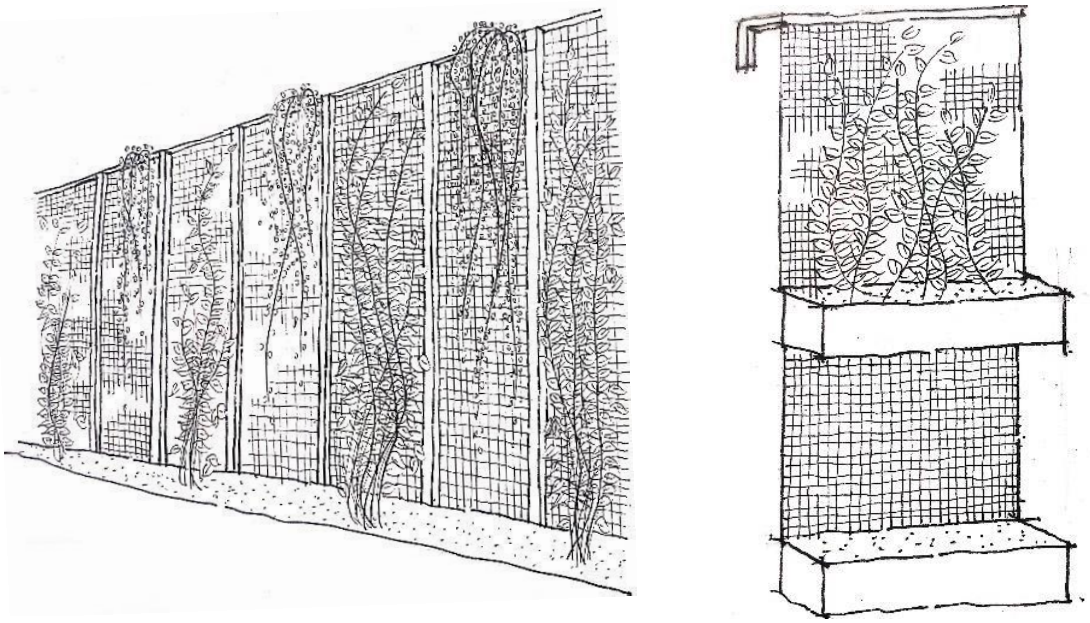

Figure 3.13: Structural supports integrated façade: trellis and mesh structural support (left); planter box with mesh support (right)

Espaliering green façade

This type of façade encourages shrubs and trees grow directly against a wall or vertical surface to form a two-dimensional effect. It could date back to ancient Rome and Egypt, but the time of Middle Ages in Europe is when it was perfected as a tree-training art. In the beginning, fruit trees were frequently espaliered against castle walls as people can pick up fruits easily without intruding on courtyard or path space (Leyshon, 2019). To date, it is mostly viewed as a kind of wall decoration or art to admire specific shapes of trimmed trees. Plants for that are still fruit trees. They can grow especially well because the walls trees are growing against absorb solar radiation to provide plants suitable warmth at the same time serve as wind insulation (Weinmaster, 2009), which could create favorable micro-climates for fruit production.

It is getting more and more popular because this type of façade is a decorative and compact vertical landscape. Trees are trained to grow flatly, which saves lots of space so suitable for small areas or personal gardens. Since trees are pruned to be more condensed, flowers are more concentrated, forming a dense and splendid view. Also, fruits are closer to each other and often ripen earlier.

As for its disadvantages, first, it requires frequent pruning and manipulating. Second, professional knowledge for plants' pruning may be required as over-pruning may destroy plants' health. Besides, espaliering façade could be boring since there will only be individual trees rather than abundant plant species on the façade, which is not as powerful as other vertical greenings to introduce large biodiversity. Especially in seasons when trees don't have flowers or fruits, there will only be branches and leaves on the wall, which may not be aesthetic visually.

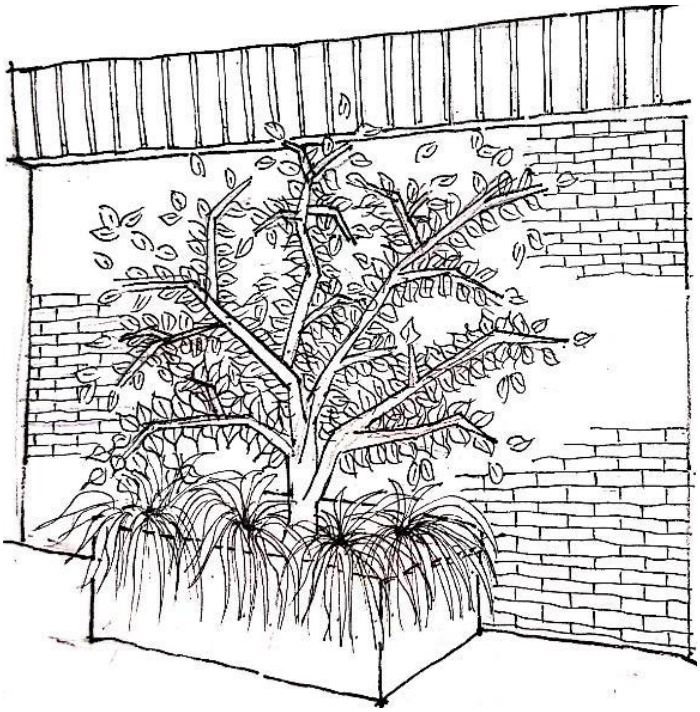

Figure 3.14: Espaliering green façade: a fruit tree is trained to grow flatly against a residential building.

Green roof

Green roof has been researched quantitatively compared with living wall system and green façade. It is an ecological roof with vegetation layer and growing media under it (Sailor, 2008). It is originally derived from the Greek word kremastós meaning "overhanging", which has a broader meaning than the modern English word "hanging" and refers to trees being planted on an elevated structure such as a terrace (Dalley, 2013; Reade, 2000). Ornamental green roofs

developed initially by the ancient civilizations of Tigris and Euphrates River Valleys in the 7th and 8th centuries B.C. (Dunnett, 2008), where the Hanging Gardens of Babylon appeared. It was applied frequently especially since the mid-1800s in Europe and America, when concrete was created as a roofing material and flat-roofed buildings were constructed mostly (Sutton, 2015). Recently, it has been viewed as an effective method to introduce biodiversity in dense urban areas. Originating in Switzerland, green roof benefiting biodiversity concentrates primarily on habitats creation on rooftops, using local soils, substrate materials, vegetation or sometimes specific local seed mixes (Dunnett, 2008). Nowadays, green roofs are prevalent, or even required, especially in some parts of Europe. In Germany, more than 10 percent of all roof areas are vegetated (Shafique, Kim, & Rafiq, 2018). Countries like USA, Canada, Singapore, Australia, Japan, China, Hong Kong and South Korea are making a strong initiative to apply the green roofs at the new as well as existing buildings to achieve the multiples benefits (Tian, Jim, & Wang, 2014; Tian, Jim, & Tao, 2012; Haaland & van den Bosch, 2015; Balick et al., 2000; Naczi, 2016; Wong, Tan, Tan, Sia, & Wong, 2010).

Green roofs are commonly divided into two categories: intensive and extensive. Intensive green roof has an individual grow media and plants tend to be maintained in the same way as they would in a ground-level garden. Soil depth is required to be at least 6 inches (Dunnett, 2008). However, lighter substrates have been created to replace soil, which help to reduce the overall weight of green roof. Plant species are various from herbaceous to trees, basically no limitation. In addition, there could be substantial pools and water features on the rooftops, such as some terraced landscape with swimming pools in hotels. People are encouraged to visit it frequently so it should have higher aesthetic and more frequent interactions with human.

Extensive green roofs are simpler relatively. Their substrates are usually 0.8 to 6-inch depth (Sutton, 2015). Plants are limited to sedums and moss (Bianchini & Hewage, 2012) and no need to be beautiful since this type of roof is not intended to let people access regularly. It is designed to be self-sustaining and require minimum maintenance.

Besides, the third type of green roof has been proposed at present: semi-extensive green roof. Obviously, it is a combination of intensive and extensive but extensive type must represent 25% or less of the total green roof area (Bianchini & Hewage, 2012). It has a great deal of potential for creations of roof planting where people intend to visit and use (Dunnett & Kinsbury, 2003). Semi-extensive green roofs keep similarly lightweight substrates and modern green-roof

construction technologies, same as extensive green roof, but with slightly deeper substrate (4 to 8 inches) (Dunnett & Nolan, 2004) so they are able to carry more diverse plant species.

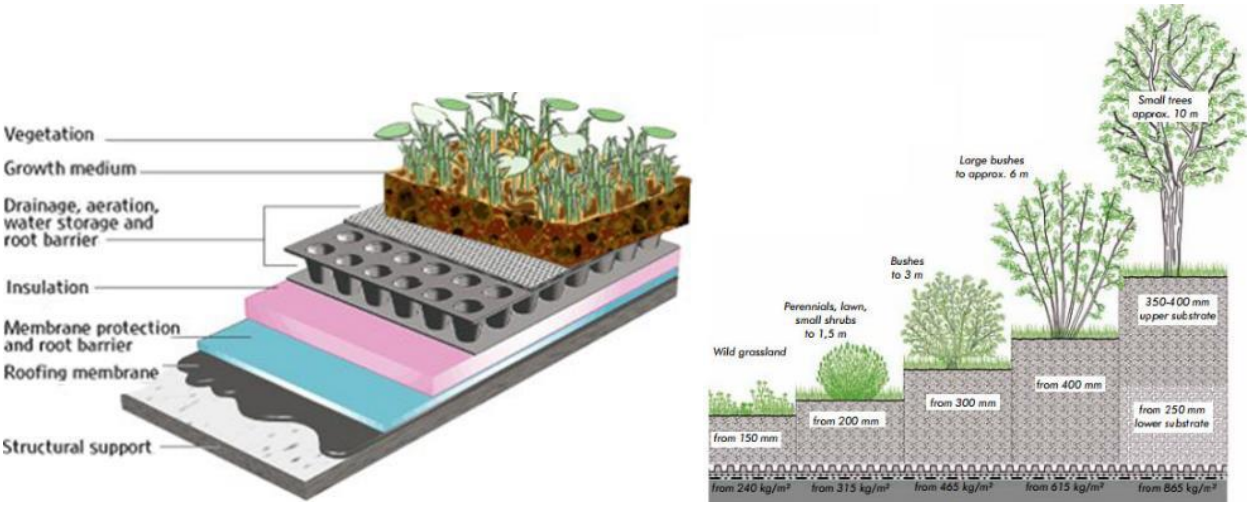

Figure 3.15: Construction details of green roof: Layers of typical green roof (left); Required substrate depth for each type of plants (right). Image sources: https://www.urbanstrong.com/intro-green-roofs-pt3-types-layers/ and https://myrooff.com/intensive-green-ro

One advantage of it is more interactions with people compared to living wall system and green façade. It just like traditional ground green space where people can walk and sit, enjoying their leisure time. Besides, landscape could be more attracting because when on the rooftop, people can admire the skyline of city, just as an old saying goes: stand high and see far. Roof gardens could be connected to other urban landscapes to get an overall amazing effect.

Disadvantages are complexities of technical requirements and limitations of visitors or viewers. Showed in Figure 3.15, these layers are so essential that lacking each will fail the green roof. The most critical factors of a green roof are waterproof and insulation layers to drainage rainwater well and protect integrations of roof's structure. In addition, only people in places higher than the roof could see the landscape. For the accessibility, people who are in this building have a priority to visit, which limits the benefits of green roof as a public green space.

Figure 3.16: Intensive green roof (left): Punggol Drive / Edgefield Plains, Singapore; Extensive green roof (right): Nanyang Technique University, Singapore

Balcony garden

This kind of vertical greening happens on private balconies or public terraces, which are raised horizontal floors at any level of buildings rather than vertical surfaces. Private balcony garden can be one of the easiest vertical greenings which could be formed just with a few planting pots. However, that doesn't mean its success will be easily. For one thing, plant selections require strong knowledge about sunlight volume the balcony gets (Schuler, 1964), for example, sunny or shady? how many hours of sunlight per day? For another thing, considering safety of a balcony should always be primary. The main issues are things falling off so make sure that drainage is in good quality and don't put too much weight on the balcony. Plants for that are often shrubs and herbaceous with beautiful flowers, fruits and fragrance, such as tomato, cucumber, lettuce, mint, rosemary, and lavender (Dunnett, 2008). Although it is a small area and doesn't require too much work, it should be delicate to pleasant daily life and be cherished by owners to show personalities. When it comes to public terrace, balcony garden is often combined with other types of vertical greening. Together, they shoulder the responsibilities to increase green space in urban environments, beautify buildings and benefit human health. It is also viewed as one kind of green roof so their technical issues could be similar.

Figure 3.17: Private balcony garden (left), image sources: https://homebnc.com/best-balcony-garden-ideas/; Public terrace garden (right): PARKROYAL Hotel on Pickering, Singapore

Table 3.1: Comparison of characteristics and pros & cons between each type of vertical greening

Type	Sub-categories	Detailed technique	Characteristics	Advanatages	Disadvantages
Living wall system	Modular system	True box	•Square boxes about 1 sf as growing environments •Individual substrate for each box •Groundcover dominated •Six to fifteen individual plants each box	•No time required for plants growing when finished construction •Replace plants easily •Purchase and transport modules easily	•Plants can't grow firmly in a small box so easy to be destroyed. •Plant selection is limited to small groundcover. •Long time required for pre-planting each box •Strong artificial signs in final appearance
		Trays with multiple cells	•Small size plants •Barely empty space between plants •Usually 30-degree slanted cells as a basement •Mental or plastic cells usually in 2"x2" or 4"x4"		
		Foam substrate	Foam bulks with holes to let plant roots plug in		
	Hydroponic system	--	•Liquid-base substrate instead of soil •Synthetic fabric as structural supports •Erected frame such as vertical beam or lattice is required. •Waterproof layer is essential. •Drip irrigation is good enough.	•Integrated system so suitable for permanent wall •Could be moveable infrastructure •Large variety of plants can be applied. •Less possibilities for pest disaster •Plants can be held strongly. •Save irrigation •Lighter weight because lack of soil	•Difficult to change plants or planting format •Take longer time to grow entirely •More maintenance at the beginning

Table 3.1 (cont.): Comparison of characteristics and pros & cons between each type of vertical greening (cont.)

Type	Sub-categories	Detailed technique	Characteristics	Advanatages	Disadvantages
Living wall system	Bio-filtration living wall	--	•Stress air-cleaning function •Regulate thermals of surrounding area •Aluminum trims with holes as air plenum to slow down air flow and prolong purification •Fans are required to force air passing through •Water pump in the catchment tank to re-circulate liquid nutrients	Purify air powerfully	•Require large area for the auxiliary facilities •Aesthetic could be destroyed by the auxiliary facilities •More techniques required for constructing the whole system
Green façade	Ground growing vegetation façade	--	•Climbers dominated •Vegetation is rooted in the ground and grow up. •No need for extra structural support	•Cheaper •Careful maintenance may not be required.	•Plants' aerial roots could destroy building facades. •Long time growing to reach full coverage •Difficult to move plants later •Less aesthetical creations for final appearance
	Cascading vegetation façade	--	•Vegetation is planted in a substrate above wall or don't need substrate like air plants. •Cascading groundcovers dominated	•Vegetation is planted in a substrate above wall. •Cascading groundcovers dominated •More exquisite final appearance	Suitable applying places are limited to small surfaces.
	Structural supports integrated façade	Steel, cables, mesh or trellis	•Usually support heavy climbers •Plants climb up without touching building façade. •Aluminium, plastic, wood and steel could be materials.	•More suitable plant species •Could be more creative depending on the shape of structural supports •Not necessarily connecting with buildings •Plants could be moved easily together with supporters	•Large quantity of structural supports could be expensive. •Frequent maintenance to make sure plants grow as the shape of supporters
		Planter boxes	•Soil in containers at any level of building •Especially useful for small climbers in a large surface		

Type	Sub-categories	Detailed technique	Characteristics	Advanatages	Disadvantages
Green façade	Espaliering green façade	--	•Plants are trained to grow against vertical surfaces flatly. •Shrubs and trees dominated, especially fruit trees •Require less spaces •Flowers are pruned to be condensed.	•Beautiful and strong landscape because of condensed flowers •Compact natural green façade so saves spaces •Fruits of it often ripen earlier.	•Require frequent pruning and manipulating •Require professional knowledge for plants' pruning •Can't increase biodiversity powerfully •Could be boring during winter
Green roof	Intensive green roof	--	•Individual growing media like ground-level gardens •Soil depth as least 6 inches •Large range of plant species •Could have water features •Encourage frequent human visit	•More human interactions compared with other vertical greening •Aesthetical value could be enhanced when connecting with urban skyline	•Complexities of technical requirements •Limitations of visitors and viewers
	Extensive green roof	--	•Thinner substrate with depth of 0.8-6". •Plants are limited to sedums and moss. •Not intended to let people access •Self-sustaining •Less requirements for maintenance		
	Semi-extensive green roof	--	•Combination of intensive and extensive •Extensive type less than 25% of total area •Substrate's depth is between 4 to 8".		
Balcony garden	Private balcony	--	•Easy making •Respect to any designs to show personalities	•Add more possible places to increase urban green space •Could be more attracting since closer to human houses	•Could have complex technical requirements •Have restrict limitations to the overall weight
	Public terrace	--	•Often combined with other types of vertical greening •Have more functions to benefit urban environments •Similar to green roof about techniques		

This research analyzed suitable conditions to apply each type of vertical greening. Table 3.2 below is an explicit summary which could guide designers to select suitable VG based on expected outcomes. All the evaluations are relative rather than absolute statements which means,

based on the literature and practical experiences, people apply the specific type of VG in this situation more commonly and successfully.

Table 3.2: Suitable VG based on specific requirements
"+" means frequently applied in this situation; "---" means it is suitable to be applied in all these situations.

VG type		Location					Overall size	
		Heavy polluted area	Green buffer area	City center	Outdoor	Indoor	Large	Small
Living wall system	**Modular system**			+	---		---	
	Hydroponic system			+	---		---	
	Bio-filtration living wall	+	+		+		---	
Green façade	**Ground growing vegetation façade**		---		+		+	
	Cascading vegetation façade		---					+
	Structural supports integrated façade		---		+		+	
	Espaliering green façade			+	+			+
Green roof	**Intensive green roof**			+	+		---	
	Extensive green roof		---		+		---	
	Semi-extensive green roof		---		+		---	
Balcony garden	**Private balcony**					+		+
	Public terrace			+	+		---	

Table 3.2 (cont.): Suitable VG based on specific requirements: "+" means frequently applied in this situation; "---" means it is suitable to be applied in all these situations.

VG type		Building type		VG's durability		Creative design possibilities	
		Private	Public	Temporary	Permanent	More	Less
Living wall system	**Modular system**	---		+		+	
	Hydroponic system	---			+	+	
	Bio-filtration living wall		+		+	---	
Green façade	**Ground growing vegetation façade**		+		+		+
	Cascading vegetation façade	---			+		+
	Structural supports integrated façade		+	---		+	
	Espaliering green façade	---			+		+
Green roof	**Intensive green roof**	---		+		+	
	Extensive green roof	---		---			+
	Semi-extensive green roof	---		+		+	
Balcony garden	**Private balcony**	+		+		+	
	Public terrace		+		+	+	

Table 3.2 (cont.): Suitable VG based on specific requirements: "+" means frequently applied in this situation; "---" means it is suitable to be applied in all these situations.

VG type		Plants growing time		Plant-species variety		Cost & Maintenance	
		Long	Short	High	Low	High	Low
Living wall system	**Modular system**		+	+		+	
	Hydroponic system	---		+		+	
	Bio-filtration living wall	---		+		+	
Green façade	**Ground growing vegetation façade**	+			+		+
	Cascading vegetation façade	+			+		+
	Structural supports integrated façade	+		+		+	
	Espaliering green façade	+			+	+	
Green roof	**Intensive green roof**	+		+		+	
	Extensive green roof		+		+		+
	Semi-extensive green roof	+		+		---	
Balcony garden	**Private balcony**		+	---			+
	Public terrace	---		---		+	

Environmental Benefits

Reduce urban heat island effect and save energy

Cities are always in the process to take up green spaces and replace them with hard surfaces which may cause glare and heat up urban environment ultimately (Ghazalli, Brack, Bai, & Said, 2019). Vertical greening can cool down the environment owing to retrofit bare surface to ecological one with ample plant species. This function has been largely researched among articles not older than 2000. VG relieves urban heat effect and save energy mainly through three ways—provide shade to building façades in summer (Rakhshandehroo et al., 2015; Perini, Ottelé, Haas, & Raiteri, 2011; Wong, Tan, Tan, Sia, & Wong, 2010), insulate heat from buildings to nature in winter (Chan, 2018; Bustami, Belusko, Ward, & Beecham, 2018; Pérez-Urrestarazu et al., 2015) and plants evapotranspiration (Pérez, Rincón, Vila, González, & Cabeza, 2011).

A large quantity of experiments in VG cooling down ambient environments have provided us some amazing numbers. In a hot climate, monitored plants surface temperature never exceeds 95 °F, while in blinds it can exceed 131 °F (Niachou, Papakonstantinou, Santamouris, Tsangrassoulis, & Mihalakakou, 2001). From Susorova, I.'s experiment, indoor temperature of an office room with green façade was 38.3 °F -38.5 °F lower than another office without (Susorova, 2015), which reduces energy consumption for air conditioning system by up to 20% (Pérez et al., 2011). Cooling effectiveness is influenced by VG's orientation (Pérez, Coma, Sol, & Cabeza, 2017; Kontoleon & Eumorfopoulou, 2010; Acero et al., 2019), plants coverage (Pérez et al., 2017; Liu & Minor, n.d.), VG's height (Acero et al., 2019).

When it comes to the specific number of energies VG saves, they are extremely impressive. According to Akbari et al., canopy trees near two monitored houses provided seasonal cooling energy savings of 30%, corresponding to an average daily savings of 3.6 and 4.8 kW h/d (per house per day) (Akbari, Kurn, Bretz, & Hanford, 1997). Besides, solar radiation incident on the area shaded by trees (100 W/m2) is significantly inferior to that area without shade (600 W/m2) (Papadakis, Tsamis, & Kyritsis, 2001). Some other articles had studied different reflection ratios of sun radiation between one identified green wall and concrete building façade near it, which showed higher reflection ratio in planting areas than cement

(Kontoleon & Eumorfopoulou, 2010). Those researches all support VG's cooling effect and energy efficiency for buildings.

Plants together with their structural supports can ameliorate temperature and humidity in ambient conditions. The space between the green screen and building wall holds a volume of air which serves as a fundamental insulation. For the living walls, the insulating capacity can depend on the substrate thickness (Pérez et al., 2011). There was an experiment that measured the heat flux distribution on a west-facing wall of a two-story building covered with thick ivy to investigate its cooling effect. It turned out that the green wall reduced the peak-cooling load transferred through the west-facing wall by 28% on a clear summer day (Djedjig, Bozonnet, & Belarbi, 2015). The heat transfer through a concrete wall is significantly lower if it is externally coated with a layer of vegetation (Lin et al., 2019). It was reported that a living wall can reduce the energy transfer into a building wall by 0.24 kW h/m2 (Hoyano, 1988).

Evapotranspiration is a process to evaporate water inside plant bodies and slowly release it to the surrounding environment. Green walls retain rainwater as soon as it drops then create cooling through plants evapotranspiration (Weinmaster, 2009). By using sun radiation as energy resource for evaporating instead of absorbing and reradiating it as heat, plants layer helps to reduce temperature outstandingly. Plant species, exposure of leaves and climatic influences decide this evaporative cooling process. Dry environments or the effect of wind can increase evapotranspiration of plants (Yannas, 2006). Also based on Susorova, I.'s experiment, described before, it was shown that the humidity level of the office with the green facade was constantly higher than the office without this mechanism, between 5% and 14% higher, demonstrating that the use of vegetation provides a large amount of extra humidity to indoor environments (Susorova, 2015).

Insulate noises

Plants have been using as barriers against traffic or other unpleasant noise for a long time (Hong, Wu, Chen, & Lin, 2018). Green walls built exteriorly with ample plants own the same function. They serve as insulation layer against noise, vibrations, and reduce sound penetration. They also help to absorb the echo bouncing off buildings, dampening the loud sounds found in modern cities (Boeri & Insulza, 2009). Studies have shown that the plant leaves reduce sound by

reflecting, refracting, and absorbing acoustic energy in small amounts (Martens & Michelsen, 1981). Plants density and leaves area decide how much noise VG would retrofit.

Absorb contaminative dust in the air

Air pollution is one of the most primary concerns especially in developing countries. Increasing population, urbanization and industrialization contribute to making it severe (Pandey, Pandey, & Tripathi, 2015). When hundreds of contaminative dust are accumulated and reach high toxicity, People's health suffers. Plant functions in purifying air are broadly known (Perini, Ottelé, Giulini, Magliocco, & Roccotiello, 2017; Li et al., 2010; Clark, Adriaens, & Talbot, 2008). Even a small vertical greening can contain thousands of plants, which could say how powerful it is to adsorb pollutants. Furry leaves or leaves with thick cuticular waxes on leaf epidermis act more functional (Perini et al., 2017). Besides, toxic particles in the air can be removed by plant roots, mainly because the microorganism layer around roots degrade and assimilate them (Al-Din, 2019).

Bio-filtration living walls maximum this function by actively drawing the air through the plant layer which aids in delivering the normally harmful chemicals to the plants and their roots (Weinmaster, 2009). Connecting with fan system, this active living wall circulates clean air back to the ambient environment.

Manage stormwater

Urbanization has made a huge intervention on surface's drainage capabilities. Cities are getting more and more impermeable, changing from soil and green space to concrete and asphalt. As water flows over hard surfaces it picks up pollutants that have been accumulating and goes directly to urban drainage system (Prodanovic, McCarthy, Hatt, & Deletic, 2019). On the one hand, the excess can overwhelm wastewater treatment plans and pollute clean water. On the other hand, it is so easy to have flooding issue especially during a rainy season because hard surfaces will barely do anything about slowing down the water runoff (Kubba, 2017). Parks, vertical greening, and other vegetated areas absorb surplus water, filter, and slowly release it back into the environment, which alleviates peak discharge and aids in flood control fundamentally.

Unfortunately, green roof is the only type of vertical greening that has been profoundly researched in this function, but not the case of living wall or green façade. So the following explanations are mainly aimed at green roof. When water passing through, the root system of plants infiltrates water and hold it for a longer time compared with hard surfaces. Roots and microorganisms living around them break down and utilize the dissolved contaminants in the water (A. M. Hathaway, W. F. Hunt, & G. D. Jennings, 2008). Natural rainwater or light greywater (bath, shower, and hand basin effluent) containing chemical elements such as nitrogen and phosphorus can provide abundant nutrients for plants growing (Prodanovic et al., 2019). Plants absorb toxic elements and purify the water naturally, far cheaper than traditional greywater treatment (Lau & Mah, 2018).

Researches have shown that variations in plant spaces and operational conditions—hydraulic loading rate, inflow concentrations and intermittent drying—will influence nutrient removal process from light greywater (Hong et al., 2018). Besides, green roofs watershed could retain 51.4% of precipitation during the study period based on area extrapolation. Overall, the green roof retained 34% more precipitation than predicted by the paired watershed calibration equation (Gregoire & Clausen, 2011). In J. T. Lau* and D. Y. S. Mah's study, they developed a computer-aided stormwater model that incorporates a green wall to investigate its effectiveness as an urban drainage system (Lau & Mah, 2018). They verified that a green wall can be effectively used as an urban drainage system in reducing surface runoff.

Reintroduce biodiversity

Natural wild ecosystems are commonly characterized by high variety of species. While modern cities and agricultural lands are taking place of natural environments and decreasing biodiversity. Vertical greening is a micro-ecosystem with various plants, microorganism and animals including butterflies, bees, ladybugs, and hummingbirds (Haaland & van den Bosch, 2015), which are living together in mutual ecosystem. VG brings nature back to cities. Potentially, people will appreciate nature and try harder to halt habitat destruction when they are up close and personal with a multitude of plant species provided by VG.

Benefit human health and well-being

Obviously, all benefits mentioned before will more or less do good to human health physically and psychologically because VGs enhance comforts, urban sustainability and environmental aesthetics. Here is to stress VG's functions especially in restoring mental health. Researches had shown that vegetated façades are preferred over bare buildings, and considered beautiful to enhance the aesthetic value of an area, making people feel connected with nature, and reduce stress (Lee, Williams, Sargent, Williams, & Johnson, 2015). Public green spaces may be unevenly distributed in cities because of land scarcity, and VG solves it effectively by providing extended visual contact with greenery, thus providing relief and restoration from visual fatigue (Ghazalli et al., 2019). Based on the biophilia concept, accessing nature will have positive effects on human attention restoration, mood and mental fatigue (Kaplan, c1998.). Even it doesn't stress on vertical greening particularly, as one type of green space, vertical greening does benefit human health and well-being in the same way (Lee et al., 2015). Many researches also focus on VG's impacts on human health and comparisons between VG and traditional ground green space. It turned out that VG does play an important role in environmental health, while it is not as powerful as traditional ground green space in human attention restoration (Timm et al., 2018). It was an interesting found as we always want to find new places to add green and we thought it will solve the problem but never think about whether they can be functional as tradition green. While this article only focused on the effectiveness of human attention restoration but not mentioned other VG's functions such as physical health and ecological benefits. Whether there are differences between VG and ground green space in functions are still not researched comprehensively.

Conclusion

Urban issues have always been primary concerns and we never stop finding potential solutions for them. It is fairly to say that vertical greening is an effective solution to the issue of insufficient green space and the consequent problems caused by that. Not only is it an aesthetical ornament, but also a masterpiece for environmental, social, and economical benefits.

From systematic review, we can confidently conclude that researches on vertical green have reached to advanced status, including domains in classification and environmental benefits. Although we now know well about how excellent VG is, there still are not enough researches on

its practical application especially in plant selections for proposed vertical greening. Besides, researches on whether vertical greening is different from ground green space in functions and how to make up these differences are lacking.

Here are some potential domains that can be researched in the future:

1) Criteria for plant selections for proposed vertical greening with specific outcomes
2) Areas that urgently need VG instead of ground green space, such as compact cities
3) Whether VG is an expensive green infrastructure compared with ground green space depending on different conditions.
4) Potential suggestions to make VG more viable all over the world
5) Differences in human health impacts between VG and ground green space
6) Potential suggestions to shorten these differences

References

[1] Acero, J. A., Koh, E. J. Y., Li, X., Ruefenacht, L. A., Pignatta, G., & Norford, L. K. (2019). Thermal impact of the orientation and height of vertical greenery on pedestrians in a tropical area. Building Simulation, 12(6), 973–984. https://doi.org/10.1007/s12273-019-0537-1

[2] Al-Din, S. S. M. (2019). The Validity of Beauty in the Functionality of the Vertical Greenery Systems (VGS) in Interior Surfaces of Buildings. *Conference Proceedings*, 20.

[3] Akbari, H., Kurn, D. M., Bretz, S. E., & Hanford, J. W. (1997). Peak power and cooling energy savings of shade trees. Energy and Buildings, 25(2), 139–148.https://doi.org/10.1016/S0378-7788(96)01003-1

[4] Ascott, K., & Kenny, M. J. (2019). Addressing the complexities of resilience in urban design and planning. *Town Planning Review*, *90*(5), 473–479. https://doi.org/10.3828/tpr.2019.30

[5] Balick, M. J., Kronenberg, F., Ososki, A. L., Reiff, M., Fugh-Berman, A., Bonnie, O., … Atha, D. (2000). Medicinal plants used by latino healers for women's health conditions in New York City. *Economic Botany*, *54*(3), 344–357. https://doi.org/10.1007/BF02864786

[6] Bianchini, F., & Hewage, K. (2012). How "green" are the green roofs? Lifecycle analysis of green roof materials. *Building and Environment*, *48*, 57–65. https://doi.org/10.1016/j.buildenv.2011.08.019

[7] Blanc, P. (2008). *The vertical garden: From nature to the city /*. New York : W.W. Norton,.

[8] Boeri, S., & Insulza, F. (2009). The Vertical Forest and New Urban Comfort. *Harvard Design Magazine*, (31), 60–65.

[9] Boisset, C. (c1988.). *Vertical gardening: Climbing plants, hanging plants, trellises, wall planting, terrace steps, window boxes /* (1st ed.). New York : Weidenfeld & Nicolson,.

[10] Bustami, R. A., Belusko, M., Ward, J., & Beecham, S. (2018). Vertical greenery systems: A systematic review of research trends. *Building and Environment*, *146*, 226–237. https://doi.org/10.1016/j.buildenv.2018.09.045

[11] Chan, C. T. W. (2018). Promoting Vertical Greening in High-rise Residential Buildings within Urban Areas. *Pacific International Journal*, *1*(2), 29–38.

[12] Chen, N., Tsay, Y., & Chiu, W. (2017). Influence of vertical greening design of building opening on indoor cooling and ventilation. *International Journal of Green Energy*, *14*(1), 24–32. https://doi.org/10.1080/15435075.2016.1233497

[13] Clark, C., Adriaens, P., & Talbot, F. B. (2008). Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits. *Environmental Science & Technology*, *42*(6), 2155–2161. https://doi.org/10.1021/es0706652

[14] Coma, J., Pérez, G., de Gracia, A., Burés, S., Urrestarazu, M., & Cabeza, L. F. (2017). Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. *Building and Environment*, *111*, 228–237. https://doi.org/10.1016/j.buildenv.2016.11.014

[15] Coma, J., Pérez, G., Solé, C., Castell, A., & Cabeza, L. F. (2014). New Green Facades as Passive Systems for Energy Savings on Buildings. *Energy Procedia*, *57*, 1851–1859. https://doi.org/10.1016/j.egypro.2014.10.049

[16] Convertino, F., Vox, G., & Schettini, E. (2019). Heat transfer mechanisms in vertical green systems and energy balance equations. *International Journal of Design & Nature and Ecodynamics*, *14*(1), 07–18. https://doi.org/10.2495/DNE-V14-N1-7-18

[17] Dalley, S. (2013). The mystery of the Hanging Garden of Babylon: An elusive world wonder traced / (1st ed.). Oxford, U.K.: Oxford University Press.

[18] Djedjig, R., Bozonnet, E., & Belarbi, R. (2015). Analysis of thermal effects of vegetated envelopes: Integration of a validated model in a building energy simulation program. *Energy and Buildings*, *86*, 93–103. https://doi.org/10.1016/j.enbuild.2014.09.057

[19] Dunnett, N., & Nolan, A. (2004). THE EFFECT OF SUBSTRATE DEPTH AND SUPPLEMENTARY WATERING ON THE GROWTH OF NINE HERBACEOUS PERENNIALS IN A SEMI-EXTENSIVE GREEN ROOF. https://doi.org/10.17660/ActaHortic.2004.643.40

[20] Dunnett, N., & Kinsbury, N. (2003). Up on the roof. Landscape Design, (321), 35–38.

[21] Dunnett, N. (2008). Planting green roofs and living walls / (Rev. and updated ed., [2nd ed.]). Portland, Or.: Timber Press,.

[22] Ghazalli, A. J., Brack, C., Bai, X., & Said, I. (2019). Physical and Non-Physical Benefits of Vertical Greenery Systems: A Review. *Journal of Urban Technology*, *26*(4), 53–78. https://doi.org/10.1080/10630732.2019.1637694

[23] Gregoire, B. G., & Clausen, J. C. (2011). Effect of a modular extensive green roof on stormwater runoff and water quality. *Ecological Engineering*, *37*(6), 963–969. https://doi.org/10.1016/j.ecoleng.2011.02.004

[24] Haaland, C., & van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening*, *14*(4), 760–771. https://doi.org/10.1016/j.ufug.2015.07.009

[25] Haddad, E., Rifkind, D., & Laurence, P. L. (Eds.). (2014). *A critical history of contemporary architecture: 1960-2010*. Burlington, VT: Ashgate Publishing Company.

[26] Hanging Gardens of Babylon. (2019). *Columbia Electronic Encyclopedia, 6th Edition*, 1–1.

[27] Hong, T., Wu, X., Chen, Y., & Lin, X. (2018). Impact of Roof Greening on the Ecological Environment of the Green Building, Exemplified by the Roof Garden of the Mingde Building in Fujian Agricultural and Forestry University. In Z. Shen, L. Huang, K. Peng, & J. Pai (Eds.), *Green City Planning and Practices in Asian Cities* (pp. 193–209). https://doi.org/10.1007/978-3-319-70025-0_9

[28] Hoyano, A. (1988). Climatological uses of plants for solar control and the effects on the thermal environment of a building. Energy and Buildings, 11(1–3), 181–199. https://doi.org/10.1016/0378-7788(88)90035-7

[29] Jain, R., & Janakiram, T. (n.d.). *Vertical Gardening: A New Concept of Modern Era*. 11.

[30] Jim, C. Y. (2015). Greenwall classification and critical design-management assessments. *Ecological Engineering*, *77*, 348–362. https://doi.org/10.1016/j.ecoleng.2015.01.021

[31] Jim, C. Y., & Chen, S. S. (2003). Comprehensive greenspace planning based on landscape ecology principles in compact Nanjing city, China. *Landscape and Urban Planning*, *65*(3), 95–116. https://doi.org/10.1016/S0169-2046(02)00244-X

[32] Kaplan, R. (c1998.). With people in mind: Design and management of everyday nature /. Washington, D.C. : Island Press,.
[33] Köhler, M. (2008). Green facades—A view back and some visions. *Urban Ecosystems*, *11*(4), 423–436. https://doi.org/10.1007/s11252-008-0063-x
[34] Kontoleon, K. J., & Eumorfopoulou, E. A. (2010). The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. *Building and Environment*, *45*(5), 1287–1303. https://doi.org/10.1016/j.buildenv.2009.11.013
[35] Kubba, S. (2017). Components of Sustainable Design and Construction. In *Handbook of Green Building Design and Construction* (pp. 55–110)https://doi.org/10.1016/B978-0-12-810433-0.00002-2
[36] Kubba, S. (2017). Green Design and Building Economics. In *Handbook of Green Building Design and Construction* (pp. 573–619)https://doi.org/10.1016/B978-0-12-810433-0.00010-1
[37] Kubba, S. (2017). The Green Design and Construction Process. In *Handbook of Green Building Design and Construction* (pp. 111–161). https://doi.org/10.1016/B978-0-12-810433-0.00003-4
[38] Kubba, S. (2017). Water Efficiency and Sanitary Waste. In *Handbook of Green Building Design and Construction* (pp. 413–441)https://doi.org/10.1016/B978-0-12-810433-0.00008-3
[39] Lau, J. T., & Mah, D. Y. S. (2018). *Green Wall for Retention of Stormwater*. 17.
[40] Lee, K. E., Williams, K. J. H., Sargent, L. D., Williams, N. S. G., & Johnson, K. A. (2015). 40-second green roof views sustain attention: The role of micro-breaks in attention restoration. *Journal of Environmental Psychology*, *42*, 182–189. https://doi.org/10.1016/j.jenvp.2015.04.003
[41] Leyshon, L. (2019, June 26). ESPALIER. Retrieved from THE west end magazine: https://www.westendmagazine.com/espalier/
[42] Li, J., Wai, O. W. H., Li, Y. S., Zhan, J., Ho, Y. A., Li, J., & Lam, E. (2010). Effect of green roof on ambient CO2 concentration. *Building and Environment*, *45*(12), 2644–2651. https://doi.org/10.1016/j.buildenv.2010.05.025
[43] Lin, C.-Y., & Huang, Y.-L. (2013). Planning Review: Application of Vertical Greening for Landscape Beautification in Taipei. *International Review for Spatial Planning and Sustainable Development*, *1*(4), 43–49. https://doi.org/10.14246/irspsd.1.4_43
[44] Lin, H., Xiao, Y., Musso, F., & Lu, Y. (2019). Green Façade Effects on Thermal Environment in Transitional Space: Field Measurement Studies and Computational Fluid Dynamics Simulations. *Sustainability*, *11*(20), 5691. https://doi.org/10.3390/su11205691
[45] Ling, T.-Y., & Chiang, Y.-C. (2018). Well-being, health and urban coherence-advancing vertical greening approach toward resilience: A design practice consideration. *Journal of Cleaner Production*, *182*, 187–197. https://doi.org/10.1016/j.jclepro.2017.12.207
[46] Liu, K., & Minor, J. (n.d.). *Performance Evaluation of an Extensive Green Roof*. 13.
[47] Lundholm, J. T. (2015). Green roof plant species diversity improves ecosystem multifunctionality. *Journal of Applied Ecology*, *52*(3), 726–734. https://doi.org/10.1111/1365-2664.12425
[48] Lundholm, J., MacIvor, J. S., MacDougall, Z., & Ranalli, M. (2010). Plant Species and Functional Group Combinations Affect Green Roof Ecosystem Functions. *PLoS ONE*, *5*(3), e9677. https://doi.org/10.1371/journal.pone.0009677
[49] Martens, M. J. M., & Michelsen, A. (1981). Absorption of acoustic energy by plant leaves. The Journal of the Acoustical Society of America, 69(1), 303–306. https://doi.org/10.1121/1.385313
[50] M. Hathaway, W. F. Hunt, & G. D. Jennings. (2008). A Field Study of Green Roof Hydrologic and Water Quality Performance. *Transactions of the ASABE*, *51*(1), 37–44. https://doi.org/10.13031/2013.24225
[51] Magliocco, A. (2018). Vertical Greening Systems. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 263–271). https://doi.org/10.1016/B978-0-12-812150-4.00024-0
[52] Manso, M., & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews*, *41*, 863–871. https://doi.org/10.1016/j.rser.2014.07.203

[53] Medl, A., Stangl, R., & Florineth, F. (2017). Vertical greening systems – A review on recent technologies and research advancement. *Building and Environment*, *125*, 227–239. https://doi.org/10.1016/j.buildenv.2017.08.054
[54] Naczi, R. F. C. (2016). New Manual of Vascular Plants of Northeastern United States and Adjacent Canada. *Brittonia*, *68*(3), 238–244. https://doi.org/10.1007/s12228-016-9416-6
[55] Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., & Mihalakakou, G. (2001). Analysis of the green roof thermal properties and investigation of its energy performance. *Energy and Buildings*, *33*(7), 719–729. https://doi.org/10.1016/S0378-7788(01)00062-7
[56] Nielsen, S. (c2004.). *Sky gardens: Rooftops, balconies, and terraces /*. Atglen, PA : Schiffer Pub.,.
[57] Othman, A. R., & Sahidin, N. (2016). Vertical Greening Façade as Passive Approach in Sustainable Design. *Procedia - Social and Behavioral Sciences*, *222*, 845–854. https://doi.org/10.1016/j.sbspro.2016.05.185
[58] Pais, A. P. T. D., & Bertoli, S. R. (2019, September 30). Sound Absorption of Vertical Greenery System: Systematic Literature Review [Text]. Retrieved November 30, 2019, from https://www.ingentaconnect.com/content/ince/incecp/2019/00000259/00000005/art00031
[59] Pan, L., & Chu, L. M. (2016). Energy saving potential and life cycle environmental impacts of a vertical greenery system in Hong Kong: A case study. *Building and Environment*, *96*, 293–300. https://doi.org/10.1016/j.buildenv.2015.06.033
[60] Papadakis, G., Tsamis, P., & Kyritsis, S. (2001). An experimental investigation of the effect of shading with plants for solar control of buildings. Energy and Buildings, 33(8), 831–836. https://doi.org/10.1016/S0378-7788(01)00066-4
[61] Peng, K.-H. (2013). The Application of Vertical Greening to Urban Rehabilitation and Maintenance. *International Review for Spatial Planning and Sustainable Development*, *1*(3), 41–52. https://doi.org/10.14246/irspsd.1.3_41
[62] Pérez, G., Coma, J., Sol, S., & Cabeza, L. F. (2017). Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect. *Applied Energy*, *187*, 424–437. https://doi.org/10.1016/j.apenergy.2016.11.055
[63] Pérez, G., Coma, J., Sol, S., & Cabeza, L. F. (2017). Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect. *Applied Energy*, *187*, 424–437. https://doi.org/10.1016/j.apenergy.2016.11.055
[64] Pérez, G., Rincón, L., Vila, A., González, J. M., & Cabeza, L. F. (2011). Green vertical systems for buildings as passive systems for energy savings. *Applied Energy*, *88*(12), 4854–4859. https://doi.org/10.1016/j.apenergy.2011.06.032
[65] Pérez-Urrestarazu, L., Fernández-Cañero, R., Franco-Salas, A., & Egea, G. (2015). Vertical Greening Systems and Sustainable Cities. *Journal of Urban Technology*, *22*(4), 65–85. https://doi.org/10.1080/10630732.2015.1073900
[66] Perini, K., & Roccotiello, E. (2018). Vertical Greening Systems for Pollutants Reduction. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 131–140). https://doi.org/10.1016/B978-0-12-812150-4.00012-4
[67] Perini, K., Ottelé, M., Giulini, S., Magliocco, A., & Roccotiello, E. (2017). Quantification of fine dust deposition on different plant species in a vertical greening system. *Ecological Engineering*, *100*, 268–276. https://doi.org/10.1016/j.ecoleng.2016.12.032
[68] Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2011). Greening the building envelope, facade greening and living wall systems. *Open Journal of Ecology*, *01*(01), 1–8. https://doi.org/10.4236/oje.2011.11001
[69] Prodanovic, V., McCarthy, D., Hatt, B., & Deletic, A. (2019). Designing green walls for greywater treatment: The role of plants and operational factors on nutrient removal. *Ecological Engineering*, *130*, 184–195. https://doi.org/10.1016/j.ecoleng.2019.02.019
[70] Qiao, G. (2016). The Sustainable Design of City Hanging Gardens. *Proceedings of the 2016 International Conference on Civil, Structure and Environmental Engineering*. Presented at the

2016 International Conference on Civil, Structure and Environmental Engineering, Guangzhou, China,. https://doi.org/10.2991/i3csee-16.2016.55
[71] Rakhshandehroo, M., Mohd Yusof, M. J., & Deghati Najd, M. (2015). Green Façade (Vertical Greening): Benefits and Threats. *Applied Mechanics and Materials*, *747*, 12–15. https://doi.org/10.4028/www.scientific.net/AMM.747.12
[72] Reade, J. (2000). Alexander the Great and the Hanging Gardens of Babylon. *Iraq*, *62*, 195. https://doi.org/10.2307/4200490
[73] Sailor, D. J. (2008). A green roof model for building energy simulation programs. *Energy and Buildings*, *40*(8), 1466–1478. https://doi.org/10.1016/j.enbuild.2008.02.001
[74] Schuler, E. (1964). *Gardens around the world: Terraces, patios, balconies, window boxes, garden décor, planting, and pools.* New York,: H. N. Abrams.
[75] Senanayake, I. P. (2013). *Assessment of Green Space Requirement and Site Analysis in Colombo, Sri Lanka—A Remote Sensing and GIS Approach*. *4*(12), 6.
[76] Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews*, *90*, 757–773. https://doi.org/10.1016/j.rser.2018.04.006
[77] Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews*, *90*, 757–773. https://doi.org/10.1016/j.rser.2018.04.006
[78] Stevens, D. (c1997.). *Roof gardens, balconies and terraces /*. New York : Rizzoli,.
[79] Sun, J., Liu, J., Wu, F., & Nian, H. (2015). Research on High-efficient Balcony Greening Based on the Concept of Low-carbon Green Buildings. *Proceedings of the 3rd International Conference on Advances in Energy and Environmental Science 2015*. Presented at the 2015 3rd International Conference on Advances in Energy and Environmental Science, Zhuhai, China. https://doi.org/10.2991/icaees-15.2015.187
[80] Susorova, I. (2015). Green facades and living walls. In Eco-Efficient Materials for Mitigating Building Cooling Needs (pp. 127–153). https://doi.org/10.1016/B978-1-78242-380-5.00005-4
[81] Sutton, R. K. (Ed.). (2015). *Green roof ecosystems*. Cham Heidelberg New York Dordrecht London: Springer.
[82] Tabb, P. (2016, December 5). Greening Architecture: The Impact of Sustainability. https://doi.org/10.4324/9781315263953-12
[83] Tian, Y., & Jim, C. Y. (2011). Factors influencing the spatial pattern of sky gardens in the compact city of Hong Kong. *Landscape and Urban Planning*, *101*(4), 299–309. https://doi.org/10.1016/j.landurbplan.2011.02.035
[84] Tian, Y., & Jim, C. Y. (2012). Development potential of sky gardens in the compact city of Hong Kong. *Urban Forestry & Urban Greening*, *11*(3), 223–233. https://doi.org/10.1016/j.ufug.2012.03.003
[85] Tian, Y., Jim, C. Y., & Tao, Y. (2012). Challenges and Strategies for Greening the Compact City of Hong Kong. *Journal of Urban Planning and Development*, *138*(2), 101–109. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000076
[86] Tian, Y., Jim, C. Y., & Wang, H. (2014). Assessing the landscape and ecological quality of urban green spaces in a compact city. *Landscape and Urban Planning*, *121*, 97–108. https://doi.org/10.1016/j.landurbplan.2013.10.001
[87] Timm, S., Dearborn, L., & Pomeroy, J. (2018). Nature and the City: Measuring the Attention Restoration Benefits of Singapore's Urban Vertical Greenery. *Technology|Architecture + Design*, *2*(2), 240–249. https://doi.org/10.1080/24751448.2018.1497377
[88] Van Mechelen, C., Dutoit, T., & Hermy, M. (2015). Adapting green roof irrigation practices for a sustainable future: A review. *Sustainable Cities and Society*, *19*, 74–90. https://doi.org/10.1016/j.scs.2015.07.007

[89] Weinmaster, M. (2009). Are Green Walls as “Green” as They Look? An Introduction to the Various Technologies and Ecological Benefits of Green Walls. *Journal of Green Building*, *4*(4), 3–18. https://doi.org/10.3992/jgb.4.4.3

[90] Wong, N. H., Tan, A. Y. K., Tan, P. Y., Sia, A., & Wong, N. C. (2010). Perception Studies of Vertical Greenery Systems in Singapore. *Journal of Urban Planning and Development*, *136*(4), 330–338. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000034

[91] Yang, L. (1982). *The terrace gardener’s handbook: Raising plants on a balcony, terrace, rooftop, penthouse, or patio /*. Beaverton, Or. : Timber Press,.

[92] Yannas, S. (2006). *Roof cooling techniques: A design handbook /*. London ; Earthscan,.

[93] Zaid, S. M., Perisamy, E., Hussein, H., Myeda, N. E., & Zainon, N. (2018). Vertical Greenery System in urban tropical climate and its carbon sequestration potential: A review. *Ecological Indicators*, *91*, 57–70. https://doi.org/10.1016/j.ecolind.2018.03.086

[94] Zhao, X., Zuo, J., Wu, G., & Huang, C. (2019). A bibliometric review of green building research 2000–2016. *Architectural Science Review*, *62*(1), 74–88. https://doi.org/10.1080/00038628.2018.1485548

CHAPTER 4: PLANT SUITABILITY FOR VERTICAL GREENING

Abstract

Vertical greening is an art combining plants with building façades practically and aesthetically. As a cradle for various plant species, vertical greening makes plants as its spirit which highly influences the final appearance of VG aesthetically and its functional performances sustainably. Failure to choose appropriate plants can lead to unpleasant visual effects, poor plant growing conditions, mosquito trouble and or maintenance problems. Plant suitability for a proposed VG, as one of the critical components to achieve VG's viability, has largely raised people's attention. This research proposed nine criteria—1) vigorous foliage, 2) climbing type (for façade's protection), 3) seasonal changing (for aesthetic value); ecological function: 4) increasing biodiversity, 5) low pest promotion and other problems, 6) climate tolerance (drought, shade, deer, cold, heat, pollution, etc.); and maintenance & other values: 7) overall weight when mature (structural supports required), 8) maintenance methods (irrigation, nutrient, replace frequency), 9) and special values—for plant selection mainly in the USDA Zone 2-7 considered different expectations of proposed VGs, together with suggestions for specific plant species coordinating with each criterion. This research aims to provide a theoretical guidance to help designers make better planting decisions for proposed VGs to improve the success rate.

Introduction

Vertical greening as a smart attempt combing nature and architecture in urban environments, its ecological and social benefits have been largely accepted up to date (Chew et al., 2019). It can reduce the urban heat-island effect by serving as a shade to cool down buildings and the surrounding environment (Rakhshandehroo et al., 2015), as a result it can help to save energy since air conditioners are merely required to open (Niachou et al., 2001). VG serving as an acoustic insulation help to minimize the noise (Boeri & Insulza, 2009). Full of plants, VG is able to absorb the contaminative dust in the air (Perini et al., 2017a) and dissolved contaminants in the rainwater (A. M. Hathaway et al., 2008), then help to purify the surrounding atmosphere. VG as a micro-ecosystem with various plants can be functional to reintroduce biodiversity to the urban environment (Haaland & van den Bosch, 2015). Moreover, it benefits human mental

health and well-being by restoring attention and bringing aesthetical satisfaction (Ghazalli et al., 2019).

However, owning so many benefits, why still VG has not been applied broadly? Apart from the advanced technical requirements for its installation, suitable plant selection for proposed VGs with different expectations is another challenge (Perini et al., 2011; Tian & Jim, 2012; Perini et al., 2017; Chew et al., 2019). It matters VG's final appearance aesthetically (Perini et al., 2017a), future maintenance economically (Chew et al., 2019), and environmental benefits sustainably (Kotzen, 2018). To be specific, failure to choose appropriate plants can lead to unpleasant visual effects, poor plant growing conditions, mosquito trouble and or maintenance problems (Köhler & Ksiazek-Mikenas, 2018; Wong et al., 2010). Plant suitability is one of the most imperative elements to achieve VG's viability. There should be more developments in plant guidelines without doubt. Before that, let's have a review about what guidelines we have for vertical greening or green building.

There are several guidelines proposed to provide strategies for one type of VG and to assess how "green" a building is. The first category is the guidelines for green roofs:

1) "FLL Guidelines" which is developed by the German Research Society for Landscape Development and Landscape Design (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. - FFL).
2) "ASTM book of standards" (American Society for Testing and Materials) relates to green roof in several of its chapters, such as ASTM E2396-05: Standard Test Method for Saturated Water Permeability of Granular Drainage Media (falling-head method) for Green Roof Systems and ASTM E2396/E2399-05 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roofs (Tolderlund et al., 2010).
3) "Green Roof Professional (GRP) Accreditation Exam" is an indicator that an individual has achieved a specific knowledge level regarding green roof design, project management, installation and maintenance.
4) "Green Roofs for Healthy Cities" is the National Green Roof Accreditation—Seminars and manuals provided by Green Roofs for Healthy Cities.
5) Some websites which contain plant knowledge: A Green Wall Guideline for Vienna, Austria (there is only a Germany version) https://www.green4cities.com/?p=918; Green Roof Technology—Form Any Function http://www.greenrooftechnology.com/fll-green-roof-

guideline; GREEN WALLS IN THE UK https://www.urbangreening.info/ Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West http://www.cityofgolden.net/media/GreenRoofsSemiAridAridWest.pdf; The ultimate guides to living green walls https://www.ambius.com/green-walls/ultimate-guide-to-living-green-walls/

The second category is guidelines for green building, mainly green building rating system. They are developed by region based on the regional policies and development situations:

1) USA— “LEED Credits” (Leadership in Energy and Environmental Design) is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. Attainment of a desired LEED® building rating (e.g., silver, gold, platinum) is based on accumulation of “points” addressing eight different credit categories: Location and Planning; Sustainable Sites; Water Efficiency; Energy and Atmosphere; Materials and Resources; Indoor Environmental Quality; Innovation and Design Process; Regional Priority (Gou & Lau, 2014).
2) Singapore— “BCA Green Mark Scheme” (Building and Construction Authority) encourages Super Low Energy (SLE) Buildings and Healthier Workplaces.
3) Japan— "Comprehensive Assessment System for Building environment Efficiency (CASBEE)” is designed to both enhance the quality of people's lives and to reduce the life-cycle resource use and environmental loads associated with the built environment, from a single home to a whole city.
4) The U.K.— "Building Research Establishment Environmental Assessment Method” (BREEAM) measures various environmental performance categories including: Energy Consumption, Sustainable Materials usage, Pollution control and minimization, Sustainable transport, Waste minimisation, Recycling and Sustainable water consumption.
5) Australia— "Green Building Council of Australia Green Star” (GBCA) is best known for developing the Green Star rating system for buildings and communities.
6) Hong Kong— “Hong Kong Building Environmental Assessment Method” (HKBEAM) is an environmental performance-based assessment scheme purpose designed for high rise buildings in Hong Kong (P. Chan & Chu, 2005).
7) China— "China Green Building Label” (GBL) was developed from “Energy-Saving and Land-Saving Residential Building” required by the central government in 2004. Specifically,

green building should be energy-saving, land-saving, water-saving and material-saving, environment-benign and pollution-reducing, summarized as “Four-Saving & One-Benign” (Ye et al., 2013).

The last category is guidelines for green cities or green communities comprehensively which mainly focuses on public park management, streetscape, and green space planning:

1) “The Green City Guidelines—Techniques for a healthy livable city” is created to demonstrate through case studies and summaries of scientific reports what can be achieved through the application of green city principles and the green city philosophy itself and draws on examples taken from three continents (M. RooV et al., 2010).
2) “Green City Development Guideline” by The Global Green Growth Institute (GGGI) includes eight steps corresponding to the four stages of the GGGI Value Chain to plan and implement green growth. (The whole pdf file can be found here: http://gggi.org/site/assets/uploads/2018/06/Greencity-development-guidelines-English.pdf)
3) “Green City Guidelines—Advice for the protection and enhancement of biodiversity in medium to high-density urban developments” provides practical guidance for planners and developers on how to integrate biodiversity into new developments, specifically medium to high-density housing developments in urban areas. (The whole pdf file can be found here: http://www.uep.ie/pdfs/guidelines_intro.pdf)

Nevertheless, those guidelines are mainly focusing on one type of VG (green roof) and sustainable building (mainly on energy efficiency), but not many guidelines for living wall system and green façade. Moreover, the guidelines for technical issues (eg. installation and irrigation) are far more numerous than those for plant selection and maintenance. Plant growth and management on walls in the urban ambiance remain fuzzy due to limited scientific research (Jim, 2015). It is fair to claim that the insufficient knowledge of plant selection and maintenance is one of the most fundamental reasons that the oldest existing VG is not more than 20 years old (Blanc, 2008), There should be more attention paid on the plant suitability for VG to achieve a sustainable vertical landscape.

Plant selection should consider the expected outcomes of proposed vertical greening primarily. Certain plants will be better for aesthetic and landscape design values, drought tolerance, water purifying, air filtering or habitat provision. Besides, it will also depend on the

climatic conditions of the VG's location: from a larger scale such as the average temperature all year round—the US Hardiness Zone (USDA Zone); from a smaller scale such as the level of natural light available. In order to prepare plant knowledge for VG's application in downtown Chicago which is in the USDA Zone 5, plant species mentioned in this research are mainly in USDA Zone 2-7 which can be safely used in the Chicago area. Plants in zone 7 or larger zones could be used in a small scale outdoor vertical greening with winter protection.

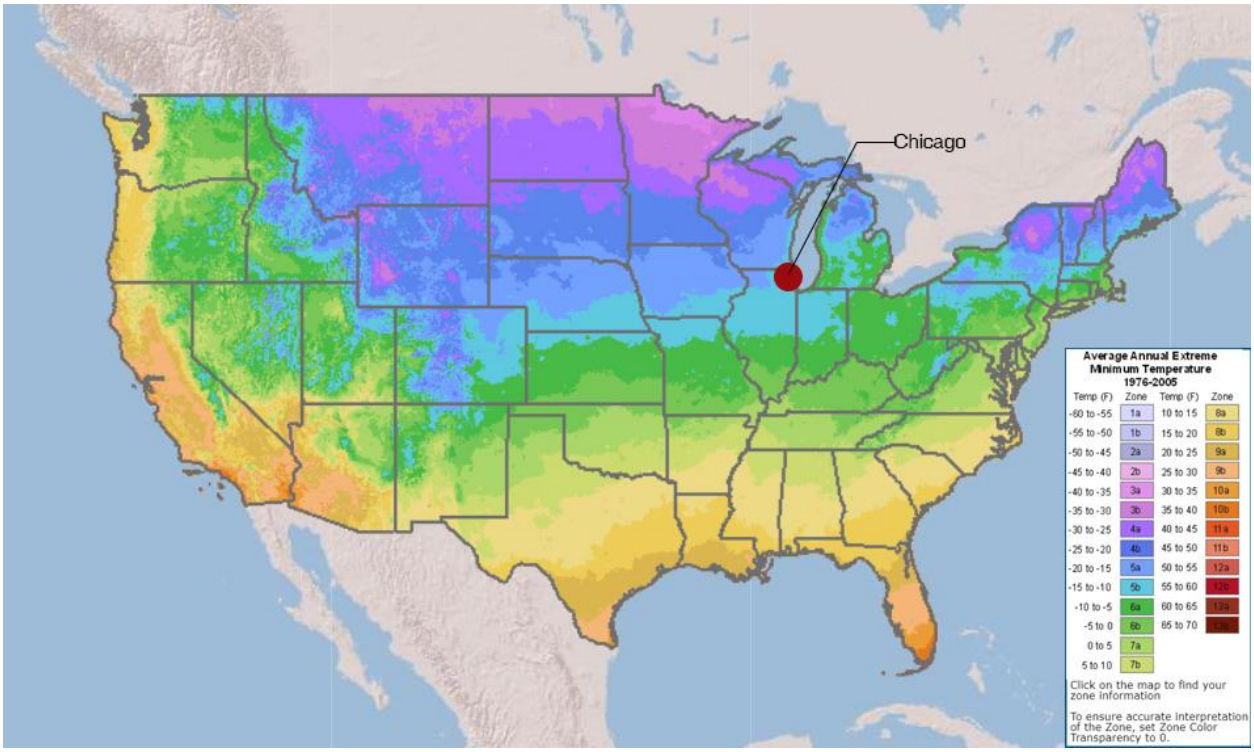

Figure 4.1: 2012 USDA plant hardiness zone map
Data source: USDA.gov. The map is based on the average annual minimum winter temperature, divided into 10-degree F zones.

This research provided nine criteria to help designers cope with the plant issues and select suitable plant species for proposed VG. Based on the ultimate expectations of VG as well as the common concerns about VG (Zhao et al., 2019; Perini et al., 2011; Pandey et al., 2015; Tian & Jim, 2012; Sun, 2005; Wong et al., 2010; Balick et al., 2000; Perini et al., 2017b; Li, 2018; Naczi, 2016; C. T. W. Chan, 2018; Othman & Sahidin, 2016; Perini & Roccotiello, 2018; Sun, 2005; Kubba, 2017), these proposed nine criteria are developed from three aspects:

- Plant innate characteristic: 1) vigorous foliage, 2) climbing type (for façade's protection), 3) seasonal changing (for aesthetic value);
- Ecological function: 4) increasing biodiversity, 5) low pest promotion and other problems, 6) climate tolerance (drought, shade, deer, cold, heat, pollution, etc.);

- Maintenance & other values: 7) overall weight when mature (structural supports required), 8) maintenance methods (irrigation, nutrient, replace frequency), 9) and other special values.

Each criterion will be explained in detail and plants selected from the most frequently used climbers and Herbaceous plants of existing green façades in the US hardiness zone 2-7 will be suggested. In order not to provide too many repetitious plant information, I aimed to discover new plant species for each criterion, although some plants are doing great jobs for more than one criterion. When talk about each criterion, the performances for other criteria of the selected plants will also be listed in the table to give people a comprehensive understanding of the plant characters. All the resources about plant characters mainly come from the following published websites: 1) Missouri Botanical Garden (plantfinder), 2) Plantfile, 3) North Carolina Extension Gardener, 4) RHS, 5) Gardenia, 6) Better Homes Gardens, and 7) Perennials.com, together with some published articles and books.

Table 4.1: Criteria are suitable for which type of vertical greening.

	Vigorous foliage	Climbing type	Seasonal changing	Increasing biodiversity	Pest & other problems	Climate tolerance	Overall weight	Maintenance	Other values
Living wall system (herbaceous)			✓	✓	✓	✓		✓	✓
Green façade (climbers)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Green roof (all types of plants)	✓		✓	✓	✓	✓	✓	✓	✓
Balcony garden (all types of plants)	✓		✓	✓	✓	✓	✓	✓	✓

Table 4.2: Three categories of criteria for plant selection

Innate characteristic		
Vigorous foliage	**Climbing type**	**Seasonal changing**
Fast growing	Sucker pad Rhizome	Evergreen
	Aerial root Thorn	Semi-evergreen
Good coverage	Tendril	Deciduous
Ecological functions		
Increasing biodiversity	**Low pest promotion and other problems**	**Climate tolerance**
Hummingbird	Pest attraction	Drought Shade
Butterfly		Cold Heat
Bee	Invasive plant	Deer Erosion Poor soil Wind
Other birds	Disease infection	Pollution
Maintenance & other values		
Overall weight when mature	**Maintenance methods**	**Other values**
No need structral support	Pruning frequency	Medicine Food
Light structral support	Irrigation volume & frequency Nutrient requirement	Brewing Tea
Sturdy structral	Replace frequency	Fragrance

Vigorous foliage

When it comes to vigorous foliage, climbing plants are mainly focused as the dominant plant species for green façade which is a type of vertical greening that only requires soil at wall-toe or any level of the wall using soil containers to permit seedlings to grow upwards to cover the wall. To form a green façade, there will be an actual witness of climbers' growing process which, for example, could take from 3 to 29 months to reach a 40 feet height depending on different species (Jim, 2015). Compared with green façade, living wall system largely uses herbs which do not have gravity-defying capability to move up a wall, instead, grow on a supporting structure to hold substrate on the vertical surface, and grow from the elevated substrate. It doesn't require a plants' growing time necessarily but a time for modules installation as the plants can be pre-grown in a nursery to create instant greening. Or the modules containing matured plants can be purchased directly from various plant companies so there will be a final appearance as soon as the installation has been done.

Nevertheless, the elaborate human maintenance and expensive technique of living wall system have stressed out many stakeholders. Then green façade is an economical choice in that case. The average cost for installing a green facade system, complete with plants, is $25 – $30 per square foot. Once installed, the annual maintenance is minimal – primarily just basic plant care (ARCHITEK, 2020). How can we build a cost-effective green façade while at the same time achieve the desirably final appearance quicker? When invested in green infrastructure, people always care about the time period when they can finally enjoy the benefits of that. That's why there is always an expectation about faster-growing plants. This criterion is more preferable in the situations such as outdoors green façade in the people-gathering areas (public plaza, bus station, transportation cross and traveling spot) or on the commercial buildings (supermall and public hotel), which all have a frequent human flow so they desire to bring the aesthetic landscapes as soon as possible.

Vigorous foliage contains two aspects: fast growing and good coverage. Through literature review and empirical research, 40 climbers have been selected through the most frequently used climbers of existing green façades in the US hardiness zone 2-7 to coordinate with the "vigorous foliage" criterion—20 fast growing plants and 20 good coverage plants. When talks about growth rate, the life cycle of climbers must be considered first which are perennial, biennial and annual. Commonly, the annual climbers grow faster (Hogan, 2003) than

other two since they are over and done in one year. While, the overall scale of annual climbers is usually small (Hogan, 2003) so they are more suitable for small vertical infrastructures such as trellis or pergola, or one-time exhibitions which last no more than a year so people don't need to replace the plants every year. Also, a combination of perennial or shrubby vines interlaced with a few 'in-fill' annual climbers may be something to consider. Considering the variety of plant species, perennial climbing plants are more frequently used in existing VGs.

Fast growing annual:

1. ***Tropaeolum peregrinum*- Canary-creeper or Canarybird flower**. Size is 10-12 ft. It can grow up to 8 ft in a year.
2. ***Lathyrus odoratus*- Sweet Pea**. Average size is 6-8ft and can grow 5-7 ft in a season (Smith, James Edward, 2018).
3. ***Ipomoea: Ipomoea purpurea***, 6-10 ft, can grow 7-9 ft in a season (Coghlan, 1975).

Figure 4.2: Left to right: *Ipomoea purpurea; Lathyrus odoratus; Tropaeolum peregrinum*
Images source: websites of "Flora of American @ efloras.org" and "Missouri Botanical Garden"

Fast growing perennial:

4. ***Fallopia baldschuanica (Polygonum)* – Russian Vine**. It is also called "mile a minute plant", making it without doubt be the fastest growing climbers. It typically grows 25-40 ft (36 ft in one season) (The Sunday Gardener, 2020) so is suitable to be planted in a large space or structure. It should be grown on its own since it is likely to smother other plants.
5. ***Campsis radicans* – Chilean Trumpet Vine.** It can grow 20-40 ft in just one season (Nikki Tilley, 2019d) (sometimes can grow 2 ft/week) according to a University of California Cooperative Extension article. With adequate care and pruning, it can be kept under control and not be invasive.
6. ***Actinidia* - The Chinese Gooseberry**. The overall height could be various from 8 ft serving as shrubs to 30 ft serving as climbers. It's a fast-growing vine.

7. ***Clematis montana*- Mountain clematis or Himalayan clematis**. Height typically is from 20-40 ft. As a vigorous climber, it is amongst the quickest growing 'covering' Clematis but a bare root infant can take 3-4 years to reach maturity (Ken Woolfenden, 2020).
8. ***Humulus lupulus*-Common hop**. An Herbaceous climbing plant usually viewed as bine plants. The average height is 15-20 ft. It can grow 15-20 ft in one year (Humulus lupulus—Plant Finder, n.d.).
9. ***Solanum jasminoides* - White Potato vine.** More of a scrambling shrub - but ideal for getting up to 30 ft long quickly (Department of Environment, Water and Natural Resources, 2013).
10. ***Parthenocissus quinquefolia*-Virginia Creeper**. The overall height can be 60-90 ft. This is a vigorous tendril-climbing vine that will rapidly grow to 30-50' long or more (Kenny, 1945).
11. ***Parthenocissus tricuspidata*- Boston Ivy.** It typically grows 30-50 ft and is one of the fastest growing vines (Jason Canon, 2012).
12. ***Lonicera japonica* - Japanese honeysuckle**. Typical height is 15-30 ft and its "vigorous" growth habit all too easily strays over into invasiveness (David Beaulieu, 2019b).
13. ***Akebia quinate*- evergreen Chocolate Vine**. It rapidly grows to 20-40 ft and sometimes the rampant growth can be a problem (Flora of North America, 2018).
14. ***Vitis coignetiae*-Crimson Glory Vine**. Overall size can be 30-60 ft. It is an extremely fast-growing tendril climber which can reach 60' (e.g., rise up to a tree top or fill a 1000 sq. ft. trellis) in several years (Iwatsuki, 1995).
15. ***Vitis vinifera 'Purpurea'*-Grape Vine**. Normally it will reach 15-30 ft. It can grow to 40-60 ft over time if left unpruned.
16. ***Pyracantha* – Firethorn.** Its size can be 6-18 ft. Sometimes it can grow more than 2 ft a year. It is particularly noted for its upright and dense habit (Hogan, 2003).
17. ***Lathyrus grandiflorus***. The normal size of them before dying down for winter hibernation is 5-6 ft. Once established it is a robust plant with the ability to scramble into other shrubs and trees (Smith, James Edward, 2018).
18. ***Lathyrus latifolius*.** Size is 6-9 ft. Plants spread by rhizomes and will easily self-seed to the point of being somewhat weedy and invasive (Sargent, 1894).

19. ***Passiflora caerulea*– Passion Flower.** Normal size is 30 ft but sometimes it will reach 45 ft. It is quite a quick growing climbing vine and will soon cover a 6x6 ft trellis in the first year (Gardenvisit, 2013).
20. ***Jasminum officinale*- Summer Jasmine or Common Jasmine.** Its height is 15-30 ft. Fast grower (Murrill, 1945).

Figure 4.3: Left to right: *Fallopia baldschuanica (Polygonum); Campsis radicans; Humulus lupulus; Vitis coignetiae*

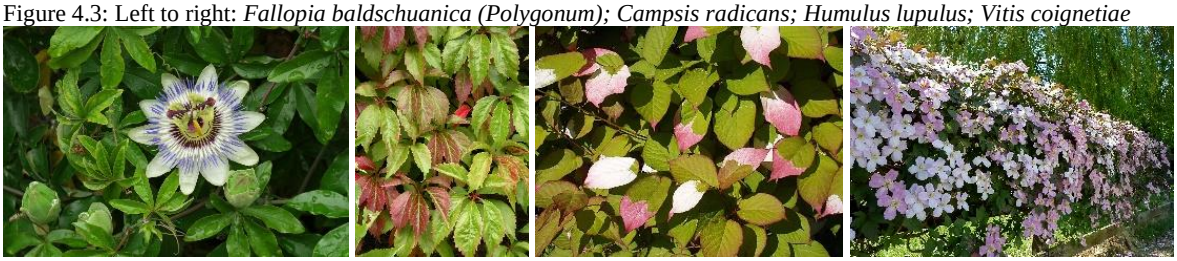

Figure 4.4: Left to right: *Passiflora caerulea; Parthenocissus quinquefolia; Actinidia; Clematis montana*

Figure 4.5: Left to right: *Solanum jasminoides; Parthenocissus tricuspidata; Lonicera japonica; Akebia quinate; Vitis vinifera 'Purpurea'*

Figure 4.6: Left to right: *Pyracantha; Lathyrus grandifloras; Lathyrus latifolius; Jasminum officinale*
Images source: websites of "Flora of American @ efloras.org" and "Missouri Botanical Garden"

For a real vertical greening project, plant selection may not restrict "fast-growing" as the only criterion, a comprehensive contemplation instead. Without doubt, together with the demand for fast growth rate, other criteria mentioned above will be considered to select plants not only with vigorous growth but also have an overall good performance. The following tables ranked

the climbers based on their growth rate, together with their performance in other criteria. For all the following tables, "—" means no outstanding characters or no serious issues; red word means it's the best-growing condition for plants; orange-filled plants are tropical plants which require winter protection or grow as annual in Chicago area—should be used in a small scale; Coverage overall score is based on empirical research meaning the percentage plants have covered the surface when they mature: >80%=5; 60%-80%=4; 40%-60%=3; 20%-40%=2; <20%=1.

Table 4.3: Score evaluation for overall plants density

Percentage plants cover a surface	>80%	60%-80%	40%-60%	20%-40%	<20%
Score	5	4	3	2	1

Table 4.4: Fast-growing annual climbing plants and their performances in "good coverage", "climbing type" and "seasonal changing". The plants with orange color are tropical plants which requires winter protection or small-scale usage.

Vigorous foliage-Annual climbing plants

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Ipomoea purpurea	**Morning Glory**	2-11	6-10	8-10ft in one season	5	Twining stems	Deciduous; Bloom from June to Oct; purple with white throat flower;
Lathyrus odoratus	**Sweet Pea**	2-11	6-8	5-7ft in a season	5	Tendrils at the leaf apex	Deciduous; Bloom from May to July; any color except yellow flower;
Tropaeolum peregrinum	**canary-creeper, or canarybird flower**	10-11	10-12	Up to 8ft in a year	5	Twining petioles	Deciduous; Bloom from May to Sep; yellow flower;

Table 4.4 (cont.): Fast-growing annual climbing plants and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value". The plants with orange color are tropical plants which requires winter protection or small-scale usage.

Vigorous foliage-Annual climbing plants

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance	Special value
Ipomoea purpurea	**Morning Glory**	Butterflies and hummingbirds	—	Full sun, deer	Trellis, fence or arbor	—	—
Lathyrus odoratus	**Sweet Pea**	Bees, butterflies and/or birds	Aphids, pollen beetle, caterpillars, thrips, slugs and snails; All parts of plant are poisonous if ingested.	Full sun, deer	trellis net, fence, strings, stakes or bamboo pyramid	—	—
Tropaeolum peregrinum	**canary-creeper, or canarybird flower**	Butterflies	Keep an eye out for aphids, caterpillars and flea beetles	Full sun, deer; drought, poor soil	trellis or fence	—	Leaves, buds, flowers, pods and seeds are edible and may be used in salads.

Table 4.5: Fast growing perennial climbers and their performances in "good coverage", "climbing type" and "seasonal changing"

Vigorous foliage-Perennial climbing plants

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Fallopia baldschuanica (Polygonum)	**Russian Vine**	4-7	25-40	36ft in a season	5	Stems climbing by rhizomes	Deciduous; Bloom from July to frost; White flower
Campsis radicans	**Chilean Trumpet Vine**	4-9	20-40	20-40ft in a season	5	Aerial roots	Deciduous; Bloom from May to Oct; orange-red flower
Humulus lupulus	**Common hop**	4-8	15-20	15-20ft per year	5	Stiff downward facing hairs that provide stability and allow them to climb	Deciduous; Bloom from Sep to Oct; yellow-green flower
Vitis coignetiae	**Crimson Glory Vine**	5-9	30-60	A robust habit of growth, reach 40ft within 5 years	4	Woody stem with tendrils and wrap themselves around any firm support	Deciduous; Bloom from July to Aug; heart-shaped leaves with gold, orange and red color in autumn; light green flower
Passiflora caerulea	**Passion Flower**	7-9	30-45	It is quite a quick growing climbing vine and will soon cover a 6x6ft trellis in the first year.	4	Leaf tendrils	Evergreen; Bloom from March to April; blue-white flower
Parthenocissus quinquefolia	**Virginia Creeper**	3-9	60-90	36-45ft in around 10 years	5	Sucker pads	Deciduous; Bloom from May to Aug; red leaves in autumn; white-green flower
Actinidia	**The Chinese Gooseberry or Kiwi vine**	4-8	8-shrubs; 30-climbers	Rampant climber	5	Hardy twining climbers	Deciduous; Bloom in late summer; white-yellow flower; leaves turn to pink-white when getting old
Clematis montana	**Mountain clematis or Himalayan clematis**	4-9	20-40	Vigorous climber but a bare root infant can take 3-4 years to reach maturity.	5	Twining leaf axles	Deciduous; Bloom in late spring about 4 weeks; white-pink flower

Table 4.5 (cont.): Fast-growing perennial climbing plants and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value"

Vigorous foliage-Perennial climbing plants

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance	Special value
Fallopia baldschuanica (Polygonum)	**Russian Vine**	Attract birds	Better grow on its own or smother other plants; Watch for Japanese beetle and leaf miners	Drought, deer, heavy shade	unsightly fences and other garden structures	—	—
Campsis radicans	**Chilean Trumpet Vine**	Attract hummingbirds and many types of birds	Could be invasive	Drought, heat, cold	lattice or trellis	—	—
Humulus lupulus	**Common hop**	Butterflies	Skin contact may cause dermatitis.	Drought	Various support structures	—	Brewing for bittering beer
Vitis coignetiae	**Crimson Glory Vine**	—	Attract Japanese beetles but not serious	Heat, cold and wind	Fence, trellis, wires, frameworks, and smaller branches of trees or shrubs	Restrictive pruning in winter and realise the extent of growth when first planting.	Medicinal plant; brewing for wines
Passiflora caerulea	**Passion Flower**	Butterflies	A few aphids outdoor; Indoor or conservatory grown plants can be infested with whitefly, scale insects and red spider mite.	Not lower than 10 °F; Drought	Trellis, pergola and beams	Regular pruning to avoid compact branches and allow more flowers	Flowers can make tea; plant can make medicine.
Parthenocissus quinquefolia	**Virginia Creeper**	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Black Walnut	—	—	—
Actinidia	**The Chinese Gooseberry or Kiwi vine**	Bees, butterflies and/or birds	—	Easily get frost damage	Strong structures such as a robust pergola or well supported trellis framework	Training and pruning are necessary	Furry fruit with a high consentration of Vitamin C.
Clematis montana	**Mountain clematis or Himalayan clematis**	Butterflies and hummingbirds	—	Resistant to clematis wilt	Sturdy trellis or arbor	Prune after flowering; regularly water during the first year	Root and stem can be used as medicine.

Table 4.5 (cont.): Fast-growing perennial climbing plants and their performances in “good coverage”, “climbing type” and “seasonal changing”. The plants with orange color are tropical plants which requires winter protection or small-scale usage.

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Parthenocissus t ricuspidata	**Boston Ivy**	4-8	60-90	One of the fastest growing vines	5	Sucker pads	Deciduous; Bloom from June to July; red-purple leaves in autumn; yellow-green flower
Lonicera japonica	**Japanese honeysuckle**	4-9	15-30	Its "vigorous" growth habit all too easily strays over into invasiveness.	5	Hardy twining climbers	Evergreen (semi); Bloom from June to Oct; white-yellow flower
Akebia quinate	**evergreen Chocolate Vine**	4-8	20-40	Grow rapidly and can suffocate other vegetation if not kept in check	4	Twining stems	Evergreen; Bloom from March to April; chocolate-purple flower
***Vitis vinifera* ‘Purpurea’**	**Grape Vine**	6-9	15-30	Grow to 40-60ft over time if left unpruned	5	Branched tendrils	Deciduous; Bloom from May to June; burgundy leaves in late summer; white-green flower; fruits are purple clusters of grapes
Pyracantha	**Firethorn**	6-9	6-18	More than 2ft a year	5	Climbing shrub	Evergreen in warm winter climates but semi-evergreen to deciduous in the St. Louis area; Bloom from March to April; white flower; bright orange-red berries in early autumn through winter
Lathyrus grandiflorus	**two-flowered Everlasting pea**	3-8	5-6	Once established it is a robust plant with the ability to scramble into other shrubs and trees	5	Branched tendrils	Deciduous; Bloom from June to Aug; magenta-pink, purple-red flower;
Lathyrus latifolius	**Everlasting pea**	3-8	6-9	Easily self-seed to the point of being somewhat weedy and invasive	5	Rhizomes and twining tendrils	Deciduous; Bloom from June to Sep; pink-white flower;
Solanum jasminoides	**White Potato vine**	7-11	12-30	Scrambling or scandent growth	5	Stems climbing by rhizomes	Evergreen or semi-evergreen; Bloom year-roundc; white flower
Jasminum officinale	**Summer Jasmine; Common Jasmine**	7-10	15-30	Fast grower	5	Climbing stems	Semi-evergreen or deciduous; Seasonal bloom; white-yellow flower

Table 4.5 (cont.): Fast-growing perennial climbing plants and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value". The plants with orange color are tropical plants which requires winter protection or small-scale usage.

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance	Special value
Parthenocissus tricus pidata	**Boston Ivy**	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut	—	—	—
Lonicera japonica	**Japanese honeysuckle**	Birds, Hummingbirds, Butterflies	Invasive plants	Deer, Drought, Black Walnut	—	May need to be tied to the support to distribute the branches well.	Flowers and leaves can be used as medicine and tea.
Akebia quinate	**evergreen Chocolate Vine**	—	—	Deer, Heavy Shade, Erosion	Canes or sturdy trellis	Prune as needed in late spring after flowers appear. May be cut to the ground to renovate	Fruits are edible.
***Vitis vinifera* 'Purpurea'**	**Grape Vine**	—	May be affected by powdery mildew and botrytis; Pests are phylloxera, grape berry moth, Japanese beetle, leaf hopper, leaf roller, mealy bugs and flea beetles	—	Pergola, wall or fence	Lightly pruned in winter; Frequently pruning ongoing attention to insect and disease pests for better fruit production	Grape fruit; wine, vineagr and juice; dried to produce raisins
Pyracantha	**Firethorn**	Blackbirds; wood pigeons	Caterpillars; Fireblight, Aphids; thorns may cause injures easily	Drought; heavy pruning	—	Regularly pruning	—
Lathyrus grandiflorus	**two-flowered Everlasting pea**	Butterflies	May be attacked by aphids, slugs and snails	Cold (down to -4°F or -20°C)	—	—	—
Lathyrus latifolius	**Everlasting pea**	Bumblebees, butterflies, hummingbirds	Slugs and snails are attracted to young plants	Full sun; Drought	Walls, arbors, trellises, along fences or around pillars	—	—
Solanum jasminoides	**White Potato vine**	—	Vegetative parts are poisonous as are the fruits	Deer, drought; not lower than 10 °F	—	Need pruning every spring	
Jasminum officinale	**Summer Jasmine; Common Jasmine**	Butterflies and hummingbirds	Aphids but not troublesome; watch for mealybugs, scale and whitefly	Deer	Trellis, pergola and beams	Pruning is required carried out right after flowering	Flowers can make tea or fragrance.

Good coverage is also a criterion for green façade rather than living wall system since climbing plants can cover every corner of the wall as long as there is a module for them to grow. While for the green façade, it is not likely to predict exactly what the final appearance looks like. What people always want is a vigorous green screen—plants can cover a wall, building façade, fence or any other unpleasing surfaces entirely (Dunnett, 2008). A full-coverage green façade

will not only bring more aesthetical value, but also can function more powerfully in shading the building, cooling down the surrounding environment and relieving the heat-island effect (Ip et al., 2010). To reach a good coverage, there are two main ways: dense branches and concentrate foliage (Jim, 2015). In Jim's research about the overall performance of 20 tropical climbers (Jim, 2015), he provided a measurement about stem density score and foliage density score:

> *Sparse = 1 (only a few stems across the plot); irregular = 2 (mixture of both wide and narrow gaps); wide gap = 3 (>6 cm between adjacent stems); narrow gap = 4 (<6 cm between adjacent stems); and no gap = 5 (contiguous adjacent stems, meaning that that branches or foliage of the two stems had established physical contact).*
>
> *—stem density score*
>
> *The proportion of the plot surface covered by stems and leaves, and assigned numerical scores: sparse (<1/3 cover) = 1; medium (1/3 to 2/3 cover) = 3; and dense (>2/3 cover) = 5*
>
> *—foliage density score*

Table 4.6: Stem density score

Stem density	branches or foliage of the two stems had established physical contact	<2.4 inches between adjacent stems	>2.4 inches between adjacent stems	mixture of both wide and narrow gaps	only a few stems across the plot
Score	5	4	3	2	1

Table 4.7: Foliage density score

Proportion of the surface covered by stems and leaves	>2/3 cover	1/3 to 2/3 cover	<1/3 cover
Foliage density score	3	2	1

Based on this measurement and empirical research, 20 species have been selected among the most frequently used climbers of existing green façades in the U.S. to coordinate with the "good coverage" criterion.

1. ***Clematis* 'Bill MacKenzie'- Clematis alpina 'Frankie'**. It is a large, vigorous climber with masses of small nodding, lantern-shaped flowers (Peter Kirland, 2020).
2. ***Lonicera japonica*- Japanese honeysuckle**. It will form a dense thicket which prevents other plant species from germinating in that area and with a leaf size of 1.2-3.1in (Murray, Johan Andreas, 1784).

3. ***Wisteria sinensis*-Chinese wisteria**. It covers structures densely and can easily take over everything in its path. Spread over 24 ft and Leaves are normally 3.9-11.8 in (Nikki Tilley, 2019c).
4. ***Parthenocissus dalzielii***. Its lush foliage will provide welcome shade in summer. Leaves are 2-8in on average (Jason Canon, 2012).
5. ***Syngonium podophyllum*- arrowhead plant, arrowhead vine.** It's mostly appreciated for its lush foliage. Leave's size start from 5.5in then 14in when getting old (Coghlan, 1975).
6. ***Pileostegia viburnoides*- Climbing hydrangea**. It is well-known for its dense panicles of creamy white flowers in late summer and its lushness (Hogan, 2003).
7. ***Parthenocissus henryana*- silver vein creeper**. Each leave can be up to 5in long with strong white veining. This vine spreads quickly to 16-20 feet but is generally more restrained and not as dense growing in comparison to other Parthenocissus species (Cullina, 2002).
8. ***Hydrangea petiolaris* (syn: Hydrangea anomala subsp. Petiolaris)- climbing hydrangea.** In midsummer it bears huge, white lacecap-style hydrangea flowers, which can almost completely cover the stems. Leaves are 1.6-4.5in long and 1.2-3.2in broad (Hogan, 2003).
9. ***Jasminum nudiflorum*-Winter jasmine**. It is ideal as bank cover since it spreads where the stems touch the ground and very pretty when cascading from the retaining walls (Meyer, 1911).
10. ***Trachelospermum jasminoides*-Confederate jasmine**. It is a vigorous vine and can provide a dense screen or cover especially during the blooming time (Gilman, 1999).
11. ***Hedera algeriensis* 'Gloire de Marengo'-Algerian ivy 'Gloire de Marengo'**. It is a vigorous climber with large leaves which are normally 4-5in (Hogan, 2003).
12. ***Clematis* 'Frances Rivis'-Clematis alpine or Old Man's Beard**. A good early flowering clematis with nodding flowers of great charm in spring. Its abundant blue silk flowers are really attractive (Thornbush, 2013).
13. ***Schizophragma integrifolium*-Chinese hydrangea vine**. Although slow growing initially, once established it will produce vigorous growth, scaling large walls with ease (Meyer, 1911).
14. ***Actinidia kolomikta*- Variegated-leaf hardy kiwi**. Its foliage is so spectacular that their not-tiny flowers are always hidden. Heart-shape leaves with 3-5in long (Andrew Fletcher & Nick Pecker, 2020).

15. ***Tropaeolum speciosum*-Flame flower**. It has a dense green foliage and when emerge into the light, it bears brilliant red flowers. It's attracting with the strong contrast of red and green (Ballyrobert Gardens, 2020).
16. ***Rosa* 'Chevy Chase'.** It is a compact shrub with a good covering of light green foliage (Hogan, 2003).
17. ***Rhodochiton atrosanguineus*-Purple bell vine**. The plants are frequently used for covering trellis or arches, or adding interest to the bare base of other climbers. Heart-shape leaves are usually 3in long (Paxton, 1836).
18. ***Vitis coignetiae*- Crimson glory vine.** Vitis coignetiae is an ornamental grape vine. It is an extremely fast-growing tendril climber which can reach 60 ft (e.g., rise up to a tree top or fill a 1000 sq. ft. trellis) in several years (Murrill, 1945).
19. ***Clematis* 'Alba Luxurians'.** One of the most vigorous of the viticella cultivars. It can have an amazing coverage in a season. It is an attractive branched foliage (Monrovia, 2019).
20. ***Rosa* 'Paul's Himalayan Musk'-Hybrid Musk Rose**. It is a fabulous Rambler Rose which is perfect to cover large areas (Meyer, 1911).

Figure 4.7: Left to right: *Lonicera japonica; Wisteria sinensis; Parthenocissus dalzielii; Pileostegia viburnoides; Hydrangea petiolaris*

Figure 4.8: Left to right: *Jasminum nudiflorum; Hedera algeriensis* 'Gloire de Marengo'; *Clematis* 'Frances Rivis'; *Schizophragma integrifolium; Syngonium podophyllum*

Figure 4.9: Left to right: *Actinidia kolomikta; Tropaeolum speciosum; Rhodochiton atrosanguineus; Vitis coignetiae; Clematis* 'Alba Luxurians'

Figure 4.10: Left to right: *Rosa* 'Paul's Himalayan Musk'; *Clematis* 'Bill MacKenzie'; *Parthenocissus henryana; Trachelospermum jasminoides; Rosa* 'Chevy Chase';
Images source: websites of "Flora of American @ efloras.org" and "Missouri Botanical Garden"

Table 4.8: Good coverage plants and their performance in "growth rate" and "climbing type"

Species name	English name	Coverage overall score (1-5)	USDA Zones	Good coverage: Stem density score (1-5)	Good coverage: Foliage density score (1-3)	Overall size/ft	Growth rate	Climbing type
Lonicera japonica	**Japanese honeysuckle**	5	4-9	5	3	15-30	Fast	Hardy twining climbers
Wisteria sinensis	**Chinese wisteria**	5	5-9	5	3	60-90	Medium	Twisting stems
Parthenocissus dalzielii	**—**	5	6-9	5	3	10-15	Medium	Sucker pad
Pileostegia viburnoides	**Climbing hydrangea**	5	7-9	5	3	12-20	Slow	Aerial roots
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	5	4-9	5	3	30-50	Slow to get started but grows rapidly	Aerial roots

Table 4.8 (cont.): Good coverage plants and their performance in "seasonal changing", "increase diversity", "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value"

Good coverage

Species name	English name	Seasonal changing	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance	Special value
Lonicera japonica	**Japanese honeysuckle**	Evergreen (semi); Bloom from June to Oct; white-yellow flower	Birds, Hummingbirds, Butterflies	Invasive plants	Deer, Drought, Black Walnut	—	May need to be tied to the support to distribute the branches well.	Flowers and leaves can be used as medicine and tea.
Wisteria sinensis	**Chinese wisteria**	Deciduous; bloom time May to June; blue drooping clusters of flower	Butterflies, bees	Invasive plants	Drought; deer	Sturdy arbor, pergola, trellise, fence	Regular prunning to control size and shape of plants to promote flowering; water weekly	—
Parthenocissus dalzielii	**—**	Deciduous; bloom time April-June; white-blue flower	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut	—	—	—
Pileostegia viburnoides	**Climbing hydrangea**	Evergreen; bloom time July to Dec; white flower;	Bees, butterflies	—	Not lower than 14°F	—	Prune in early spring	—
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	Deciduous; bloom time May to June; white flower	—	—	Heavy shade, drought	Sturdy arbors, fences or the trunks of large trees, or sprawled over low stone walls, unsightly tree stumps or rock piles	Prune after flowering	Flowers are used as bouquets.

Table 4.8 (cont.): Good coverage plants and their performance in "growth rate" and "climbing type"

Species name	English name	Coverage overall score (1-5)	USDA Zones	Stem density score (1-5)	Foliage density score (1-3)	Overall size/ft	Growth rate	Climbing type
Jasminum nudiflorum	**Winter jasmine**	5	6-10	5	3	10-15	Medium	Twining stems
***Hedera algeriensis* 'Gloire de Marengo'**	**Algerian ivy 'Gloire de Marengo'**	5	6-11	4	3	7-12	Fast	Aerial roots
***Clematis* 'Frances Rivis'**	**Clematis alpina or Old Man's Beard**	5	3-9	5	3	6-8	Fast	Twining leaf-stalks
Schizophragma integrifolium	**Chinese hydrangea vine**	5	7-10	4	3	24-36	Slow to get started but grows rapidly	Aerial roots
Syngonium podophyllum	**arrowhead plant, arrowhead vine**	5	10-11; serve as annual in cold zone	5	3	3-6	Medium	Adventitious roots
Actinidia kolomikta	**Variegated-leaf hardy kiwi**	5	4-8	5	3	15-20	Fast	Hardy twining climbers

Table 4.8 (cont.): Good coverage plants and their performance in “seasonal changing”, “increase diversity”, “pest promotion and other issues”, “climate tolerance”, “structural support”, “maintenance”, and “special value”.
The plants with orange color are tropical plants which requires winter protection or small-scale usage.

Species name	English name	Seasonal changing	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance	Special value
Jasminum nudiflorum	Winter jasmine	Deciduous; bloom time March to April; yellow flower; willowy green stems in the late winter	—	—	Hard pruning; heavy shade	Fences, trellises, arbors and arches	Prune in early spring right after flowering is completed	—
Hedera algeriensis ‘Gloire de Marengo’	Algerian ivy 'Gloire de Marengo'	Evergreen; bloom time May to June; white flower; grey-green leaves margined with creamy-white	Birds	—	Deer, drought	—	—	—
Clematis ‘Frances Rivis’	Clematis alpina or Old Man's Beard	Deciduous; Bloom time April to May; blue flower	Butterflies, hummingbirds	Young shoots may be troubled by aphids and caterpillars; petals can be eaten by earwigs	Deer	Trellises, arbors, posts, fences	Prune lightly after flowering	—
Schizophragma integrifolium	Chinese hydrangea vine	Deciduous; bloom time June to July; white flower; white-green leaves	—	—	Heavy shade	Only need supports during the first few years.	Prune after flowering	—
Syngonium podophyllum	arrowhead plant, arrowhead vine	Evergreen; rarely flowers; green-white flower;	—	Poisonous when ingest	—	Trellises	—	—
Actinidia kolomikta	Variegated-leaf hardy kiwi	Deciduous; bloom time April; white flower; white-pink leaves when older	Bees, butterflies and/or birds	—	Cold down to −40 °F	—	Prune before flowering complete if expect more fruits	Fruits

Table 4.8 (cont.): Good coverage plants and their performance in “growth rate” and “climbing type”
The plants with orange color are tropical plants which requires winter protection or small-scale usage.

Species name	English name	Coverage overall score (1-5)	USDA Zones	Stem density score (1-5)	Foliage density score (1-3)	Overall size/ft	Growth rate	Climbing type
Tropaeolum speciosum	Flame flower	5	7-10	5	3	8-12	Medium	Rhizomes
Rhodochiton atrosanguineus	Purple bell vine	5	2-11; lower zone grow as annual	5	3	5-12	Fast	Twining stems
Vitis coignetiae	Crimson glory vine	5	5-9	5	3	30-60	Fast	Tendril climber
Clematis ‘Alba Luxurians’	Clematis viticella 'Alba Luxurians'	5	3-9	5	3	8-12	Fast	Twining leaf-stalks
Rosa ‘Paul’s Himalayan Musk’	Hybrid Musk Rose	5	4-9	4	3	20-30	Fast	Twining stems
Clematis ‘Bill MacKenzie’	Clematis alpina 'Frankie'	4	5-9	5	2	6-8	Fast	Twining leaf-stalks
Parthenocissus henryana	Silver vein creeper	4	6-9	4	2	20-30	Fast	Sucker pad
Trachelospermum jasminoides	Confederate jasmine	4	8-10	4	2	3-6	Fast	Twining stems
Rosa ‘Chevy Chase’	—	4	5-9	3	3	9-15	Slow	Twining stems

Table 4.8 (cont.): Good coverage plants and their performance in “seasonal changing”, “increase diversity”, “pest promotion and other issues”, “climate tolerance”, “structural support”, “maintenance”, and “special value”
The plants with orange color are tropical plants which requires winter protection or small-scale usage.

Species name	English name	Seasonal changing	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance	Special value
Tropaeolum speciosum	**Flame flower**	Deciduous; bloom time June-Sep; red flower	—	May be attacked by caterpillars, flea beetles and blackfly	Not lower than 10°F; not long periods of snow cover	—	Prune every spring; difficult to establish	—
Rhodochiton atrosanguineus	**Purple bell vine**	Deciduous; bloom time May to Sep; red-purple flower	—	May be attacked by glasshouse whitefly and glasshouse re d spider mite	Cold	Fences, trellises, arbors and arches	—	—
Vitis coignetiae	**Crimson glory vine**	Deciduous; bloom time July to Aug; light green flower	—	Attractive to the Japanese beetle	Deer, heat, cold	Fences, trellises, arbors and arches	Prune hard in fall or early spring to control rapid growth	—
Clematis **‘Alba Luxurians’**	**Clematis viticella 'Alba Luxurians'**	Deciduous; bloom time July to Sep; white flower	—	Wilt, powdery mildew, rust, fungal spots, and stem cankers are common.	Full sun	Structure support for climbing. No structure support serve as cascading groundcover	Weekly watering or more often in extreme heat; prune every spring	—
Rosa **‘Paul’s Himalayan Musk’**	**Hybrid Musk Rose**	Deciduous; bloom time May to June; pink-white flower	Butterflies	Watch for thorny stems	Full sun	Fences, trellises, arbors and arches	Prune after flowering	Flowers can make perfume oil
Clematis **‘Bill MacKenzie’**	**Clematis alpina 'Frankie'**	Deciduous; bloom time June to November; yellow flowers;	Hummingbirds, Butterflies	Aphids. Watch for thorns	Deer	Tall fences, arbors or unsightly buildings	Hard pruning in late winter or early spring	
Parthenocissus henryana	**Silver vein creeper**	Deciduous; bloom time April-June; green flower; leaves with silver veins and turn to burgundy in autumn	Birds	Keep an eye out for glasshouse red spider mite and vine weevil	Deer, clay soil	—	—	—
Trachelospermum jasminoides	**Confederate jasmine**	Evergreen; bloom time May to June; yellow-green flower; willowy green stems in the late winter	Bees	—	Heavy shade, drought	Fences, trellises, arbors and arches	Prune in early spring	Flowers can make perfume oil; Stems can produce a bast fibre.
Rosa **‘Chevy Chase’**	—	Deciduous; bloom time June to Sep; red flower	Bees	Watch for thorny stems	Full sun	Need to be tied as near horizontal as possible on to wires, trellis or similar	Pruning needed for newly planted rose; prune in October or November again	Flowers can make perfume oil

Climbing type

When it comes to how plants climb up, there are two ways: self-clinging and twining climbing. Self-clinging plants can be relied upon to cover a wall of their own accord, clinging to it by their aerial roots, simple hooks or by sucker pads or adhesive discs (Darwin, 1880). Some vines such as *Parthenocissus*-Virginia creeper, ivy, and Hedera species belong to this category. Twining climbing plants spirally twine round a support, those which ascend by the movement of the foot-stalks or tips of their leaves, and those which ascend by true tendrils, these tendrils being either modified leaves or flower-peduncles, or perhaps branches. Besides, the tendrils may

evaluate to thorny stems which can twine around the support and grow themselves up, such as Rosa species. Also, rhizomes are another way for stems to climbing such as *Fallopia baldschuanica* (Polygonum) and *Lathyrus latifolius*. Relatively, twining climbers have more ways to climb than self-clinging climbers.

Table 4.9: Classification of climbing ways

Climbing way	Sub-division	Example
Self-clinging	Aerial root	***Campsis radicans***
	Hook or spine	***Galium aparine***
	Sucker pad	***Parthenocissus quinquefolia***
Twining climbing	Stem tendril	***Akebia quinate***
	Leaf apex tendril	***Clematis montana***
	Leaf tendril	***Passiflora caerulea***
	Petiole tendril	***Tropaeolum peregrinum***
	Thorny stem	***Rosa* 'Chevy Chase'**
	Rhizome	***Fallopia baldschuanica (Polygonum)***

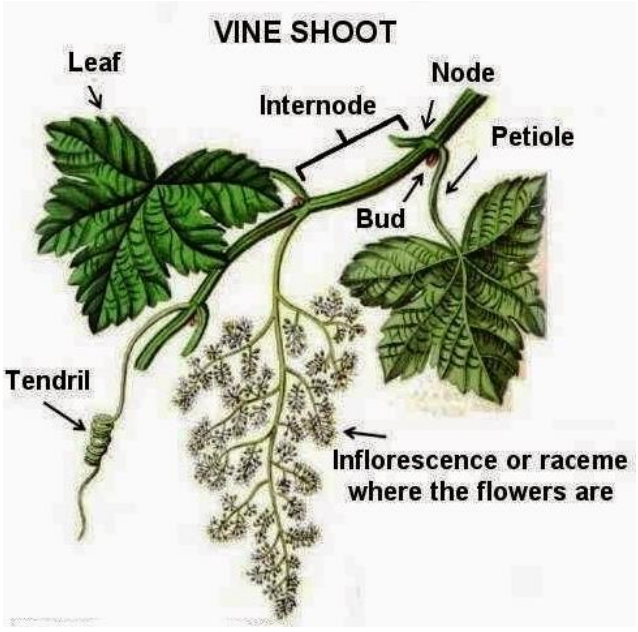

Figure 4.11: Typical compounds of a vine shoot
Image source: ASPB Website http://www.plantcell.org/content/17/4/1046.full

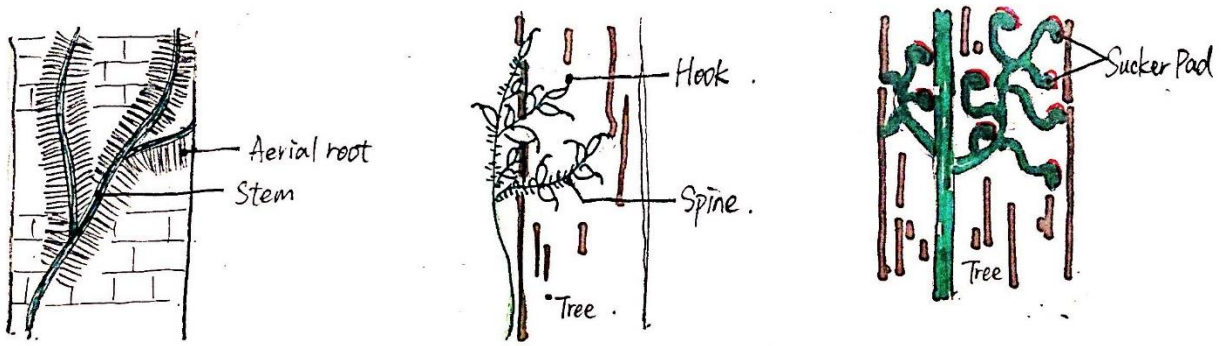

Figure 4.12: Three types of self-clinging: (left to right) aerial root, hook or spine, and sucker pad

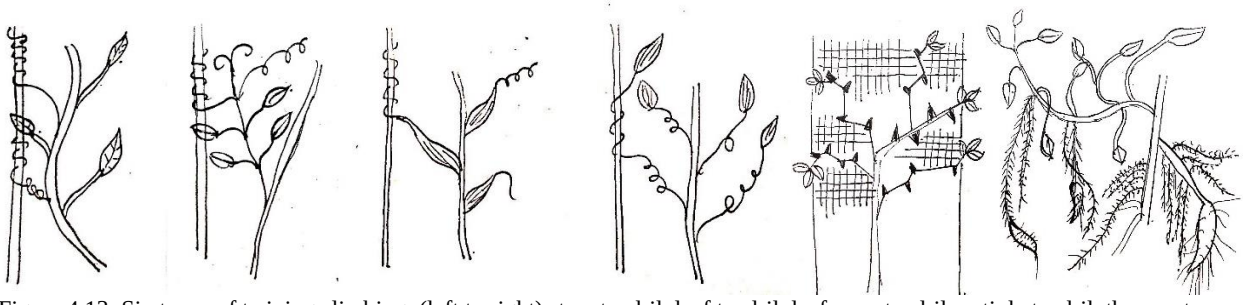
Figure 4.13: Six types of twining climbing: (left to right) stem tendril, leaf tendril, leaf apex tendril, petiole tendril, thorny stem, and rhizome stem

A common concern of climbers used against a building façade is that they may destroy the integrity of façade's structure (Kibbel, 2019; Wong et al., 2010). That usually happens when climbers have aerial roots or thorny tendrils since they can penetrate gaps and even the tiniest cracks, widening the gaps and cracks and allow extra moisture to enter into the wall assembly. Freeze-thaw cycles can then increase the size of the openings and even dislodge masonry units.

Normally, such problems are most likely with older properties, those built on clay soils and already have some cracks on the surface. Sound masonry and newly built architectures are unaffected. Second, a structural support can be provided for climbers such as wire, trellis or arbor so they will not grow directly against the façade.

Seasonal changing

We prefer a green screen all year round, while we also prefer various scenes during different seasons such as flower season, autumn foliage and evergreen leaves in the winter. To achieve so, we can select evergreen plants for the whole vertical greening, but there are not many choices especially in the Chicago area, leading to a limited aesthetic and design creativity. Another strategy is to use evergreen plants as a framework and those which have stunning flower seasons or colorful leaves as scattered embellishment, which requires a careful plant

configuration to make sure that there will always be an overall vigorous vertical greening. There will be 20 climbers and 20 Herbaceous plants selected from the most frequently used plants of existing vertical greening to coordinate with “high season changing” criterion. Deciduous and evergreen will be contained together.

Climbers:

1. ***Celastrus scandens*-American bittersweet.** A deciduous plant is best known for its bright red berries and yellow leaves in the fall and winter. Bloom time is May to June with greenish white to yellow flowers (Missouri Botanical Garden, 2019; NC Extension Gardener, 2019).
2. ***Rosa* 'Dortmund'-Kordesii rose.** Deciduous plants with scarlet and white eyes flowers. Bloom time May to frost. Leaves are dark green from summer to fall.
3. ***Hydrangea petiolaris*- Climbing hydrangea**. This is an extremely versatile vine with year-round interest. Masses of fragrant white flowers held in flattened clusters. Resembling lacecap flowers, each cluster consists of tiny, creamy-white to greenish-yellow flowers in May to June (Sargent, 1894).
4. ***Campsis radicans*-Trumpet Vine**. It has showy trumpet-shaped flowers in bright shades of orange or red. Appearing throughout the summer, these flowers are borne in clusters and provide a long-lasting and spectacular floral display (Gardenia, 2019a).
5. ***Lonicera sempervirens*-Coral honeysuckle**. It is one of the showiest of the vining honeysuckles. Large, non-fragrant, narrow, trumpet-shaped flowers are scarlet to orangish red on the outside and yellowish inside. Flowers appear in late spring at stem ends in whorled clusters (Hogan, 2003).
6. ***Ipomoea alba*-Moonflower.** It is noted for its fragrant nocturnal white blooms (moonflowers) and its deep green foliage. Flowers unfold in early evening before nightfall and remain open all night and eventually close before noon the following day (Missouri Botanical Garden, 2019).
7. ***Wisteria sinensis*-Chinese wisteria.** It is prized by gardeners for its vigorous habit, beauty and sweet fragrance. Masses of drooping clusters of scented, pea-like flowers appear in late spring before the leaves (Meyer, 1911).
8. ***Akebia quinate*-Chocolate Vine.** Small chocolate-purple flowers bloom in drooping axillary racemes in spring. Foliage is semi-evergreen in warm winter with dark green leaves. Flowers

are often hidden by the foliage, but are quite interesting on close inspection and have a pleasant fragrance (Flora of North America, 2018).

9. ***Parthenocissus quinquefolia*-Virginia Creeper.** Compound-palmate leaves emerge purplish in spring, mature to dull green in summer and change to attractive shades of purple and crimson red in fall (Snodgrass, 2006).
10. ***Clematis viticella*-Etoile Violette Clematis.** This outstanding vine produces masses of small, nodding, dark violet-purple flowers with a creamy boss of stamens. Creates an excellent vertical effect in smaller spaces and containers (Cullina, 2002).
11. ***Clematis terniflora*-Sweet autumn clematis.** It is very florific, with the creamy-white flowers nearly completely covering the foliage so it is very showy in the mid-summer (Susan, 2017).
12. ***Clematis virginiana*-Woodbine.** Features sweetly aromatic, fragrant pure white flowers in axillary panicles from late August to October in a profuse bloom which typically covers the foliage (Meyer, 1911).
13. ***Humulus lupulus*-Common hops**. Yellow-green male flowers bloom in catkins. Female flowers and subsequent seeds are born in cone-like structures (strobiles) which mature in late summer to early fall (Missouri Botanical Garden, 2019g).
14. ***Aristolochia macrophylla*-Dutchman's Pipe**. It has very interesting flowers that are shaped like a small pipe. They are inconspicuous, mahogany and cream, yellowish-green flowers that superficially resemble Dutch smoking pipes (Boltz, c1958).
15. ***Bignonia capreolata* 'Tangerine Beauty'- 'Tangerine Beauty' Crossvine**. It provides an abundance of stunning, tangerine-colored blooms over a long season. Axillary clusters (2-5 flowered cymes) of fragrant, trumpet-shaped, orange-red flowers (to 2" long) appear in spring (Darwin, 1880).
16. ***Gelsemium sempervirens*- Carolina jessamine**. Bright, fragrant, funnel-shaped, yellow flowers (to 1.5" long) appear either solitary or in clusters in late winter to early spring (February – April depending on location). Flowers often serve as a demonstrative signal that winter is coming to an end (Missouri Botanical Garden, 2019e).
17. ***Fallopia baldschuanica (Polygonum*)-Russian Vine**. Wispy clusters of tiny white or pink-tinged flowers occur at stem tips and little side branches along the stems (The Sunday Gardener, 2020).

18. ***Parthenocissus tricuspidata*- Boston ivy.** It features tri-parted leaves that are glossy green and turn orange-red in fall. This vine also produces dark blue-black berries, which are important food for birds (Cullina, 2002).
19. ***Passiflora incarnata*- purple passionflower**. Fringed flowers have white petals and sepals and a central crown of pinkish-purple filaments. Flowers bloom in summer and are fragrant. Fleshy, egg-shaped, edible fruits called maypops appear in July and mature to a yellowish color in fall (Boisset, c1988.).
20. ***Ampelopsis brevipedunculata*-Porcelain vine**. Features are deep green leaves. Clusters (cymes) of non-showy, greenish flowers appear in the leaf axils in July. Flowers give way in fall to showy clusters of rounded-to-oval, pale lilac-blue fruits which mature to brighter and deeper shades of amethyst to porcelain blue (Missouri Botanical Garden, 2019a).

Figure 4.14: Left to right: *Celastrus scandens, Rosa* 'Dortmund', *Hydrangea petiolaris, Campsis radicans, Lonicera sempervirens*

Figure 4.15: Left to right: *Ipomoea alba, Wisteria sinensis, Akebia quinate, Parthenocissus quinquefolia, Clematis viticella*

Figure 4.16: Left to right: *Clematis terniflora, Clematis virginiana; Humulus lupulus; Aristolochia macrophylla; Bignonia capreolata* 'Tangerine Beauty'

Figure 4.17: Left to right: *Gelsemium sempervirens, Fallopia baldschuanica (Polygonum), Parthenocissus tricuspidata, Passiflora incarnata, Ampelopsis brevipedunculata*

Table 4.10: Climbers with various seasonal changing and their performances in "growth rate", "good coverage", "climbing type" and "increase biodiversity"

			Seasonal changing--Climbers					
Species name	**English name**	**USDA Zones**	**Seasonal changing**	**Overall size/ft**	**Growth rate**	**Coverage (1-5)**	**Climbing type**	**Increase biodiversity**
Celastrus scandens	**American bittersweet**	3-8	Deciduous; bloom time May to June, greenish white-yellow flowers, orange-colored fruits in fall and winter	15-20	Fast	5	Twining woody vine	Birds, bees, butterflies
***Rosa* 'Dortmund'**	**Kordesii rose**	4-10	Deciduous; bloom time May to frost, scarlet with white eyes flowers	6-10	Fast	5	Thorny stem	Butterflies
Hydrangea petiolaris	**climbing hydrangea**	4-9	Deciduous; bloom time May to June; white flower	30-50	Slow to get started but grows rapidly	5	Aerial roots	—
Campsis radicans	**Trumpet Vine**	4-9	Deciduous; bloom time July; red and orange flower	20-40	Fast	5	Aerial rootlets	Hummingbirds
Lonicera sempervirens	**Coral honeysuckle**	4-9	Deciduous; bloom time May to June; Scarlet/orange with yellow inside flower; red berries in late summer to early fall	8-15	Fast	5	Twining vine	Birds, Hummingbirds, Butterflies
Ipomoea alba	**Moonflower**	4-7 annual; 8-12 perennial	Deciduous; bloom time July to Oct; white flower; heart-shaped leaves	10-15	Fast	5	Twining stems	Night-flying moths
Wisteria sinensis	**Chinese wisteria**	5-9	Deciduous; bloom time May to June; blue drooping clusters of flower	60-90	Medium	5	Twisting stems	Butterflies, bees
Akebia quinate	**evergreen Chocolate Vine**	4-8	Evergreen; Bloom from March to April; chocolate-purple flower	20-40	Fast	4	Twining stems	—
Parthenocissus quinquefolia	**Virginia Creeper**	3-9	Deciduous; Bloom from May to Aug; red leaves in autumn; white-green flower	60-90	Fast	5	Sucker pads	Birds

Table 4.10 (cont.): Climbers with various seasonal changing and their performances in "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value"

Seasonal changing--Climbers						
Species name	**English name**	**Pest promotion or other problems**	**Climate tolerance**	**Structural support**	**Maintenance**	**Special value**
Celastrus scandens	**American bittersweet**	Euonymus scale and two-marked treehoppers may cause significant damage in some areas	Full sun; deer, drought	Fences, arbors, trellises, posts	Prune in late winter to early spring; one male plant need 6-9 female plants to produce fruits	—
***Rosa* 'Dortmund'**	**Kordesii rose**	Disease: Black spot, powdery mildew, rust and rose rosette; Pest: aphids, beetles, borers, scale, thrips, rose midges, leafhoppers and spider mites	Full sun; poor soil	Walls, arbors, trellises, along fences or around pillars	Water deeply and regularly (mornings are best); no pruning in the first two years	Flowers can be made fragrance.
Hydrangea petiolaris	**climbing hydrangea**	—	Heavy shade, drought	Sturdy arbors, fences or the trunks of large trees, or sprawled over low stone walls, unsightly tree stumps or rock piles	Prune after flowering	Flowers are used as bouquets.
Campsis radicans	**Trumpet Vine**	Aggressive spreader	Heat, cold, drought, deer, clay soil	Sturdy trellises, walls, fences or arbors	Prune in late winter to early spring	—
Lonicera sempervirens	**Coral honeysuckle**	Watch for aphids	Deer, Clay Soil, Black Walnut	Trellises, arbors and fences	Prune right after flowering	—
Ipomoea alba	**Moonflower**	—	Deer	Fences, decks, trellises or other structures	—	—
Wisteria sinensis	**Chinese wisteria**	Invasive plants	Drought; deer	Sturdy arbor, pergola, trellise, fence	Regular prunning to control size and shape of plants to promote flowering; water weekly	—
Akebia quinate	**evergreen Chocolate Vine**	—	Deer, Heavy Shade, Erosion	Canes or sturdy trellis	Prune as needed in late spring after flowers appear. May be cut to the ground to renovate	Fruits are edible.
Parthenocissus quinquefolia	**Virginia Creeper**	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Black Walnut	—	—	—

Table 4.10 (cont.): Climbers with various seasonal changing and their performances in "growth rate", "good coverage", "climbing type" and "increase biodiversity"

Species name	English name	USDA Zones	Seasonal changing	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Increase biodiversity
Clematis viticella	**Etoile Violette Clematis**	4-9	Deciduous; Bloom from July to Sep; violet-purple flowers	10-15	Fast	5	Twining stems	Butterflies, hummingbirds
Clematis terniflora	**Sweet autumn clematis**	4-9	Deciduous; Bloom from Aug to Sep; white flowers	15-30	Fast	5	Twining vine	—
Clematis virginiana	**Woodbine**	3-8	Deciduous; Bloom from Aug to Oct; white flowers	12-20	Fast	5	Twining vine	Birds
Humulus lupulus	**Common hop**	4-8	Deciduous; Bloom from Sep to Oct; yellow-green flower	15-20	Fast	5	Stiff downward facing hairs that provide stability and allow them to climb	Butterflies
Aristolochia macrophylla	**Dutchman's Pipe**	4-8	Deciduous; Bloom from March to June; yellow-green flower resemble Dutch smoking pipes	20-30	Fast	5	Twining stems or leaf stalks	Butterflies
Bignonia capreolata 'Tangerine Beauty'	**'Tangerine Beauty' Crossvine**	5-9; die in winter in Zone 5 and evergreen in warmer zones	Deciduous; Bloom from May to June; Tangerine-orange trumpet flower; Foliage turns reddish-purple in fall.	20-30	Fast	4	Branched tendrils with adhesive disks	Hummingbirds, bees, butterflies
Gelsemium sempervirens	**Carolina jessamine**	6-10, insulated from winter winds in cold zones	Deciduous; Bloom from Feb to April; yellow flower; yellow to purple leaves in winter	12-20	Medium	5	Twining vine	Butterflies and bumblebees
Fallopia baldschuanica (Polygonum)	**Russian Vine**	4-7	Deciduous; Bloom from July to frost; White flower	25-40	Fast	5	Stems climbing by rhizomes	Birds
Parthenocissus tricuspidata	**Boston Ivy**	4-8	Deciduous; Bloom from June to July; red-purple leaves in autumn; yellow-green flower	60-90	Fast	5	Sucker pads	Birds
Passiflora incarnata	**Purple passionflower Maypop**	5-9	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature	6-8	Fast	4	Root suckers and tendrills	Butterflies, bees
Ampelopsis brevipedunculata	**Porcelain vine**	4-8	Deciduous; Bloom from July to Aug; greenish flower; light-blue berries in fall	15-20	Fast	4	Tendril climbing	Birds, mammals

Table 4.10 (cont.): Climbers with various seasonal changing and their performances in "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value"

Species name	English name	Pest promotion or other problems	Climate tolerance	Structural support	Maintenance	Special value
Clematis viticella	**Etoile Violette Clematis**	—	Deer	Arbor, fence, or trellis, or allow to climb through shrubbery	Water weekly, or more often in extreme heat or containers.	—
Clematis terniflora	**Sweet autumn clematis**	Clematis wilt is a potentially fatal fungal disease.	Deer, Black Walnut	Trellises, arbors, posts, fences	Prune hard in fall after flowering or in early spring.	—
Clematis virginiana	**Woodbine**	Clematis wilt is a potentially fatal fungal disease.	Deer, Black Walnut	Trellises, arbors, or posts	Prune hard in fall after flowering or in early spring.	—
Humulus lupulus	**Common hop**	Skin contact may cause dermatitis.	Drought	Various support structures	—	Brewing for bittering beer
Aristolochia macrophylla	**Dutchman's Pipe**	—	Drought, urban pollution	Trellises, arbors, wires or chain-link fences	Pruning is best done in late winter or early spring	—
Bignonia capreolata 'Tangerine Beauty'	**'Tangerine Beauty' Crossvine**	—	Heavy shade	Fences, arbors, walls, pillars, large trellises	Water regularly - weekly, or more often in extreme heat; Prune annually after flowering to reduce size.	—
Gelsemium sempervirens	**Carolina jessamine**	—	Full sun; drought	Trellis, arbor, pergola, fence or wall	Yearly cutting in late spring after flowering	—
Fallopia baldschuanica (Polygonum)	**Russian Vine**	Better grow on its own or smother other plants; Watch for Japanese beetle and leaf miners	Drought, deer, heavy shade	unsightly fences and other garden structures	—	—
Parthenocissus tricuspidata	**Boston Ivy**	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut	—	—	—
Passiflora incarnata	**Purple passionflower Maypop**	Roots can spread aggressively. Root rot can occur in wet, poorly-drained soils, particularly in winter.	Drought	Trellises, arbors, walls or fences.	Prune to control it growing	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.
Ampelopsis brevipedunculata	**Porcelain vine**	Watch for Japanese beetles. Fruits are not edible.	—	Trellises, arbors, walls or fences.	Trim stems as needed to maintain desired shape	—

Herbaceous plants:

1. ***Lathyrus latifolius*- Sweat Pea or everlasting pea**. It produces attractive rose to white pea-like flowers over a long summer bloom. Showy flowers in colors of rose, pink-purple or white bloom early summer to fall in racemes of 6-11 flowers. Flowers are not fragrant. Flowers give way to flattened, pea-like seed pods (Armitage, c1989.).
2. ***Lathyrus ochroleucus*-Cream pea.** The flowers are whitish or yellowish-white and appear in May to July (Hogan, 2003).
3. ***Tropaeolum majus*- Common Nasturtium**. The showy flowers from early summer until frost are long-stalked, funnel-shaped and range in color from creamy white to orange, mahogany, red, and yellow (Gardenia, 2019g).
4. ***Campanula carpatica* 'Deep Blue Clips'-Carpathian Bellflower**. It has compact flowers in a clear medium-blue, cup shade. It will continue blooming for weeks if spent blossoms are regularly removed. Excellent choice for the rock garden, edging and in containers (RHS, 2019a).
5. ***Campanula glomerata* 'Superba'-Clustered bellflower**. It forms a dense foliage clump of medium green basal leaves. Upward facing, bell-shaped, violet to lavender blue flowers bloom in spherical terminal clusters atop smaller-leaved stems rising above the basal clump to 12-18 inches tall. Smaller flower clusters simultaneously bloom in the upper leaf axils (Armitage, c1989.).
6. ***Campanula poscharskyana*-Serbian bellflower**. Campanulate, lilac-blue flowers with flaring, star-shaped lobes (to 1 inche wide) appear in loose panicles along the stems in late spring (Missouri Botanical Garden, 2019c).
7. ***Geum* 'Mrs. J. Bradshaw'-Avens**. 'Mrs. J. Bradshaw' features semi-double, orange-scarlet flowers. Long, late spring to early summer bloom period may be extended by prompt removal of spent flower stems. Attractive, fluffy seed heads form after bloom (Missouri Botanical Garden, 2019f).
8. ***Heuchera* 'Melting Fire'-Coral Bells 'Melting Fire'**. Grown from flower seed, this Heuchera Melting Fire, also known as Coral Bells Melting Fire, has strong, curled, intense purple-red foliage. Flower stems are also deep-red, carrying small clusters of white flowers from May through June (Armitage, c1989.).

9. ***Salvia nemorosa* 'New Dimension'-Sage.** Lavender to violet blue flowers subtended by tiny reddish-purple bracts bloom from June to September in dense, terminal, upright, spike-like racemes rising well above the foliage (Hogan, 2003).
10. ***Scabiosa columbaria Pink Mist*-Pincushion Flower**. It is noted for its very long blooming season and is a compact clump-forming perennial with uniquely shaped, eye-catching flowers. Blooming time is from early summer until fall (Armitage, c1989.).
11. ***Impatiens balsamina*-Garden balsam**. Cup-shaped single to mostly double flowers with incurved spurs come in various shades of pink, rose, red, purple, white and bicolor versions thereof. Flowers are often spotted (Meyer, 1911).
12. ***Impatiens flaccida*-Jewelweed.** The orchid-shaped flowers are with a long, curved "tail" in back. The color is a vivid shade of pinkish lavender, with bright magenta at the center (Sargent, 1894).
13. ***Impatiens omeiana*-Hardy impatiens**. It features narrow-elliptic, dark green leaves with a white strip on the midrib and yellow snapdragon-like flowers that bloom in early autumn (Missouri Botanical Garden, 2018e).
14. ***Begonia sutherlandii*-Hardy Orange Begonia**. A very handsome hardy tuberous Begonia with showy orange flowers. This makes a nice clump and can be left in the garden over winter (Meyer, 1911).
15. ***Begonia grandis*-Hardy Begonia**. Plants are handsome for the large heart-shaped leaves, green above and red beneath. Sprays of slightly fragrant pale pink flowers are produced in early summer and continue until frost (Armitage, c1989.).
16. ***Petunia Supertunia Priscilla***. It has lovely double-flowered blooms that are light purple with deep purple veins. It blooms continuously, does not need to be deadheaded, has wonderful fragrance, and will attract butterflies and hummingbirds (Hogan, 2003).
17. ***Heuchera* 'Obsidian'- Coral Bells 'Obsidian'**. Coral Bells 'Obsidian' is a magnificent gleaming beauty in the garden, its ultra-dark foliage. These leaves unfurl in spring a rich, midnight-green that really stands out (Dunnett, 2008).
18. ***Heuchera micrantha* 'Palace Purple'- Alum root 'Palace Purple'**. It features very large, lustrous, star-shaped leaves, ranging in color from deep olive green to purplish-bronze to brilliant deep purple. Small, bell-shaped, yellow-white flowers bloom on slender (Armitage, c1989.).

19. ***Butterfly Blue Scabiosa*- Pincushion flower**. Long and profuse bloom from late April until frost. Blooms almost all year in mild winter climates. Flowers feature an outer ring of frilly, flat, lavender-blue petals and a paler domed center cushion with protruding stamens (Missouri Botanical Garden, 2018f)
20. ***Ajuga reptans* 'Burgundy Glow'-Bugleweed**. Whorls of tiny, blue-violet flowers appear in mid to late spring on spikes rising above the foliage to 10". It features shiny dark green leaves (Hogan, 2003).

Figure 4.18: Left to right: *Lathyrus latifolius; Lathyrus ochroleucus; Tropaeolum majus; Campanula carpatica* 'Deep Blue Clips'; *Campanula glomerata* 'Superba'

Figure 4.19: Left to right: *Campanula poscharskyana; Geum 'Mrs J. Bradshaw'; Heuchera* 'Melting Fire'; *Salvia nemorosa* 'New Dimension'; *Scabiosa columbaria Pink Mist*

Figure 4.20: *Impatiens balsamina; Impatiens flaccida; Impatiens omeiana; Begonia sutherlandii; Begonia grandis*

Figure 4.21: Left to right: *Petunia Supertunia Priscilla; Heuchera* 'Obsidian'; *Heuchera micrantha* 'Palace Purple'; *Butterfly Blue Scabiosa; Ajuga reptans* 'Burgundy Glow'
Images source: websites of "Flora of American @ efloras.org" and "Missouri Botanical Garden"

Table 4.11: Herbaceous plants with various seasonal changing and their performances in "growth rate" and "increase biodiversity"

Seasonal changing--Herbaceous

Species name	English name	USDA Zones	Seasonal changing	Overall size	Growth rate	Increase biodiversity
Lathyrus latifolius	**Sweat Pea or everlasting pea**	3-8	Deciduous; Bloom from June to Sep; pink-white flower	6-9ft	Fast	Bumblebees, butterflies, hummingbirds
Lathyrus ochroleucus	**Cream Pea**	2-8	Deciduous; Bloom from May to July; White-yellow flower	2.7-3.6ft	Fast	Bumblebees, butterflies, hummingbirds
Tropaeolum majus	**Common Nasturtium**	2-11	Annual. Bloom from May to Sep, orange-red flowers	6-8in	Fast	Butterflies
Campanula carpatica **'Deep Blue Clips'**	**Carpathian Bellflower**	4-9	Deciduous. Bloom from May to Sep, blue, upturned, bell shaped flowers.	6-8in	Medium	Hummingbirds
Campanula glomerata **'Superba'**	**Clustered bellflower**	3-8	Deciduous. Bloom from June to July, violet blue-deep purple bell shaped flowers.	12-18in	Fast	—
Campanula poscharskyana	**Serbian Bellflower**	3-8	Deciduous. Bloom from May to June, blue-lilac bell shaped flowers. Foliage is semi-evergreen to evergreen in warm winter.	8-12	Fast	—
Geum **'Mrs J. Bradshaw'**	**Avens**	5-9	Evergreen; Bloom from May to June; massed scarlet orange flower	23-29in	Medium	Butterflies
Heuchera **'Melting Fire'**	**Coral Bells Melting Fire**	4-9	Deciduous. Bloom from June to July, white flowers, purple foliage retained in winter	10-18in	Medium	Butterflies, hummingbirds
Salvia nemorosa **'New Dimension'**	**Sage**	5-8	Deciduous. Bloom from June to Sep, violet-blue flowers	8-10in	Medium	Butterflies, bees, hummingbirds

Table 4.11 (cont.): Herbaceous plants with various seasonal changing and their performances in “pest promotion and other issues”, “climate tolerance”, “structural support”, “maintenance”, and “special value”

Seasonal changing--Herbaceous						
Species name	**English name**	**Pest promotion or other problems**	**Climate tolerance**	**Structural support**	**Maintenance**	**Special value**
Lathyrus latifolius	**Sweat Pea or everlasting pea**	Slugs and snails are attracted to young plants	Full sun; Drought	Walls, arbors, trellises, along fences or around pillars	—	—
Lathyrus ochroleucus	**Cream Pea**	All parts of plant are poisonous if ingested	Full sun	Walls, arbors, trellises, along fences or around pillars	—	—
Tropaeolum majus	**Common Nasturtium**	—	Deer	Trellises, arbors, walls or fences.	—	Flower buds contain mustard oil and are used for seasonings; peppery flavor or the unripe seed pods can be used in salads.
Campanula carpatica **‘Deep Blue Clips’**	**Carpathian Bellflower**	May be damaged by slugs and snails	Full sun; Drought	—	—	—
Campanula glomerata **'Superba'**	**Clustered bellflower**	—	Full sun	—	Needs regular moisture, Promptly remove spent flower stems to encourage additional bloom.	—
Campanula poscharskyana	**Serbian Bellflower**	—	—	—	Needs regular moisture, clumps may be divided in spring.	—
Geum **‘Mrs J. Bradshaw’**	**Avens**	May be short-lived in heavy clay soils and/or hot summer climates	Deer	—	Prune hard after blooming	—
Heuchera **‘Melting Fire’**	**Coral Bells Melting Fire**	—	Deer, shade	—	Remove stems of faded flowers to encourage additional bloom.	—
Salvia nemorosa **‘New Dimension’**	**Sage**	Some susceptibility to powdery mildew, leaf spot and rust.	Deer, Drought, Dry Soil, Air Pollution	—	Cut plants back after flowering	—

Table 4.11 (cont.): Herbaceous plants with various seasonal changing and their performances in "growth rate" and "increase biodiversity"

Species name	English name	USDA Zones	Seasonal changing	Overall size	Growth rate	Increase biodiversity
Scabiosa columbaria Pink Mist	**Pincushion Flower**	3-9	Deciduous. Bloom from April to frost, pink flowers	12-18in	Medium	Butterflies, bees, birds
Impatiens balsamina	**Garden balsam**	2-11	Annual. Bloom from May to frost, pink, rose, red, purple, white and bicolor flowers	6-15in	Fast	—
Impatiens flaccida	**Jewelweed**	2-11, need winter protection in 6+ zones	Annual. Bloom from May to frost, pinkish lavender with bright magenta flowers	10-18in	Fast	—
Impatiens omeiana	**Hardy impatiens**	6-9, winter protection in colder zones	Annual. Bloom from Sep to Oct, yellow flowers	9-18in	Fast	—
Begonia sutherlandii	**Hardy Orange Begonia**	6-9, winter protection in colder zones	Annual. Bloom from June to July, orange flowers	8-15in	Medium	—
Begonia grandis	**Hardy Begonia**	5-9	Deciduous. Bloom from July to Oct, pink flowers, heart-shaped leaves with green above and red beneath	15-24in	Medium	—
Petunia Supertunia Priscilla	**Petunia**	9-11 perennial, annual in colder zones	Annual. Bloom from June to July, purple shades flowers	6-10in	Medium	Butterflies, Hummingbirds, bees
Heuchera **'Obsidian'**	**Coral Bells 'Obsidian'**	4-9	Evergreen; Bloom from March to June; dark-purple foliage; cream-colored flowers	6-10in	Medium	Butterflies
Heuchera micrantha **'Palace Purple'**	**Alum root 'Palace Purple'**	4-9	Evergreen; Bloom from March to April; star-shaped foliage, deep olive green, purple-bronze, and brilliant deep purple leaves; yellowish-white flowers	8-12in	Medium	Butterflies
Butterfly Blue Scabiosa	**Pincushion flower**	5-9	Deciduous. Bloom from April to frost, lavender-blue flowers	12-15in	Medium	Butterflies
Ajuga reptans **'Burgundy Glow'**	**Bugleweed**	3-10	Deciduous. Bloom from May to June, blue-purple flowers; green-purple-sliver foliage	8-15in	Fast	—

Table 4.11 (cont.): Herbaceous plants with various seasonal changing and their performances in "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value"

Species name	English name	Pest promotion or other problems	Climate tolerance	Structural support	Maintenance	Special value
Scabiosa columbaria Pink Mist	**Pincushion Flower**	Watch for aphids and whiteflies.	Deer, drought	—	Cut off dead outer leaves in spring; cut back old flowering stems in winter	—
Impatiens balsamina	**Garden balsam**	—	Drought, Dry Soil	—	—	—
Impatiens flaccida	**Jewelweed**	—	Drought, Dry Soil	—	It prefers moist, well draining soil of good fertility. Bright, indirect light or filtered sun is best.	—
Impatiens omeiana	**Hardy impatiens**	—	Heavy shade	—	—	—
Begonia sutherlandii	**Hardy Orange Begonia**	—	Not lower than 2 degree F	—	Keep soil moist	—
Begonia grandis	**Hardy Begonia**	Winter hardiness is a concern in St. Louis.	Heavy Shade, Black Walnut	—	Keep soil moist	—
Petunia Supertunia Priscilla	**Petunia**	—	Drought, Dry Soil	—	Perform best with regular watering	—
Heuchera **'Obsidian'**	**Coral Bells 'Obsidian'**	—	Heat, humidity, deer	—	Apply a protective winter mulch once the ground has frozen.	—
Heuchera micrantha **'Palace Purple'**	**Alum root 'Palace Purple'**	—	Deer, salt	—	Divide clumps in spring every 3-4 years; apply winter mulch aftre the ground freezes	—
Butterfly Blue Scabiosa	**Pincushion flower**	Must have well-drained soil to thrive.	Drought, deer	—	Protect from excessive winter moisture. Good drainage is important.	—
Ajuga reptans **'Burgundy Glow'**	**Bugleweed**	Crown rot can be a problem, particularly in the humid conditions	Deer, Black Walnut	—	Avoid planting in wet, heavy soils, provide good air circulation and divide when clumps become overcrowded.	—

Increasing biodiversity

According to the World Health Organization, the loss of biological diversity in a region can have a direct effect on human health (Manso & Castro-Gomes, 2015). Without biological diversity ecosystems can also become unbalanced, which can lead to the proliferation of some species at the expense of others. This can even lead to outbreaks of infectious diseases in some instances (C. T. W. Chan, 2018). So it would appear that biodiversity can have a significant impact on our health and wellbeing, often in ways that might not be very obvious – particularly to those of us living in built-up areas.

While, continuous urbanization is depriving people's access to nature, and cities are the least connective areas to the natural ecosystem. As a part of the ecosystem, we shoulder the responsibility to promise the integration of our nature by protecting urban biodiversity principally through the provision of suitable habitat—green space. As cities keeping developing densely with barely green space left on the ground, green cities up is an efficient strategy to increase urban biodiversity. Through the discussion of the former criteria, there are various plants that are attractive to bees, butterflies, hummingbirds or other birds, which is primarily how they function to increase biodiversity in an urban area. Because a green façade is usually made up of one plant species as it may grow rapidly to cover the whole façade, a green façade commonly has low plant diversity so as biodiversity compared with living wall system which even contains more than 10,000 plants in a square foot. Broadly speaking, plants with brilliant colors such as orange or red, with delightful fragrance, with generous amounts of nectar and with bird-favorable berries are much likely to attract pollinators and birds. There will be 10 climbers and 20 Herbaceous plants which are functional to increase biodiversity suggested among the frequently used plants in the existing vertical greening in America, but plants which can live in hardiness zone 5 (Chicago area) are mainly focused in this research.

Climbers:

1. ***Campsis radicans*- Trumpet creeper**. Birdwatchers are often tempted to plant trumpet vine because its orange flower attracts hummingbirds (Gardenia, 2019a).
2. ***Passiflora incarnata*-Wild passion flower.** A larval host plant for an array of butterflies, this vine features striking fringed flowers that supply nectar to butterflies from July through September. Edible fruits called maypops mature in fall to feed the birds (Boltz, c1958).

3. ***Clematis virginiana*-Virgin's bower**. Densely growing plant supplies birds with shelter, nesting sites, nest-building materials and seeds that persist into winter.
4. ***Clematis paniculate*-Sweet Autumn clematis**. It is beneficial for pollinators and attracts butterflies, hummingbirds and bees when it blooms from summer to frost (Meyer, 1911).
5. ***Clematis lanuginosa* 'Candida'- Clematis 'Candida'**. It grows large snow white flowers with light yellow centers on 6- to 9-foot-long vines in the late spring and again in the fall and attract hummingbirds (Darwin, 1880).
6. ***Bignonia capreolata* 'Tangerine Beauty'-Cross vine**. It blooms from May to June with spectacular tangerine-colored flowers. The sweet fragrance and brightly colored blossoms bring the hummingbirds to the vines to feed on the nectar (Missouri Botanical Garden, 2019b).
7. ***Lonicera heckrottii*- Flame Honeysuckle**. When it blooms throughout much of the growing season in terminal whorls, the extremely fragrant tubular, rose pink flowers with yellow interiors will attract hummingbirds and bees (Missouri Botanical Garden, 2019l).
8. ***Rosa* 'Zephirine Drouhin'-'Zephirine Drouhin' Climbing Rose**. Its blooms are produced with pink flowers in great quantities and almost continuously from late spring to frost and butterflies love it (Gardenia, 2020d).
9. ***Rosa* 'Strawberry Hill'-English Rose**. Its rose-pink with yellow stamen flowers are very fragrant and preferred by butterflies (Darwin, 1880).
10. ***Phaseolus coccineus*- Scarlet runner bean**. With pink to red flowers, it is attractive to bees, butterflies and/or birds (Hogan, 2003).

Figure 4.22: *Campsis radicans, Passiflora incarnata, Clematis virginiana, Clematis paniculate, Clematis lanuginosa* 'Candida'

Figure 4.23: Left to right: *Bignonia capreolata* 'Tangerine Beauty', *Lonicera heckrottii, Rosa* 'Zephirine Drouhin', *Rosa* 'Strawberry Hill', *Phaseolus coccineus*

Table 4.12: Climbers attractive to pollinators and their performances in "growth rate", "good coverage" and "climbing type" Plant filled with orange is tropical plant and becomes annual plant or needs winter protection to grow in Chicago area.

Increasing biodiversity--Climbers

Species name	English name	USDA Zones	Increase biodiversity	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type
Campsis radicans	**Chilean Trumpet Vine**	4-9	Attract hummingbirds and many types of birds	20-40	Fast	5	Aerial roots
Passiflora incarnata	**Wild passion flower**	5-9	Butterflies, bees, birds	6-8	Fast	4	Root suckers and tendrills
Clematis virginiana	**Woodbine**	3-8	Birds	12-20	Fast	5	Twining leaf stalks
Clematis paniculata	**Sweet Autumn clematis**	4-9	Butterflies, hummingbirds, bees	20-30	Fast	5	Twining leaf stalks
Clematis lanuginosa **'Candida'**	**Clematis 'Candida'**	4-8	Hummingbirds	8-12	Fast	5	Twining leaf stalks
Bignonia capreolata **'Tangerine Beauty'**	**Cross-vine**	5-9, apply winter mulch in zone 5	Hummingbirds	20-30	Fast	5	Branched tendrils with adhesive disks
Lonicera heckrottii	**Flame Honeysuckle**	5-9	Hummingbirds, Butterflies	10-15	Fast	5	Twining vine
***Rosa* 'Zephirine Drouhin'**	**Zephirine Drouhin" Climbing Rose**	5-9	Butterflies	15-20	Fast	5	Thornless twining stems
***Rosa* 'Strawberry Hill'**	**English rose**	5-10	Butterflies	3-4	Fast	5	Thorny twining stems
Phaseolus coccineus	**Scarlet runner bean**	7-11, serve as annual in colder zones	Hummingbirds, butterflies, birds and bees	8-12	Medium	5	Twining vine

Table 4.12 (cont.): Climbers attractive to pollinators and their performances in "seasonal changing", "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value"

Increasing biodiversity--Climbers

Species name	English name	Seasonal changing	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance	Special value
Campsis radicans	**Chilean Trumpet Vine**	Deciduous; Bloom from May to Oct; orange-red flower	Could be invasive	Drought, heat, cold	lattice or trellis	—	—
Passiflora incarnata	**Wild passion flower**	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature	Roots can spread aggressively. Root rot can occur in wet, poorly-drained soils, particularly in winter.	Drought	Trellises, arbors, walls or fences.	Prune to control it growing	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.
Clematis virginiana	**Woodbine**	Deciduous; Bloom from Aug to Oct; white flowers	Clematis wilt is a potentially fatal fungal disease.	Deer, Black Walnut	Trellises, arbors, or posts	Prune hard in fall after flowering or in early spring.	—
Clematis paniculata	**Sweet Autumn clematis**	Deciduous; Bloom from June to Sep; creamy-white flowers, delightful fragrance	—	Deer	Sturdy arbors, pergolas, trellises, walls, and fences	Hard prune in late winter or early spring, cut back immediately after bloom	—
Clematis lanuginosa **'Candida'**	**Clematis 'Candida'**	Deciduous; Bloom from May to Sep; white color flowers	Susceptible to wilt/stem rot (can be fatal), powdery mildew, leaf spots, rust and viruses.	Deer, Black Walnut	Trellis, fence, arbor, porch, lamppost or other stationary structure	—	—
Bignonia capreolata **'Tangerine Beauty'**	**Cross-vine**	Deciduous; Bloom from May to June; tangerine color flowers, reddish-purple foliage in fall	—	Heavy Shade	Fences, arbors, walls, pillars, large trellises and other structures	Prune after flowering if needed.	—
Lonicera heckrottii	**Flame Honeysuckle**	Deciduous; Bloom from June to August; rose pink with yellow interior flowers	Powdery mildew and leaf spots may occur.	Deer, Black Walnut, needs good air circulation	Trellises or espaliers; fences	—	—
Rosa **'Zephirine Drouhin'**	**Zephirine Drouhin" Climbing Rose**	Deciduous; Bloom from June to Oct; pink flowers with fragrance	—	Full sun, well-drained; poor soil	Trellises or arbors; fences	Remove spent flowers to encourage rebloom. Prune as needed in late winter to early spring.	Flowers can be made fragrance.
Rosa **'Strawberry Hill'**	**English rose**	Deciduous; Bloom from April to frost; pink with yellow stamen at the center flowers with fragrance	—	Full sun	Trellises or arbors; fences	—	Flowers can be made fragrance.
Phaseolus coccineus	**Scarlet runner bean**	Deciduous; Bloom from June to Oct; red flowers	Mosaic viral disease, bacterial blight, and anthracnose may appear.	—	Sunny porch or split rail fence, or train on tripods, trellises or pergolas	Pick beans when ripe to encourage new flowers	Produce beans as vegetables

Herbaceous plants:

1. ***Lobelia erinus*****- Edging lobelia**. It is noted for its profuse bloom of intensely colored flowers. Flowers have large, fan-shaped lower lips characteristic of the lobelias and are attractive to butterflies (Missouri Botanical Garden, 2019k).
2. ***Zahara™ Zinnia*****- Zinnia marylandica Zahara™ Series Patented**. Big flowers, colorful Zahara is perfect for brightening garden beds and borders. Attracts butterflies so well.

3. ***Zinnia elegans* ‘Dreamland Series’ - Bedding zinnia**. Early flowering with large, showy blooms it draws attention in packs, is a dynamic landscape item which is favored by bees and butterflies (Hogan, 2003).
4. ***Monarda* ‘Balmy Rose’-Bee Balm Balmy Rose.** It is a compact-flowering perennial plant and borne in dense, globular terminal heads. Flowers rest upon a whorl of decorative bracts and attract scores of butterflies, hummingbirds and other beneficial pollinators (Armitage, c1989.).
5. ***Monarda* 'Balmy Purple'- Bee Balm Balmy Purple.** Compact and early flowering, it produces bright purple flowers and attracts butterflies, hummingbirds (Gardenia, 2019f).
6. ***Phlox paniculata* ‘Cosmopolitan’ - Cosmopolitan Phlox.** Phlox Cosmopolitan with bright pink blossoms will fill the air with sweet perfume. Dwarf, compact and well-branched, it will have large blossoms in a range of colors which attract butterflies and hummingbirds (Menlo Park, Calif., Lane Pub. Co., 1954).
7. ***Heuchera* 'Wild Rose' PPAF-Wild Rose Heuchera.** It has tiny bell rosy pink blooms on slender stems. Foliage grows in mounds with dark veining on large black purple leaves. It attracts glorious butterflies and hummingbirds (Armitage, c1989.).
8. ***Heuchera* ‘Electra’-Coral Bells Electra**. The leaves emerge in the spring a bright yellow with red veins, mellow to a softer yellow-green, and then finally fade to tan over the winter. Dense cones of white flowers bloom on slender stems and attract butterflies, hummingbirds and bees (Gardenia, 2019e).
9. ***Heuchera* ‘Glitter’- Coral Bells 'Glitter'.** It has bright-sliver leaves with contrasting black veins and soft violet undersides. In summer, sprays of small, bell-shaped, fuchsia-pink flowers bloom on slender stems. It is attractive to butterflies and hummingbirds (Meyer, 1911).
10. ***Trillium recurvatum*-Purple Prairie Trillium or wood lily.** Leaves, petals and sepals all come in groups of three. Leaves are mottled with purple. The flower features purple to brownish-purple. Bees and butterflies love it (Missouri Botanical Garden, 2019n).
11. ***Primula acaulis* 'Zebra Blue'-Blue Zebra™ Primrose**. It has spectacular blue and white stripes highlighted by yellow centers. The large, fragrant flowers keep coming from mid spring to early summer, attracting butterflies and hummingbirds, bees friendly (Hogan, 2003).

12. ***Hosta sieboldiana* 'Elegans' -Hosta.** Thick, puckered, cupped, wide-oval leaves have distinctive veining, cuspidate tips and cordate lobes. Leaves often emerge smoky-blue in spring. Funnel-shaped, mostly white (sometimes lilac tinged at the base) flowers appear in early to mid summer, attracting hummingbirds (Sargent, 1894).
13. ***Aquilegia vulgaris* 'Clementine Red'- Clementine Red Aquilegia.** Dainty, nodding, red flowers resemble double-flowering clematis well above the lacy green foliage mound, which attracts hummingbirds and butterflies (Perennials.com, 2020).
14. ***Lakota Fire Echinacea*- Lakota Fire Echinacea Coneflower**. It is a compact variety with gorgeous flowers shades of red to reddish-orange to pinkish-red. Bees and butterflies are attracted to its pollen while hummingbirds enjoy the seed heads once they dry out (Armitage, c1989.).
15. ***Phlox stolonifera* 'Sherwood Purple'- Sherwood Purple Woodland Phlox.** Short upright stems appear in mid-spring, bearing clusters of sweetly-fragrant, deep purple-blue flowers for several weeks. Attract butterflies (Hogan, 2003).
16. ***Dianthus caryophyllus SuperTrouper™ Orange*- Super Trouper Orange Dianthus**. It has fragrant, orange with peach accent blooms and attracts butterflies and hummingbirds (Sargent, 1894).
17. ***Dianthus deltoides* 'Arctic Fire' (Maiden Pink)- Maiden Pink 'Arctic Fire'.** With evergreen foliage, in late spring and summer, the foliage mound is covered by a profusion of small, white, single flowers adorned with fringed petals and a red eye. The dainty blossoms attract bees and butterflies (Gardenia, 2019c).
18. ***Hepatica acutiloba*- Sharp-lobed hepatica.** It is one of the earlieast woodland wildflowers. The bright blue to pink flowers (sometimes white) are an important early nectar source for many different pollinators (Armitage, c1989.).
19. ***Calamintha nepeta subsp. nepeta*-Calamint.** It has delicate lavender and white flowers that bloom from August to October. Fragrant flowers and leaves attract butterflies, bees and other pollinators (Missouri Botanical Garden, 2020c).
20. ***Stachys* 'Lilac Falls'.** It produces an abundance of beautiful lilac lavender flowers and blooms continuously from early spring through autumn. It works well as a cascading plant and attract lots of pollinators (Hogan, 2003).

Figure 4.24: Left to right: *Lobelia erinus; Zahara™ Zinnia; Zinnia elegans* ‘Dreamland Series’; *Monarda* ‘Balmy Rose’; *Monarda* 'Balmy Purple'

Figure 4.25: Left to right: *Phlox paniculata* ‘Cosmopolitan’; *Heuchera* 'Wild Rose' PPAF; *Heuchera Electra*; *Heuchera* ‘Glitter’; *Trillium recurvatum*

Figure 4.26: Left to right: *Primula acaulis* 'Zebra Blue'; *Hosta sieboldiana* 'Elegans'; *Aquilegia vulgaris* ‘Clementine Red’; *Lakota Fire Echinacea*; *Phlox stolonifera* 'Sherwood Purple'

Figure 4.27: Left to right: *Dianthus caryophyllus SuperTrouper™ Orange; Dianthus deltoides* 'Arctic Fire' (Maiden Pink); *Hepatica acutiloba; Calamintha nepeta subsp. Nepeta; Stachys* 'Lilac Falls'

Table 4.13: Herbaceous plants attractive to pollinators

Increasing biodiversity--Herbaceous

Species name	English name	USDA Zones	Increase biodiversity	Overall size/in	Growth rate	Seasonal changing
Lobelia erinus	**Edging lobelia**	2-11; 2-9 annual, 10-11 perennial	Butterflies	6-9	Medium	Deciduous; bloom time from April to June; Blue to violet with yellow to white throat flowers
Zahara™ Zinnia	**Zinnia marylandica Zahara™ Series Patented**	2-11; 2-9 annual, 10-11 perennial	Butterflies	12-18	Medium	Deciduous; bloom time from March to July; muticolored flowers
***Zinnia elegans* 'Dreamland Series'**	**Bedding zinnia**	2-11; 2-9 annual, 10-11 perennial	Bees, butterflies	8-12	Medium	Deciduous; bloom time from May to August; flowers are in apricot, ivory, red, yellow, pink, and many shades in between.

Increasing biodiversity--Herbaceous

Species name	English name	Pest promotion or other problems	Climate tolerance	Structural support	Maintenance	Special value
Lobelia erinus	**Edging lobelia**	Mid-summer die back is usually the most serious problem.	Deer	Hanging baskets, containers or window boxes which enable the flowering stems to cascade downward over the sides.	Cut back after summer blooming to encourage a fall bloom	—
Zahara™ Zinnia	**Zinnia marylandica Zahara™ Series Patented**	—	Highly mildew resistant; urban polution; well-draining soil; Full sun	Container Planting; Hanging Baskets	Occasional watering; Trim off the flower heads after they fade to encourage more blooms	—
***Zinnia elegans* 'Dreamland Series'**	**Bedding zinnia**	Bacterial and fungal spots, bacterial wilt, powdery mildew, caterpillars, mealybugs, spider mites	well-draining soil; Full sun	—	Deadhead spent blossoms to continue flowering	—

Table 4.13 (cont.): Herbaceous plants attractive to pollinators and their performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Increase biodiversity	Overall size/in	Growth rate	Seasonal changing
***Monarda* 'Balmy Rose'**	**Bee Balm Balmy Rose**	4-9	Birds, butterflies, hummingbirds	10-12	Fast	Deciduous; bloom time from April to August; rose pink flowers.
***Monarda* 'Balmy Purple'**	**Bee Balm Balmy Purple**	4-9	Birds, butterflies, hummingbirds	10-12	Fast	Deciduous; bloom time from May to August; bright purple flowers.
***Phlox paniculata* 'Cosmopolitan'**	**Cosmopolitan Phlox**	4-8	Butterflies, hummingbirds	12-16	Medium	Deciduous; bloom time from May to Sep; bright pink flowers.
***Heuchera* 'Wild Rose' PPAF**	**Wild Rose Heuchera**	4-9	Butterflies, hummingbirds	8-10	Fast	Deciduous; bloom time mid summer; pink flowers. Rosy purple leaves with deep gray veining
Heuchera Electra	**Coral Bells 'Electra'**	4-9	Butterflies, hummingbirds, bees	8-12	Fast	Semi-evergreen; bloom time June to July; white flowers; yellow with blood-red veins leaves in spring
***Heuchera* 'Glitter'**	**Coral Bells 'Glitter'**	4-9	Butterflies, hummingbirds	10-16	Fast	Semi-evergreen; bloom time June to Sep; fuchsia-pink flowers; mirror-bright silver foliage with black veins
Trillium recurvatum	**Purple Prairie Trillium; wood lily**	4-9	Butterflies, bees	12-18	Medium	Deciduous; bloom time mid summer; purple to wine-red flowers. Dark green leaves with mottled appearance

Table 4.13 (cont.): Herbaceous plants attractive to pollinators and their performances in "pest promotion and other issues", "climate tolerance", "structural support", "maintenance", and "special value"

Species name	English name	Pest promotion or other problems	Climate tolerance	Structural support	Maintenance	Special value
***Monarda* 'Balmy Rose'**	**Bee Balm Balmy Rose**	—	Clay soil and wet site conditions, deer	—	Cut to the ground after flowering; divide every 3 years	—
***Monarda* 'Balmy Purple'**	**Bee Balm Balmy Purple**	Powdery mildew	Clay soil, deer	—	Cut to the ground after flowering; divide every 3 years; good air circulation	—
***Phlox paniculata* 'Cosmopolitan'**	**Cosmopolitan Phlox**	—	Good mildew resistance; Sandy and clay soil; good air circulation	—	Cut back by 1/2 in late spring/early summer	—
***Heuchera* 'Wild Rose' PPAF**	**Wild Rose Heuchera**	—	Full shade, deer	Container Planting; Hanging Baskets	—	—
Heuchera Electra	**Coral Bells 'Electra'**	—	Vigor, heat, humidity, deer	—	Remove stems of faded flowers; winter mulch	—
***Heuchera* 'Glitter'**	**Coral Bells 'Glitter'**	—	Drought, full shade	—	Remove stems of faded flowers; winter mulch	—
Trillium recurvatum	**Purple Prairie Trillium; wood lily**	May attract carrion beetles and flesh flies	Full shade	—	—	—

Table 4.13 (cont.): Herbaceous plants attractive to pollinators and their performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Increase biodiversity	Overall size/in	Growth rate	Seasonal changing
***Primula acaulis* 'Zebra Blue'**	**Blue Zebra™ Primrose**	4-8, mulch protection in winter	Hummingbirds, butterflies, bees	6-8	Medium	Semi-evergreen; bloom time March to Sep; blue and white striped petals with a bright yellow center flowers
***Hosta sieboldiana* 'Elegans'**	**Hosta**	4-9	Hummingbirds	12-24	Slow	Evergreen; bloom time May to June, white with a lavender tinge; large smoky-blue rounded leaves
***Aquilegia vulgaris* 'Clementine Red'**	**Clementine Red Aquilegia**	3-9	Butterflies, hummingbirds	12-18	Medium	Deciduous; bloom time April to June; red flowers. Lacy green foliage
Lakota Fire Echinacea	**Lakota Fire Echinacea Coneflower**	4-8	Butterflies, hummingbirds, bees	12-16	Medium	Deciduous; bloom time June to Sep; colorful coneflower with reddish-orange and pinkish red flowers

Table 4.13 (cont.): Herbaceous plants attractive to pollinators and their performances in “pest promotion and other issues”, “climate tolerance”, “structural support”, “maintenance”, and “special value”

Species name	English name	Pest promotion or other problems	Climate tolerance	Structural support	Maintenance	Special value
***Primula acaulis* 'Zebra Blue'**	**Blue Zebra™ Primrose**	—	Full shade, deer	—	Crown of plant should rest just at or above the soil surface after watering in.	—
***Hosta sieboldiana* 'Elegans'**	**Hosta**	Slugs and snails are attracted to the foliage.	Full shade	—	Wet, Well Draining soil; Divide plants as needed in spring or autumn.	—
***Aquilegia vulgaris* 'Clementine Red'**	**Clementine Red Aquilegia**	Leaf miners or sawfly may disfigure the leaves around flowering time.	Drought, deer, shade	—	Simply trim off the ugly foliage	—
Lakota Fire Echinacea	**Lakota Fire Echinacea Coneflower**	—	Drought, deer	—	Needs Good Drainage	—

Table 4.13 (cont.): Herbaceous plants attractive to pollinators and their performances in “growth rate” and “seasonal changing”

Species name	English name	USDA Zones	Increase biodiversity	Overall size/in	Growth rate	Seasonal changing
***Phlox stolonifera* 'Sherwood Purple'**	**Sherwood Purple Woodland Phlox**	5-9	Butterflies	6-10	Medium	Evergreen; bloom time April to June; purple flowers
Dianthus caryophyllus SuperTrouper™ Orange	**Super Trouper Orange Dianthus**	5-9	Butterflies, hummingbirds	8-10	Medium	Evergreen; bloom time May to August; orange with peach accent flowers
***Dianthus deltoides* 'Arctic Fire' (Maiden Pink)**	**Maiden Pink 'Arctic Fire'**	3-9	Butterflies, bees	6-8	Medium	Evergreen; bloom time April to August; white serrated petals surrounding a deep fiery red eye
Hepatica acutiloba	**Sharp-lobed hepatica**	4-9	Butterflies, bees	4-8	Slow	Evergreen; bloom time March to May; white to lavender blooms with an occasional pink bloom.
Calamintha nepeta subsp. nepeta	**Calamint**	5-7	Butterflies, bees	12-18	Medium	Deciduous; bloom time Aug to Oct; lavender and white flowers, flowers and leaves are fragrant
***Stachys* 'Lilac Falls'**	**—**	5-8	Butterflies, bees	8-12	Medium	Deciduous; bloom time June to Sep; carpet of lavender flowers that add color to borders

Table 4.13 (cont.): Herbaceous plants attractive to pollinators and their performances in “pest promotion and other issues”, “climate tolerance”, “structural support”, “maintenance”, and “special value”

Species name	English name	Pest promotion or other problems	Climate tolerance	Structural support	Maintenance	Special value
Phlox stolonifera 'Sherwood Purple'	**Sherwood Purple Woodland Phlox**	—	Shade, drought	—	Occasional shearing to stimulate growth. After flowering or late summer.	—
Dianthus caryophyllus SuperTrouper™ Orange	**Super Trouper Orange Dianthus**	—	Heat, clay and sandy soil, deer	—	Provide average, evenly moist, well-drained soil.	Flowers are ideal for bouquets
Dianthus deltoides 'Arctic Fire' (Maiden Pink)	**Maiden Pink 'Arctic Fire'**	—	Sandy soil, deer, humidity, drought	—	—	Flowers are perfect for small bouquets
Hepatica acutiloba	**Sharp-lobed hepatica**	—	Shade, deer	—	Prefers well-drained soil	Leaves can be made herbal remedy.
Calamintha nepeta subsp. nepeta	**Calamint**	Foliage may decline in hot and humid summer; Watch for powdery mildew.	Drought, Erosion, Dry Soil, Shallow-Rocky Soil, deer	—	Prefers well-drained soil	—
Stachys **'Lilac Falls'**	**—**	Aphids, spider mites and whiteflies; Watch for root rot	—	Hanging baskets and works well as a cascading plant in combination planters.	—	—

Low pest promotion and other problems

When it comes to the most common concern followed by increasing biodiversity, people tend to worry that plants for vertical greening should only bring more beneficial pollinators but not pests such as flies, mosquitos, or beetles. Indeed, no one wants a green screen nearby buzzing with flies and mosquitos, or they would rather never have that green screen ever. To deter flies and mosquitos, we need to pay attention to the drainage capability of the substrate for plants to grow and the frequency of irrigation. There should not be any water-holding situations in every corner of the VG since little pools of water is preferred by mosquitos for laying eggs. Besides, plant leaves should not shape like “pocket”, “pool” or “bowl” so they don’t hold water for a long time. For other pests such as beetles, aphids and slugs, careful plant selection is necessary to avoid or reduce the possibility of their appearance, although they are prevalent pests for most plants. Other problems include invasive plants (while sometimes people do prefer this character since it usually grows vigorously and bring a spectacular landscape, so it could be solved by only planted this species by it own), common diseases such as root rot, leaf spot and rust, and

powdery mildew, or some uncomfortableness after skin contact. Careful plant selection can avoid these issues fundamentally. There will be 10 climbers and 20 Herbaceous plants which are resistant to pest and diseases suggested among the frequently used plants in the existing vertical greening in America, but plants which can live in hardiness zone 5 (Chicago area) are mainly focused in this research.

Climbers:

1. ***Campsis radicans***. They are resistant to insect infestations and diseases.
2. ***Passiflora incarnata***. This perennial vine is not bothered by insects or diseases.
3. ***Antigonon leptopus*- Coral vine**. It is resistant to disease and insect infestation and is drought-tolerant but the leaves are sometimes eaten by caterpillars (Missouri Botanical Garden, 2018c).
4. ***Akebia quinate*-Chocolate vine**. Insects and diseases are not a problem for this vine.
5. ***Lonicera sempervirens*-Trumpet honeysuckle**. This vine is resistant to deer, disease and insect infestation (Darwin, 1880).
6. ***Jasminum mesnyi*- Chinese jasmine.** It is resistant to insects and disease (Meyer, 1911).
7. ***Wisteria frutescens*- American wisteria**. No significant diseases and foliage-chewing insects issues (Cullina, 2002).
8. ***Clematis* 'Hagley Hybrid'-Large-Flowered Clematis 'Hagley Hybrid'**. It has strong tolerance to climate exposures but watch for spider mites (Gardenia, 2019b).
9. ***Hydrangea anomala subsp. Petiolaris*-Climbing hydrangea**. No serious insect or disease problems while intolerant of the hot and humid conditions (Missouri Botanical Garden, 2019h).
10. ***Schizophragma hydrangeoides*-Japanese hydrangea vine**. No serious insect or disease problems (Missouri Botanical Garden, 2019m).

Figure 4.28: Left to right: *Campsis radicans; Passiflora incarnata; Antigonon leptopus; Akebia quinate; Lonicera sempervirens*

Figure 4.29: Left to right: *Jasminum mesnyi; Wisteria frutescens; Clematis* 'Hagley Hybrid'; *Hydrangea anomala subsp. Petiolaris; Schizophragma hydrangeoides*

Table 4.14: Climbers that have low pest promotion and high disease resistance. Their performances in "growth rate", "good coverage", "climbing way", and "seasonal changing"

Low pest promotion and other problems-Climbers

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Campsis radicans	**Trumpet Vine**	4-9	20-40	Fast	5	Aerial rootlets	Deciduous; bloom time July; red and orange flower
Passiflora incarnata	**Purple passionflower Maypop**	5-9	6-8	Fast	4	Root suckers and tendrills	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature
Antigonon leptopus	**Coral vine**	8-11, annual in colder zones	8-10	Fast	5	Tendril-climbing	Deciduous (evergreen in 9-11 zones); seasonal bloomer; pink to white flowers
Akebia quinate	**Chocolate vine**	4-8	20-40	Fast	4	Twining stems	Evergreen; Bloom from March to April; chocolate-purple flower
Lonicera sempervirens	**Trumpet honeysuckle**	4-9	8-15	Fast	5	Twining vine	Semi-evergreen; Bloom from May to June; Scarlet/orange with yellow inside flower
Jasminum mesnyi	**Chinese jasmine**	8-10, annual in colder zones	5-10	Medium	5	Twining stems	Deciduous (evergreen in 8-10 zones); seasonal bloomer spring and winter; yellow flowers
Wisteria frutescens	**American wisteria**	5-9	15-30	Fast; Produce flowers second or third year after planting	5	Twining vine	Deciduous; bloom time April to May; lilac-purple flowers
***Clematis* 'Hagley Hybrid'**	**Large-Flowered Clematis 'Hagley Hybrid'**	4-11	7-10	Fast	5	Twisting petioles	Deciduous; bloom time June to Sep; shell pink flowers with a touch of lavender flowers with deep-red anthers

Table 4.14 (cont.): Climbers that have low pest promotion and high disease resistance. Their performances in "increase biodiversity", "climate tolerance", "structural support", "maintenance" and "special value"

Low pest promotion and other problems-Climbers

Species name	English name	Increase biodiversity	Climate tolerance	Structural support	Maintenance	Special value
Campsis radicans	**Trumpet Vine**	Hummingbirds	Heat, cold, drought, deer, clay soil	Sturdy trellises, walls, fences or arbors	Prune in late winter to early spring	—
Passiflora incarnata	**Purple passionflower Maypop**	Butterflies, bees	Drought	Trellises, arbors, walls or fences.	Prune to control it growing	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.
Antigonon leptopus	**Coral vine**	—	Drought	Trellises, arbors or fences	Prune annually in late winter to early spring to remove frost damaged foliage and to maintain desired size	—
Akebia quinate	**Chocolate vine**	—	Deer, Heavy Shade, Erosion	Canes or sturdy trellis	Prune as needed in late spring after flowers appear. May be cut to the ground to renovate	Fruits are edible.
Lonicera sempervirens	**Trumpet honeysuckle**	Birds, Hummingbirds, Butterflies	Deer, Clay Soil, Black Walnut	Trellises, arbors, or fences.	Prune as needed immediately after flowering.	—
Jasminum mesnyi	**Chinese jasmine**	—	—	Trellises, arbors or fences	Prune after flowering to keep in control	—
Wisteria frutescens	**American wisteria**	Butterflies, bees	Deer	Freestanding arbors, pergolas, posts, trellises, fences or terrace walls.	—	—
Clematis **'Hagley Hybrid'**	**Large-Flowered Clematis 'Hagley Hybrid'**	Butterflies, hummingbirds	Deer, Black Walnut	Trellises, arbors, walls or fences.	Hard prune in late winter or early spring	—

Table 4.14 (cont.): Climbers that have low pest promotion and high disease resistance

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	4-9	30-50	Fast	5	Aerial roots	Deciduous; bloom time May to June; white flower
Schizophragma hydrangeoides	**Japanese hydrangea vine**	5-8	20-30	Fast	5	Stem-borne adhesive rootlets	Deciduous; bloom time June to July; white flower; Reddish-brown stems provide some interest in winter.

Species name	English name	Increase biodiversity	Climate tolerance	Structural support	Maintenance	Special value
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	—	Heavy shade, drought	Sturdy arbors, fences or the trunks of large trees, or sprawled over low stone walls, unsightly tree stumps or rock piles	Prune after flowering	Flowers are used as bouquets.
Schizophragmahydrangeoides	**Japanese hydrangea vine**	—	Heavy shade	Walls, arbors or trees	—	—

Herbaceous plants:

1. ***Dianthus gratianopolitanus* 'Firewitch'- Cheddar Pink 'Firewitch'.** It is easy to grow and resist to diseases and pest (Gardenia, 2020a).
2. ***Convallaria majalis*- Lily of the valley**. No serious insect or disease problems. Watch for aphids and spider mites (Hogan, 2003).
3. ***Hosta* 'El Niño'- Plantain lily.** Excellent slug and other pest resistance (Meyer, 1911).
4. ***Hosta undulata var. undulata*-Wavy Plantain Lily.** No significant issues about pest and disease. Watch for slugs and snails (Armitage, c1989.).
5. ***Asplenium scolopendrium*- Hart's tongue fern.** No serious insect or disease problems. Root rot can be a problem in poorly drained soils (Missouri Botanical Garden, 2020a).
6. ***Anemone multifida*- Anemone.** No serious pest and disease issues and easy to care (Armitage, c1989.).

7. ***Anemone blanda* 'White Splendour'-Grecian Windflower**. Leaf spot and rhizome rot are infrequently reported problems but not significant (Missouri Botanical Garden, 2018b).
8. ***Pulmonaria angustifolia*-Blue Lungwort.** No serious pest and diseases (Armitage, c1989.).
9. ***Pulmonaria* 'Dark Vader'-Dark Vader Lungwort**. No serious insect or disease problems. Slugs and snails are occasional insect pests (Hogan, 2003).
10. ***Oxalis triangularis* 'Atropurpurea'- Purple and Black False Shamrock.** It is very easy to cultivate and maintain, resist to pest and diseases (Gardenia, 2020c).
11. ***Brunnera macrophylla* 'Jack Frost'- Jack Frost Siberian Bugloss**. No serious insect or disease problems. Slugs and snails are occasional visitors (Missouri Botanical Garden, 2020b).
12. ***Scilla siberica*-Siberian Squill.** Pests don't seem to bother with Siberian squill. It requires a well-draining soil or root rot can be a problem (Armitage, c1989.).
13. ***Scilla mischtschenkoana*-White Squill.** No serious insect or disease problems. Crown rot may occur in moist but poorly drained soils (Hogan, 2003).
14. ***Eranthis hyemalis*-Winter Aconite**. Virtually pest and disease free. Watch for smut (Gardenia, 2020b).
15. ***Cyclamen coum*-Persian Violet.** It's a really hardy perennial and no serious issues reported. Watch for spider mites and Vine weevil (Paxton, 1836).
16. ***Ocimum basilicum*-Sweet basil.** Repels house flies and mosquitoes. Leaves also can be used to make an insect repellent spray (Tom Oder, 2019).
17. ***Thymus citriodorus*- Lemon thyme.** Repels mosquitoes. Virtually disease free especially in colder zones. Root rot is common in poorly drained soil. Watch out for spider mites (Sargent, 1894).
18. ***Mentha balsamea*-Peppermint.** Repels mosquitoes because of its fragrant leaves. It is so easy growing and barely needs maintenance (Meyer, 1911).
19. ***Salvia lavandulaefolia*-Spanish Sage.** The scented smoke helps keep away unwanted insects. You can make a bug repellant spray using sage (Armitage, c1989.).
20. ***Chrysanthemum multicaule*-Yellow clump daizy.** Repel roaches, ants, Japanese beetles, ticks, silverfish, lice, fleas, bedbugs, spider mites, harlequin bugs and root-knot nematodes. (Missouri Botanical Garden, 2018a).

Figure 4.30: Left to right: *Dianthus gratianopolitanus* 'Firewitch'; *Convallaria majalis; Hosta* 'El Niño'; *Hosta undulata var. undulata; Asplenium scolopendrium*

Figure 4.31: Left to right: *Anemone multifida; Anemone blanda* 'White Splendour'; *Pulmonaria angustifolia; Pulmonaria* 'Dark Vader'; *Oxalis triangularis* 'Atropurpurea'

Figure 4.32: Left to right: *Brunnera macrophylla* 'Jack Frost'; *Scilla siberica; Scilla mischtschenkoana; Eranthis hyemalis; Cyclamen coum*

Figure 4.33: Left to right: *Ocimum basilicum; Thymus citriodorus; Mentha balsamea; Salvia lavandulaefolia; Chrysanthemum multicaule*

Table 4.15: Herbaceous plants that have low pest promotion and disease resistance. Performances in "growth rate" and "seasonal changing"

Low pest promotion and other problems-Herbaceous

Species name	English name	USDA Zones	Overall size/in	Growth rate	Seasonal changing
***Dianthus gratianopolitanus* 'Firewitch'**	**Cheddar Pink 'Firewitch'**	3-9	6-8	Slow	Evergreen; Bloom from April to Sep; purplish-pink flowers; blue-gray, sliver foliage
Convallaria majalis	**Lily of the valley**	3-8	8-12	Medium	Deciduous; bloom time April; white flower

Table 4.15 (cont.): Herbaceous plants that have low pest promotion and disease resistance. Performances in "increase biodiversity", "climate tolerance", "maintenance" and "special value"

Low pest promotion and other problems-Herbaceous

Species name	English name	Increase biodiversity	Climate tolerance	Maintenance	Special value
***Dianthus gratianopolitanus* 'Firewitch'**	**Cheddar Pink 'Firewitch'**	Butterflies, bees	Drought, deer, pollution	Mulch with pea stone or gravel to keep foliage clean and dry	—
Convallaria majalis	**Lily of the valley**	Bees	Deer, Heavy Shade, Erosion, Clay Soil, Dry Soil	Needs regular watering in pots	—

Table 4.15 (cont.): Herbaceous plants that have low pest promotion and disease resistance. Performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Seasonal changing
***Hosta* 'El Niño'**	**Plantain lily**	2-9	16-18	Medium	Evergreen; Bloom from July to Aug; Pale lavender flowers; pointy powder-blue leaves with streaky white margins
Hosta undulata var. undulata	**Wavy Plantain Lily**	3-8	13-17	Medium	Evergreen; Bloom from April to Sep; tubular flowers; variegated leaves with a narrow cream-colored centre and a broad green margin
Asplenium scolopendrium	**Hart's tongue fern**	5-9	12-18	Fast	Evergreen; no flowering; tongue-shaped, leathery, bright green leaves
Anemone multifida	**Anemone**	5-9	8-12	Slow	Deciduous; bloom time May to July; butter-yellow flower; fern-like, sliver-green foliage
***Anemone blanda* 'White Splendour'**	**Grecian Windflower**	4-8	4-6	Medium	Deciduous; bloom time spring; butter-daisy-like flower with greenish-yellow center and pink-tinted backs; fern-like, sliver-green foliage
Pulmonaria angustifolia	**Blue Lungwort**	2-7	9-12	Medium	Semi-evergreen; bloom time seasonal blooming spring, bright deep blue, funnel-shaped flowers; roughly hairy, ovate dark green basal leaves

Table 4.15 (cont.): Herbaceous plants that have low pest promotion and disease resistance. Performances in “increase biodiversity”, “climate tolerance”, “maintenance” and “special value”

Species name	English name	Increase biodiversity	Climate tolerance	Maintenance	Special value
***Hosta* ‘El Niño’**	**Plantain lily**	Bees	Deer	Needs regular watering in pots	—
Hosta undulata var. undulata	**Wavy Plantain Lily**	Bees	Deer, clay soil	Cut off the stems after blooming to encourage the plant's growth	—
Asplenium scolopendrium	**Hart's tongue fern**	—	Heavy shade	Require medium moisture, well-drained, alkaline to slightly acidic soils	—
Anemone multifida	**Anemone**	Bees	Heavy shade	Easily divided in fall or early spring.	—
***Anemone blanda* ‘White Splendour’**	**Grecian Windflower**	Bees	Deer, Black Walnut	Foliage may be cut back after it yellows	—
Pulmonaria angustifolia	**Blue Lungwort**	Bees	Full shade	Requires consistently moist soil	—
***Pulmonaria* ' Dark Vader'**	**Dark Vader Lungwort**	Bees and other pollinators	Full shade, deer, clay soil, Black Walnut	Cut back hard immediately after blooming	—

Table 4.15 (cont.): Herbaceous plants that have low pest promotion and disease resistance. Performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Seasonal changing
***Oxalis triangularis* 'Atropurpurea'**	**Purple and Black False Shamrock**	6-11; winter mulch in colder zones	6-12	Medium	Evergreen; Bloom time summer; white or lavender-pink flowers; deep burgundy, trifoliate leaves with the shape of little heart, triangular like butterfly wings
***Brunnera macrophylla* 'Jack Frost'**	**Jack Frost Siberian Bugloss**	3-8	10-12	Slow	Evergreen; Bloom time April to May; blue flowers; heart-shaped, dark green, basal foliage
Scilla siberica	**Siberian Squill**	2-8	3-6	Medium	Deciduous; bloom time March to April; intense blue bell-shaped nodding flowers; grassy foliage
Scilla mischtschenkoana	**White Squill**	4-8	3-6	Medium	Deciduous; bloom time seasonal-spring and winter; starry ice-blue flowers with a dark stripe through each petal
Eranthis hyemalis	**Winter Aconite**	4-9	4-6	Medium	Deciduous; bloom time March to April; cup-shaped, bright yellow flowers; Lobed, basal, green leaves emerge after the flowers
Cyclamen coum	**Persian Violet**	4-8	4-6	Medium	Deciduous; bloom time December to April; white, pink or magenta flowers; heart-shaped glossy leaves with sliver patterns
Ocimum basilicum	**Sweet basil**	2-11	12-18	Medium	Annual; bloom time June to frost; magenta flowers

Table 4.15 (cont.): Herbaceous plants that have low pest promotion and disease resistance. Performances in “increase biodiversity”, “climate tolerance”, “maintenance” and “special value”

Species name	English name	Increase biodiversity	Climate tolerance	Maintenance	Special value
***Oxalis triangularis* 'Atropurpurea'**	**Purple and Black False Shamrock**	Butterflies	Deer	Water regularly during the active growing season	—
***Brunnera macrophylla* 'Jack Frost'**	**Jack Frost Siberian Bugloss**	—	Deer, full shade	Water regularly during the hot summer	—
Scilla siberica	**Siberian Squill**	Butterflies	Deer	Well-draining soil	—
Scilla mischtschenkoana	**White Squill**	Bees	Deer, full shade		—
Eranthis hyemalis	**Winter Aconite**	—	Deer, Black Walnut	Needs consistent moisture year-round	—
Cyclamen coum	**Persian Violet**	—	Full shade	Cover the plants with mulch for over-wintering	—
Ocimum basilicum	**Sweet basil**	—	Deer	Mulch to retain moisture. Pinch out centers to encourage bushy growth.	Leaves are delicious in salads; they can be mede an insect repellent spray.

Table 4.15 (cont.): Herbaceous plants that have low pest promotion and disease resistance.

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Seasonal changing
Thymus citriodorus	**Lemon thyme**	7-9; annual in colder zones	10-12	Fast	Evergreen in zone 8-9; Bloom time summer; lavender-pink flowers; deep burgundy, trifoliate leaves with the shape of little heart, triangular like butterfly wings
Mentha balsamea	**Peppermint**	3-10	12-18	Fast	Evergreen; Bloom time summer; purple, pink or white flowers; fragrant leaves
Salvia lavandulaefolia	**Spanish Sage**	6-11	6-12	Fast	Evergreen; Bloom time May to June; blue-violet flowers; fragrant hairy leaves
Chrysanthemum multicaule	**Yellow clump daizy**	5-9	10-15	Medium	Deciduous; bloom time Aug to Oct; yellow single daisy-like flowers

Species name	English name	Increase biodiversity	Climate tolerance	Maintenance	Special value
Thymus citriodorus	**Lemon thyme**	Bees, butterflies	Drought	Mulch with limestone gravel or builder's sand to improve drainage and prevent root rot.	Leaves are eaten raw in salads or used as a fresh or dried flavoring herb in cooking and for herbal teas; essential oil
Mentha balsamea	**Peppermint**	—	—	Constantly moist soil with adequate drainage	Salads, essential oil, herb medicine
Salvia lavandulaefolia	**Spanish Sage**	—	Full sun, drought	Needs a sheltered position but usually overwinters if given full sun and good drainage. cut back the stems back to 2 inches from the ground in the late fall. Alternatively, leave them until early spring.	Essential oil, herb medicine
Chrysanthemum multicaule	**Yellow clump daizy**	Bees, butterflies	Full sun		—

Climate tolerance

Climate tolerance contains the tolerance to various soil conditions (drought, clay soil), extreme weather (heat, cold, wind), shade and urban pollution. For the first two aspects, selected plants would have broader living areas physically and require less human maintenance mostly since they can adjust to the environment and grow well by themselves. For the aspects of shade and urban pollution, selected plants may be needed to apply in specific areas such as north-facing surface (shade) or industrial area (urban pollution). Another benefit for plants with high tolerance to urban pollution is that they can be the best choice to apply in the bio-filtration living wall which is a type of vertical greening serving as a functional air filtration particularly in the heavy-polluted area. Deer eating is becoming a serious issue for urban green space especially for those which locate in the city margin or the corridor between suburban and urban. The requirement for deer resistance is becoming a common view for farmers and landscape designers. We discussed many plant species that have a good tolerance to soil conditions and extreme weather. So for this "climate tolerance" part, shade and urban pollution tolerance will be discussed in detail.

Climbers that tolerate shade:

1. ***Clematis montana* 'Van Gogh'**. It is a vigorous grower that will grow in light shade and east-facing wall (Cullina, 2002).
2. ***Hydrangea anomala* 'Petiolaris'- Climbing hydrangeas**. It is a great plant for shade (Missouri Botanical Garden, 2019h).
3. ***Pileostegia viburnoides*- Climbing hydrangeas**. It is another climbing hydrangea for shade that self-clings (RHS, 2019b).
4. ***Hedera helix*- English ivy**. Easily grown in average, medium moisture, well-drained soils in part shade to full shade (Missouri Botanical Garden, 2018d).
5. ***Hedera colchica*- Bullock's heart ivy**. It is a good plant for shade with colorful yellow-patterned leaves. These ivies are perfect for brightening up dark garden areas and adding lush greenery to bare walls (Dunnett, 2008).
6. ***Rose* 'Danse de feu'-Dance of fire**. It is a great climber for shade with dark green leaves and open pinky red flowers (RHS, 2019c).
7. ***Rose* 'Alberic Barbier'**. Very vigorous. Shade tolerant. Disease susceptibility: very disease resistant (Meyer, 1911).

8. ***Parthenocissus quinquefolia*-Virginia Creeper**. It has a high tolerance to heavy shade and is perfect to light up north-facing façade (Missouri Botanical Garden, 2017b).
9. ***Parthenocissus tricuspidata*-Boston Ivy**. It is a good climbers for shade, with big leaves to keep houses cool on hot summer days (Boltz, c1958).
10. ***Lonicera henryii*-Henry's honeysuckle**. It prefers partial shade but can tolerant full shade and full sun as long as with well-drained soil (RHS, 2018).

Figure 4.34: Left to right: *Clematis montana* 'Van Gogh'; *Hydrangea petiolaris; Pileostegia viburnoides; Hedera helix; Hedera colchica*

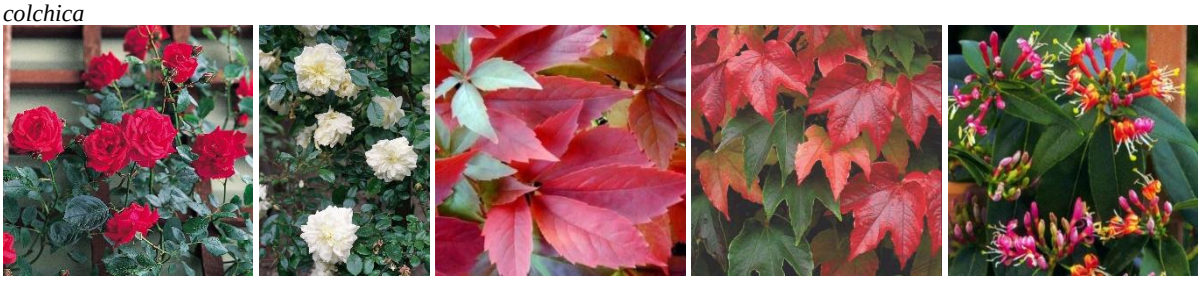

Figure 4.35: Left to right: *Rose* 'Danse de feu'; *Rose* 'Alberic Barbier'; *Parthenocissus quinquefolia; Parthenocissus tricuspidata; Lonicera henryii*

Table 4.16: Climbers that can tolerate shade and their performance in "growth rate", "coverage", "climbing type" and "seasonal changing"

Shade tolerance-Climbers

Species name	English name	USDA Zones	Climate tolerance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
***Clematis montana* 'Van Gogh'**	**Mountain clematis or Himalayan clematis**	4-9	Shade; Resistant to clematis wilt	20-40	Fsst	5	Twining leaf axles	Deciduous; Bloom from May to June; pale pink centre and rich, slightly purply red margins flower
Hydrangea petiolaris*-*Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	4-9	Heavy shade, drought	30-50	Slow to get started but grows rapidly	5	Aerial roots	Deciduous; bloom time May to June; white flower
Pileostegia viburnoides	**Climbing hydrangea**	4-9	Heavy shade, drought	12-24	Slow	5	Aerial roots	Evergreen; bloom time May to June; white flower

Table 4.16 (cont.): Climbers that can tolerate shade and their performance in "increase biodiversity", "pest promotion and other issues", "structural support", "maintenance" and "special value"

Shade tolerance-Climbers

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Structural support	Maintenance	Special value
***Clematis montana* 'Van Gogh'**	**Mountain clematis or Himalayan clematis**	Butterflies and hummingbirds	—	Sturdy trellis or arbor	Prune after flowering; regularly water during the first year	Root and stem can be used as medicine.
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	—	—	Sturdy arbors, fences or the trunks of large trees, or sprawled over low stone walls, unsightly tree stumps or rock piles	Prune after flowering	Flowers are used as bouquets.
Pileostegia viburnoides	**Climbing hydrangea**	—	—	Sturdy arbors, fences or the trunks of large trees, or sprawled over low stone walls, unsightly tree stumps or rock piles	Prune after flowering	—

Table 4.16 (cont.): Climbers that can tolerate shade and their performance in "growth rate", "coverage", "climbing type" and "seasonal changing"

Species name	English name	USDA Zones	Climate tolerance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Hedera helix	**English ivy**	5-9	Drought, Heavy Shade	60-90	Fast	5	Aerial rootlets with matted pads	Evergreen; bloom time June to Sep; greenish-yellow flower
Hedera colchica	**Bullock's heart ivy**	6-9, winter protection in colder zones	Drought, Heavy Shade, Dry Soil	30-50	Fast	5	Aerial rootlets	Evergreen; bloom time Sep to Oct; greenish-white flower
***Rose* 'Danse de feu'**	**Dance of fire**	6-9, winter protection in colder zones	Heavy shade	9-12	Medium	4	Thorny stems	Deciduous; bloom time June to Sep; orange-red flower

Table 4.16 (cont.): Climbers that can tolerate shade and their performance in “increase biodiversity”, “pest promotion and other issues”, “structural support”, “maintenance” and “special value”

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Structural support	Maintenance	Special value
Hedera helix	**English ivy**	Bees, other pollinators, birds	Mites can be significant problem. Watch for leaf spots, canker, bacterial leaf spot, stem rot and powdery mildew.	—	Prune to control size	—
Hedera colchica	**Bullock's heart ivy**	Bees, birds	Leaf spots and mites can be significant problems. Slugs and snails will sometimes hide and breed in the thick foliage.	—	Trim plants in early spring to control growth and maintain attractive appearance.	—
Rose **‘Danse de feu’**	**Dance of fire**	Bees	Aphids, rose leafhopper, glassh ouse red spider mite, scale insects,	Fences, trellises, arbors and arches	Mulch in late winter or early spring	—

Table 4.16 (cont.): Climbers that can tolerate shade and their performance in “growth rate”, “coverage”, “climbing type” and “seasonal changing”

Species name	English name	USDA Zones	Climate tolerance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Rose **‘Alberic Barbier’**	—	6-9 (winter hardy up to 5°F), winter protection in colder zones	Heavy shade	12-24	Fast	5	Thorny stems	Evergreen; bloom time May to June; cream coloured flowers with a light yellow center flower
Parthenocissus quinquefolia	**Virginia Creeper**	3-9	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Black Walnut	60-90	Fast	5	Sucker pads	Deciduous; Bloom from May to Aug; red leaves in autumn; white-green flower
Parthenocissus tricus pidata	**Boston Ivy**	4-8	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut	60-90	Fast	5	Sucker pads	Deciduous; Bloom from June to July; red-purple leaves in autumn; yellow-green flower
Lonicera henryii	**Henry's honeysuckle**	4-9; (winter hardy up to 5°F)	Shade, deer, drought	15-20	Fast	5	Twining vine	Evergreen; bloom time June to July; Subdued coral & yellow scented tubular flowers; blue berries

Table 4.16 (cont.): Climbers that can tolerate shade and their performance in "increase biodiversity", "pest promotion and other issues", "structural support", "maintenance" and "special value"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Structural support	Maintenance	Special value
***Rose* 'Alberic Barbier'**	—	Bees	Susceptible to mildew, Resistant to black spot	Fences, trellises, arbors and arches		—
Parthenocissus quinquefolia	**Virginia Creeper**	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	—	—	—
Parthenocissus tricuspidata	**Boston Ivy**	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	—	—	—
Lonicera henryii	**Henry's honeysuckle**	Birds, butterflies	May be prone to aphids; May be affected by powdery mildews	May need to be tied to the support to distribute the branches well.	Prune in late winter or early spring.	—

Herbaceous plants that tolerate shade:

1. ***Heuchera*-Coralbells**. They grow in the shade and are known for their ease. They come in a whole rainbow of colors (purple/burgundy, chartreuse/gold, gray/sliver), with some varieties grown specifically for their masses of flowers (green, red, white and pink) (Meyer, 1911).
2. ***Lamium galeobdolo*- Yellow archangel**. Vigorous ground cover that is best for dry shady areas. Grows well in shady woodland borders (Missouri Botanical Garden, 2019j).
3. ***Lamium maculatum* 'Orchid Frost'- Spotted Deed Nettle**. It's ideal to brighten shady gardens and create a dramatic backdrop for the masses of small, tubular orchid pink flowers (Paul Pilon, 2002).
4. ***Tiarella cordifolia* - Foamflower**. Foamflower is a close cousin to coral bells, another favorite shade-garden plant (Armitage, c1989.).
5. ***Athyrium niponicum Red Beauty*- Japanese Painted Fern Red Beauty**. It is equally elegant though not quite as showy. Either will add interest and texture to your shady spots (Hogan, 2003).

6. ***Mertensia virginica*- Virginia Bluebells**. Virginia bluebells grow best in part shade and moist soil. Their native habitat is moist woodland areas (Armitage, c1989.).
7. ***Pulmonaria*-Lungwort.** It prefers light shade and tolerate full shade and withstand the toxic effects of the Black Walnut tree (Avent, 2012).
8. ***Hakonechloa macra* 'Aureola' - Golden Japanese Forest Grass**. A graceful, colorful groundcover for shaded borders and container gardens (David Beaulieu, 2019a).
9. ***Primula polyantha*- Primrose**. They are suitable for use in shaded garden beds and borders as well as in containers or for naturalizing areas of the lawn (Nikki Tilley, 2019b).
10. ***Pachysandra terminalis*- Japanese Spurge**. It is an excellent ground cover for shady and problem areas as it grows in any soil and is one of the few ground covers that will grow under pine trees (Missouri Botanical Garden, 2017a).
11. ***Alchemilla mollis*- Lady's Mantle**. It is a simple Herbaceous plants that has classic beauty and would certainly add some character to a shady spot in the garden (Hogan, 2003).
12. ***Coleus blumei*** – **Coleus**. It usually performs best in areas with partial shade, though many varieties can also tolerate sun (Nikki Tilley, 2019a).
13. ***Abutilon spp*.- Flowering Maple**. A flowering maple requires partial shade outdoors and a bright room indoors. The plant may require shading from afternoon sun (Molly Allman, 2018).
14. ***Geranium Cranesbill*-Hardy Geraniums**. It does incredibly well in sunny borders and woodland setting. It prefers full sun to partial shade conditions (Gardenia, 2019d).
15. ***Heucherella* 'Sweet Tea'**. Shade is best for most heucherella varieties (Armitage, c1989.).
16. ***Hosta* 'Captain's Adventure'-Hosta**. Hosta are among the most popular of perennials for shady areas, with literally hundreds of varieties now readily available (Hogan, 2003).
17. ***Hosta* 'Popcorn'**. One of those hostas that needs a little more sun to perform well but not too much or the centers will burn.
18. ***Hosta* 'Raspberry Sundae'.**
19. ***Impatiens***. It prefers partial shade and tolerates well in full shade as long as with well-drained soil (Meyer, 1911).
20. ***Strobilanthes dyerianus*- Persian shield**. It will show more brilliant foliage with less light. The less water the Persian shield plant gets, the more shade it will need (Murrill, 1945).

Figure 4.36: Left to right: *Heuchera; Lamium galeobdolo; Lamium maculatum* ‘Orchid Frost’; *Tiarella cordifolia; Athyrium niponicum Red Beauty*

Figure 4.37: Left to right: *Mertensia virginica; Pulmonaria; Hakonechloa macra* 'Aureola'; *Primula polyantha; Pachysandra terminalis*

Figure 4.38: Left to right: *Alchemilla mollis; Coleus blumei; Abutilon spp.; Geranium Cranesbill; Heucherella* 'Sweet Tea'

Figure 4.39: Left to right: *Hosta* ‘Captain’s Adventure’; *Hosta* 'Popcorn'; *Hosta* ' Raspberry Sundae '; *Impatiens; Strobilanthes dyerianus*

Table 4.17: Herbaceous plants that can tolerate shade and their performances in "growth rate", and "seasonal changing"

Shade tolerance-Herbaceous

Species name	English name	USDA Zones	Climate tolerance	Overall size/in	Growth rate	Seasonal changing
Heuchera	**Coralbells**	3-9	Heavy shade, deer	12-20	Medium	Deciduous. Spring Bloom Fall Bloom Summer Bloom Colorful Fall Foliage Winter Interest; Green, Red, White, Pink flowers, purple, gold, sliver foliage retained in winter
Lamium galeobdolo	**Yellow archangel**	4-9	Deer, Drought, Heavy Shade, Erosion, Dry Soil, Shallow-Rocky Soil, Air Pollution	9-15	Fast	Deciduous. Bloom time June; Yellow, flecked brown flowers, variegated with silver-gray markings
***Lamium maculatum* 'Orchid Frost'**	**Spotted Deed Nettle**	4-8	Heavy shade, deer, urban pollution	4-6	Fast	Deciduous. Bloom time April to June; orchid-pink flowers; Scalloped blue-green margins and shimmering silvery centers
Tiarella cordifolia	**Foamflower**	3-9	Heavy shade, deer	6-12	Medium	Deciduous. Bloom time spring; white-pink flowers; colorful fall foliage
Athyrium niponicum Red Beauty	**Japanese Painted Fern Red Beauty**	4-9	Heavy shade, deer	12-18	Medium	Evergreen; silver-tinged green fronds that sport deep-burgundy stems and veins
Mertensia virginica	**Virginia Bluebells**	3-9	Heavy shade, deer	10-18	Medium	Deciduous. Bloom time March to July; pink buds that later mature into lavender-blue flowers
Pulmonaria	**Lungwort**	3-9	Heavy shade, deer, urban pollution, black walnut	12-14	Medium	Evergreen; Bloom time April to May; blue, deep-purple bells flowers; hairy dark-green leaves are heavily spotted in silver

Table 4.17 (cont.): Herbaceous plants that can tolerate shade and their performances in “increase biodiversity”, “pest promotion and other issues”, “maintenance” and “special value”

Shade tolerance-Herbaceous

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Maintenance	Special value
Heuchera	**Coralbells**	Butterflies, hummingbirds, birds	—	Remove stems of faded flowers to encourage additional bloom.	—
Lamium galeobdolo	**Yellow archangel**	—	Slugs and snails are occasional visitors. Leaf blight. Mites. Can spread invasively.	If plants become leggy, shear back to 4-6” or to new fresh basal leaves in order to shape plants and to promote new foliage growth.	—
Lamium maculatum **‘Orchid Frost’**	**Spotted Deed Nettle**	Butterflies	—	They may be trimmed to shape growth or cut back if desired; Water regularly to maintain evenly moist soil	—
Tiarella cordifolia	**Foamflower**	Birds	—	Prefer well-drained soil with consistent moisture	—
Athyrium niponicum Red Beauty	**Japanese Painted Fern Red Beauty**	—	—	Mulch the plants to maintain consistent soil moisture.	—
Mertensia virginica	**Virginia Bluebells**	Hummingbirds, bees	—	Water plants regularly during the first year after planting	—
Pulmonaria	**Lungwort**	Bees and other pollinators	—	Cut back hard immediately after blooming	Some can be used as herb medicine.

Table 4.17 (cont.): Herbaceous plants that can tolerate shade and their performances in "growth rate", and "seasonal changing"

Species name	English name	USDA Zones	Climate tolerance	Overall size/in	Growth rate	Seasonal changing
***Hakonechloa macra* 'Aureola'**	**Golden Japanese Forest Grass**	4-9	Shade, deer, urban pollution	12-18	Slow	Evergreen; bloom time from July to Aug, yellow-green flowers; Slender stems holding bright yellow leaves with thin green stripes
Primula polyantha	**Primrose**	2-8	Shade, deer	6-12	Medium	Deciduous. Bloom time spring; Blue Green Red Orange White Pink Yellow flowers; blue/green foliage
Pachysandra terminalis	**Japanese Spurge**	3-10	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil	4-12	Slow	Evergreen. Bloom time March to April; White flowers
Alchemilla mollis	**Lady's mantle**	3-8	Shade, deer, drought	10-12	Fast	Deciduous. Bloom time June to Sep; Yellow flowers; fuzzy, cup-like leaves
Coleus blumei	**Coleus**	3-9	Heavy shade, deer	6-12	Fast	Evergreen. Bloom time summer; White flowers; colored foliage—in combinations of green, yellow, pink, red, maroon, etc.
Abutilon spp.	**Flowering Maple**	8-11, annual in colder zones	Shade	6-12	Fast	Evergreen. Bloom time June to Oct; orange-red flowers; maple-like leaves
Geranium Cranesbill	**Hardy Geraniums**	3-9	Shade, deer, drought	15-18	Medium	Deciduous. Bloom time May to Sep; blue-purple blooms; bright orange to red color foliage
***Heucherella* 'Sweet Tea'**	**—**	4-9	Drought, Heat, Humidity, shade, deer	12-20	Medium	Evergreen. Bloom time spring; white flowers; Bronze, Brown, Burgundy, Copper, Gold, Orange, Red, Rose, Variegated foliage

Table 4.17 (cont.): Herbaceous plants that can tolerate shade and their performances in "increase biodiversity", "pest promotion and other issues", "maintenance" and "special value"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Maintenance	Special value
***Hakonechloa macra* 'Aureola'**	**Golden Japanese Forest Grass**	—	—	Water regularly to maintain evenly moist soil	—
Primula polyantha	**Primrose**	Hummingbirds, butterflies, bees, birds	—	Prefer consistent moisture, well-drained soil is a must	—
Pachysandra terminalis	**Japanese Spurge**	—	Leaf blight; Root/stem rot may also occur. Watch for scale and mites.	—	—
Alchemilla mollis	**Lady's mantle**	—	—	Require supplemental water in high heat or full sun areas to prevent leaves from turning brown	Used in making lotions and soaps
Coleus blumei	**Coleus**	—	—	Keep the soil evenly moist, but never soggy.	—
Abutilon spp.	**Flowering Maple**	—	Watch out for whiteflies and scale insects	Keep the soil evenly moist, but never soggy.	—
Geranium Cranesbill	**Hardy Geraniums**	Butterflies, hummingbirds	—	Moist but well-drained soil	—
***Heucherella* 'Sweet Tea'**	**—**	Butterflies	—	Well-drained soil is critical	—

Table 4.17 (cont.): Herbaceous plants that can tolerate shade and their performances in "growth rate", and "seasonal changing"

Species name	English name	USDA Zones	Climate tolerance	Overall size/in	Growth rate	Seasonal changing
***Hosta* 'Captain's Adventure'**	**Hosta**	2-9	Heavy shade, drought, urban pollution	14-16	Medium	Evergreen. Bloom time spring; Mauve/Lilac flowers; Chartreuse, Deep Green, White foliage
***Hosta* 'Popcorn'**	**Hosta**	3-9	Heavy shade, drought, urban pollution	10-12	Medium	Evergreen. Bloom time July; Pale lavender flowers; bright yellow with a nice blue margin foliage
***Hosta* 'Raspberry Sundae'**	**Hosta**	3-9	Heavy shade	10-20	Medium	Evergreen. Bloom time Aug to Sep; lavender-purple flowers; Creamy yellow leaves that turn white quickly, the red of the petioles goes into the white center of the leaf
Impatiens	**Busy Lizzie**	10-11, annual in colder zones	Shade	6-18	Medium	Deciduous. Bloom time May to Sep; Orange, Pink, Purple, Red, White, Yellow blooms
Strobilanthes dyerianus	**Persian shield**	8-11; annual in cooler regions	Heavy shade	12-24	Medium	Deciduous. Bloom time Sep to Oct; cone-shaped blue flowers; neon shades of purple, veined with green foliage

Table 4.17 (cont.): Herbaceous plants that can tolerate shade and their performances in “increase biodiversity”, “pest promotion and other issues”, “maintenance” and “special value”

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Maintenance	Special value
***Hosta* ‘Captain’s Adventure’**	**Hosta**	Hummingbirds	Slugs and snails are attracted to the foliage.		—
***Hosta* 'Popcorn'**	**Hosta**	Hummingbirds	—	Cleaned up in early spring before it resumes active growth for the season.	—
***Hosta* 'Raspberry Sundae'**	**Hosta**	Hummingbirds	—	Humus-rich, moist but well-drained soil.	—
Impatiens	**Busy Lizzie**	Birds	Watch out for Spider mites Impatiens Downy Mildew (IDM)	Humus-rich, moist but well-drained soil.	—
Strobilanthes dyerianus	**Persian shield**	—	—	Prune it after blooming to keep compact foliage	—

Climbers that tolerate urban pollution:

All the resources about plant characters mainly come from the following published websites: 1) Missouri Botanical Garden (plantfinder), 2) Plantfile, 3) North Carolina Extension Gardener, 4) RHS, 5) Gardenia, 6) Better Homes Gardens, and 7) Perennials.com, together with some published articles and books.


Figure 4.40: Left to right: Hedera helix; Cistus 'Jessamy Beauty'; Ipomoea palmata


Figure 4.41: Left to right: Ipomoea purpurea; Antigonon leptopus; Lonicera heckrottii

Table 4.18: Climbers that can tolerate urban pollution and their performances in "growth rate", "good coverage", "climbing type" and "seasonal changing"

Urban pollution tolerance-Climbers

Species name	English name	USDA Zones	Climate tolerance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Hedera helix	**English ivy**	4-9	Urban dust, Drought, Heavy Shade	20-80	Fast	5	Stems with adventitious roots	Evergreen. Bloom time Sep to Oct; Greenish white flowers followed by blue-black berries
***Cistus* 'Jessamy Beauty'**	**Rockrose 'Jessamy Beauty'**	6-11 (to 5 °F)	Deer, poor soil, urban pollution	3-6	Fast	4	Twining stem	Evergreen. Bloom time June to July; pink flowers
Ipomoea palmata	**Mile-a-minute Vine**	2-11	Urban dust, Drought, Heavy Shade	8-10	Fast	5	Twining stem	Evergreen. Bloom time seasonal ; lavender flowers with a darker purple centre
Ipomoea purpurea	**Morning Glory**	2-11	Full sun, deer, urban pollution	6-10	Fast	5	Twining stems	Deciduous; Bloom from June to Oct; purple with white throat flower;
Antigonon leptopus	**Coral vine**	8-11, annual in colder zones	Drought, urban pollution	8-10	Fast	5	Tendril-climbing	Deciduous (evergreen in 9-11 zones); seasonal bloomer; pink to white flowers
Lonicera heckrottii	**Flame Honeysuckle**	5-9	Deer, Urban pollution, Black Walnut,	10-15	Fast	5	Twining vine	Deciduous; Bloom from June to August; rose pink with yellow interior flowers

Table 4.18 (cont.): Climbers that can tolerate urban pollution and their performances in “increase biodiversity”, “pest promotion and other issues”, “structural support”, “maintenance” and “special value”

Urban pollution tolerance-Climbers

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Structural support	Maintenance	Special value
Hedera helix	**English ivy**	Birds	Aphids, mealybugs, caterpillars, loopers and scale may appear. Watch for leaf spots, canker, bacterial leaf spot, stem rot and powdery mildew.	Fences, trellises or walls	—	—
***Cistus* ‘Jessamy Beauty’**	**Rockrose 'Jessamy Beauty'**	—	—	Fences, trellises, arbors and arches	Needs a sheltered position in full sun	—
Ipomoea palmata	**Mile-a-minute Vine**	Butterflies and hummingbirds	—	Fences, trellises, arbors and arches	—	Can be used as medicine
Ipomoea purpurea	**Morning Glory**	Butterflies and hummingbirds	—	Trellis, fence or arbor	—	—
Antigonon leptopus	**Coral vine**	—	—	Trellises, arbors or fences	Prune annually in late winter to early spring to remove frost damaged foliage and to maintain desired size	—
Lonicera heckrottii	**Flame Honeysuckle**	Hummingbirds, Butterflies	Powdery mildew and leaf spots may occur.	Trellises or espaliers; fences	Needs good air circulation	—

Herbaceous plants that tolerate urban pollution:

For these Herbaceous plants, they can not only tolerate polluted air and urban dust, but also can absorb these contaminate particles in the atmosphere and purify the environment. They can be used largely in the bio-filtration living wall system.

Figure 4.42: Left to right: *Bergenia cordifolia; Geranium endressii; Helleborus niger; Hosta; Lamium maculatum* 'White Nancy'

Figure 4.43: Left to right: *Lamium maculatum Aureum; Lamium Shell Pink; Pulmonaria; Chlorophytum comosum; Chrysanthemum morifolium*

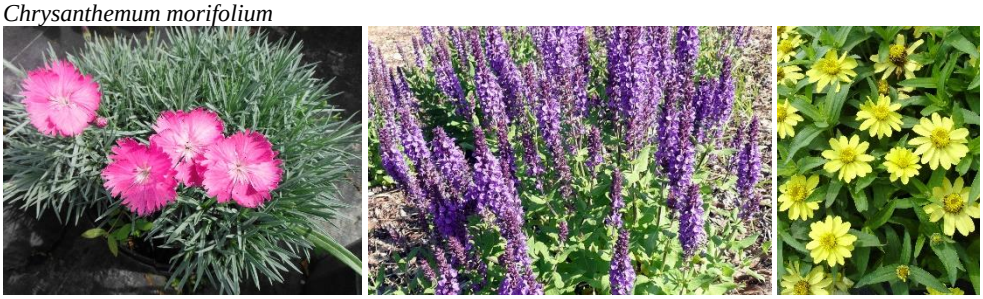

Figure 4.44: Left to right: *Dianthus gratianopolitanus* 'Firewitch'; *Salvia nemorosa* 'New Dimension'; *Zahara™ Zinnia*

Table 4.19: Herbaceous plants that can tolerate urban pollution and their performances in "growth rate" and "seasonal changing"

Pollution tolerance-Herbaceous

Species name	English name	USDA Zones	Climate tolerance	Overall size/in	Growth rate	Seasonal changing
Bergenia cordifolia	**Pigsqueak**	3-8	Deer, Drought, Heavy Shade, Erosion, Dry Soil, urban pollution	12-18	Medium	Deciduous; Bloom from April to May; deep-pink flower; heart-shaped leaves
Geranium endressii	**Cranesbill Geranium**	3-9	Shade, polluted air, clay soil	12-20	Medium	Semi-evergreen; Bloom from April to Aug; deep-pink flower; heart-shaped leaves
Helleborus niger	**Black hellebore**	3-8	Deer, Dry Soil, polluted air, full shade	8-12	Slow	Evergreen; Bloom from Feb to March; White fading to blush pink with yellow stamens flowers
Hosta	**—**	3-9	Heavy shade, drought, urban pollution	6-12	Medium	Evergreen. Bloom time summer; purple, white flowers; blue/green, chartreuse/gold foliage
Lamium maculatum **'White Nancy'**	**Spotted Dead Nettle**	3-8	Heavy shade, deer, urban pollution	6-8	Fast	Evergreen. Bloom time May to June; white flowers; silvery leaves with narrow green margins

Table 4.19 (cont.): Herbaceous plants that can tolerate urban pollution and their performances in “increase biodiversity”, “pest promotion and other issues”, “maintenance” and “special value”

Pollution tolerance-Herbaceous

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Maintenance	Special value
Bergenia cordifolia	**Pigsqueak**	Butterflies	—	Prompt remove spent flowering stems	—
Geranium endressii	**Cranesbill Geranium**	—	—	Cut back hard in midsummer to encourage fresh new foliage	—
Helleborus niger	**Black hellebore**	—	Crown rot and leaf spot are occasional problems. Watch for aphids and slugs.	Protect them from cold winter winds; remove faded flowers stem to promote new growth	—
Hosta	**—**	Butterflies, hummingbirds	—	Easy care and low maintenance	—
Lamium maculatum 'White Nancy'	**Spotted Dead Nettle**	Butterflies	—	Shear back to 4 to 6" if it gets leggy or cut back to new leaves at base of plant in midsummer	—

Table 4.19 (cont.): Herbaceous plants that can tolerate urban pollution and their performances in “growth rate” and “seasonal changing”

Species name	English name	USDA Zones	Climate tolerance	Overall size/in	Growth rate	Seasonal changing
Lamium maculatum A ureum	**Spotted Dead Nettle**	3-9	Heavy shade, deer, urban pollution, dry soil	6-8	Fast	Evergreen. Bloom time May to June; rose purple flowers; Citrus yellow leaves with a white slash down the center of each leaf
Lamium Shell Pink	**Spotted Dead Nettle**	3-8	Heavy shade, deer, urban pollution, clay soil	10-12	Fast	Evergreen. Bloom time April to July; snapdragon-like, pink flowers; heart-shaped green leaves with a white stripe down the middle

Table 4.19 (cont.): Herbaceous plants that can tolerate urban pollution and their performances in "increase biodiversity", "pest promotion and other issues", "maintenance" and "special value"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Maintenance	Special value
Lamium maculatum A ureum	**Spotted Dead Nettle**	Butterflies	—	Shear back to 4 to 6" if it gets leggy or cut back to new leaves at base of plant in midsummer	—
Lamium Shell Pink	**Spotted Dead Nettle**	Butterflies	—	Shear back to 4 to 6" if it gets leggy or cut back to new leaves at base of plant in midsummer	—

Table 4.19 (cont.): Herbaceous plants that can tolerate urban pollution and their performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Climate tolerance	Overall size/in	Growth rate	Seasonal changing
Pulmonaria	**Lungwort**	4-8	Heavy shade, deer, urban pollution, black walnut	10-14	Medium	Evergreen; Bloom time April to May; blue, deep-purple bells flowers; hairy dark-green leaves are heavily spotted in silver
Chlorophytum comosum	**Spider Plant**	usually used indoor, winter mulch when below 50 °F	Shade, deer, urban pollution	6-12	Fast	Evergreen; Bloom time spring, fall, winter; white flowers; blue/green foliage a white stripe down the middle
Chrysanthemum morifolium	**Florist's Chrysanthemum**	5-9	Deer, urban pollution	12-20	Slow	Deciduous; Bloom from April to May; lavender, white, yellow, red, orange flower
Dianthus gratianopolitanus **'Firewitch'**	**Cheddar Pink 'Firewitch'**	3-9	Drought, deer, pollution	6-8	Slow	Evergreen; Bloom from April to Sep; purplish-pink flowers; blue-gray, sliver foliage
Salvia nemorosa **'New Dimension'**	**Sage**	5-8	Deer, Drought, Dry Soil, Air Pollution	8-10	Medium	Deciduous. Bloom from June to Sep, violet-blue flowers
Zahara™ Zinnia	**Zinnia marylandica Zahara™ Series Patented**	2-11; 2-9 annual, 10-11 perennial	Highly mildew resistant; urban polution; well-draining soil; Full sun	12-18	Medium	Deciduous; bloom time from March to July; muticolored flowers

Table 4.19 (cont.): Herbaceous plants that can tolerate urban pollution and their performances in “increase biodiversity”, “pest promotion and other issues”, “maintenance” and “special value”

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Maintenance	Special value
Pulmonaria	**Lungwort**	Bees and other pollinators	—	Cut back hard immediately after blooming	Some can be used as herb medicine.
Chlorophytum comosum	**Spider Plant**	—	Watch our for aphids, mealybugs, whiteflies, and spider mites	Provide them with ample water and food, and within two years; well-drained soil	—
Chrysanthemum morifolium	**Florist’s Chrysanthemum**	Bees and other pollinators	—	Water the plant deeply, and then water regularly throughout the season.	People use the flowers to make medicine; ideal for cut flower bonquets
Dianthus gratianopolitanus **'Firewitch'**	**Cheddar Pink 'Firewitch'**	Butterflies, bees	—	Mulch with pea stone or gravel to keep foliage clean and dry	—
Salvia nemorosa **‘New Dimension’**	**Sage**	Butterflies, bees, hummingbirds	Some susceptibility to powdery mildew, leaf spot and rust.	—	—
Zahara™ Zinnia	**Zinnia marylandica Zahara™ Series Patented**	Butterflies	—	Occasional watering; Trim off the flower heads after they fade to encourage more blooms	—

Overall weight when mature

When considering the overall weight, think about what kinds of structural support should provide for the climbers growing. Some climbers such as Wisteria sinensis are extremely woody when mature so they require sturdy support, galvanized or powder-coated steel, painted or treated wood for example. While other climbers such as Rosa don’t necessarily require as strong of a support. Wicker and lightly wood can support them well. We need fully take the overall weight into consideration when we plant climbers, or the structural support for vertical greening will collapse suddenly one day. For green roof and balcony garden, they need a delicate calculation before planting landscape and the support is not only decided by the plants, but also the weight of soil, drainage pipe and human’s weight, which is quite an elaborate calculation. In this research, we mainly focus on structural supports for green façade.

The first thing we should keep in mind is that choose supports that are sturdy enough for the vines. Supports should be made of weatherproof materials (such as galvanized or powder-coated steel, painted or treated wood), especially if climbers are perennial vines or woody vines. Secondly, think about whether we need a support to be a decorative garden feature, or if the support's only job is to show off the plant. Decorative plant supports can serve as interesting focal points in the garden (arbors marking an entryway, an obelisk marking the end of a pathway), or can provide a sense of enclosure by screening views and/or delineating boundaries (fences, trellis panels, walls, pergolas). Lastly, think about what kinds of plants should be grown. A climbing rose, for example, requires to be tied up with wires, different type of support than a sweet pea (self-twining). There are seven commonly used structural supports for green façade.

Arches: They could be various styles and scales and should be compatible with proposed green façade. These structures are most often made of wood, which can be painted or stained to resist the elements. Steel and plastic versions are also available, and are a better choice if the climbers are extremely heavy.

Flat trellises: These are often used to define a space or provide a sense of privacy. They may be freestanding or can be anchored to a wall or posts. Sometimes permanently located, they are also relatively easy to move if people want to try out different effects. Examples of flat trellises would be wood lattice panels, metal trellises of various kinds, and those made of plastic mesh.

Obelisks, tripods and teepees: It’s more decorative than functional. It provides a three-dimensional erected plant landscape, like exclamation points. They're most effective when not overused. Make sure the structure is tall enough to support the type of plants to grow. Normally, this structural should be at least 8-10 feet tall to support most climbers. Bamboo canes make inexpensive and attractive teepees for the vegetable garden.

Cages and ladders: Vegetable supports should be sturdy and made of durable materials, and tall enough for the plants they'll support. Choices include a traditional cage, a tower, a teepee, or a ladder. It also provides a three-dimensional final appearance. Tomato vines or cucumber, for example, could perform well on this structure.


Figure 4.45: Left to right: Arches; Flat trellises; Obelisks, tripods and teepees; Cages and ladders.

Fencing and porches: Climbers are ideal to cover the rusty fences or porches as long as they have a good coverage or eye-catching seasonal changing. Climbing roses look beautiful draped over a post-and-rail fence. When they get a little help from strings or plastic netting, sweet peas look terrific growing against a picket fence. Porch railings and banisters can be wrapped with plastic trellis netting.

Walls: This is the simplest vertical support since this is how green façades came into being—a combination with green and walls. For climbers that only need a wall as a support, they are mostly self-climbing plants with aerial roots or sucker pads. These climbers are easy to maintenance relatively. Clinging plants like Boston ivy, can attach themselves to almost any wall with no other support necessary.

Twiggy branches: They are also called "pea sticks" because they are ideal for supporting sweet peas. Collect some branches about 3 to 5 feet in length, and then simply push them into the soil. The tinier twigs, the better. Branches from shrubs often work better than trees. They're cheap (even free) and are also quick to install, almost invisible when covered with vines, and can be composted at year's end.


Figure 4.46: Left to right: Fencing and porches; Walls; Twiggy branches. Image sources: The Enduring Gardener

Climbers here are all mentioned in the previous part. I just reclassified them into three categories: 1) need sturdy structural support (such as galvanized or powder-coated steel, painted or treated wood), 2) need non-sturdy structural support (such as wire and bamboo), and 3) no need for structural support (plants can grow directly against a wall).

Climbers that need sturdy structural supports:

Table 4.20: Climbers that need sturdy structural supports and their performances in "growth rate", "good coverage", "climbing type" and "seasonal changing"

Sturdy structural support								
Species name	English name	USDA Zones	Structural support	Overall size/ft	Growth rate	Coverage overall score (1-5)	Climbing type	Seasonal changing
Campsis radicans	**Trumpet Vine**	4-9	Sturdy trellises, fences or arbors (using structural supports if want to protect the façade)	20-40	Fast	5	Aerial rootlets	Deciduous; bloom time July; red and orange flower
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	4-9	Sturdy arbors, fences or the trunks of large trees, unsightly tree stumps or rock piles (using structural supports if want to protect the façade)	30-50	Fast	5	Aerial roots	Deciduous; bloom time May to June; white flower
Fallopia baldschuanica (Polygonum)	**Russian Vine**	4-7	unsightly fences and other garden structures	25-40	Fast	5	Stems climbing by rhizomes	Deciduous; Bloom from July to frost; White flower
Actinidia	**The Chinese Gooseberry or Kiwi vine**	4-8	Strong structures such as a robust pergola or well supported trellis framework	8-shrubs; 30-climbers	Fast	5	Hardy twining climbers	Deciduous; Bloom in late summer; white-yellow flower; leaves turn to pink-white when getting old
Wisteria sinensis	**Chinese wisteria**	5-9	Sturdy arbor, pergola, trellise, fence	60-90	Medium	5	Twisting stems	Deciduous; bloom time May to June; blue drooping clusters of flower
***Clematis* 'Bill MacKenzie'**	**Clematis alpina 'Frankie'**	5-9	Tall fences, arbors or unsightly buildings	6-8	Fast	4	Twining leaf-stalks	Deciduous; bloom time June to November; yellow flowers;
Clematis paniculata	**Sweet Autumn clematis**	4-9	Sturdy arbors, pergolas, trellises, walls, and fences	20-30	Fast	5	Twining leaf stalks	Deciduous; Bloom from June to Sep; creamy-white flowers, delightful fragrance
Clematis montana	**Anemone Clematis**	5-9	Sturdy trellis or arbor	20-40	Fast	5	Twining leaf axles	Deciduous; Bloom from May to June; white flower and many golden stamens
Clematis virginiana	**Woodbine**	3-8	Sturdy trellises, arbors, or posts	12-20	Fast	5	Twining leaf stalks	Deciduous; Bloom from Aug to Oct; white flowers
***Clematis lanuginosa* 'Candida'**	**Clematis 'Candida'**	4-8	Strong trellis, fence, arbor, porch, lamppost or other stationary structure	8-12	Fast	5	Twining leaf stalks	Deciduous; Bloom from May to Sep; white color flowers
Akebia quinate	**Chocolate vine**	4-8	Canes or sturdy trellis	20-40	Fast	4	Twining stems	Evergreen; Bloom from March to April; chocolate-purple flower

Table 4.20 (cont.): Climbers that need sturdy structural supports and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "maintenance" and "special value"

Sturdy structural support

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance	Special value
Campsis radicans	**Trumpet Vine**	Hummingbirds	—	Heat, cold, drought, deer, clay soil	Prune in late winter to early spring	—
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	—	—	Heavy shade, drought	Prune after flowering	Flowers are used as bouquets.
Fallopia baldschuanica (Polygonum)	**Russian Vine**	Attract birds	Better grow on its own or smother other plants; Watch for Japanese beetle and leaf miners	Drought, deer, heavy shade	—	—
Actinidia	**The Chinese Gooseberry or Kiwi vine**	Bees, butterflies and/or birds	—	Easily get frost damage	Training and pruning are necessary	Furry fruit with a high consentration of Vitamin C.
Wisteria sinensis	**Chinese wisteria**	Butterflies, bees	Invasive plants	Drought; deer	Regular prunning to control size and shape of plants to promote flowering; water weekly	—
Clematis 'Bill MacKenzie'	**Clematis alpina 'Frankie'**	Hummingbirds, Butterflies	Aphids. Watch for thorns	Deer	Hard pruning in late winter or early spring	
Clematis paniculata	**Sweet Autumn clematis**	Butterflies, hummingbirds, bees	—	Deer	Hard prune in late winter or early spring, cut back immediately after bloom	—
Clematis montana	**Anemone Clematis**	Butterflies and hummingbirds	—	Shade; Resistant to clematis wilt	Prune after flowering; regularly water during the first year; mulch to keep soil cool	Root and stem can be used as medicine.
Clematis virginiana	**Woodbine**	Birds	Clematis wilt is a potentially fatal fungal disease.	Deer, Black Walnut	Prune hard in fall after flowering or in early spring.	—
Clematis lanuginosa 'Candida'	**Clematis 'Candida'**	Hummingbirds	Susceptible to wilt/stem rot (can be fatal), powdery mildew, leaf spots, rust and viruses.	Deer, Black Walnut	—	—
Akebia quinate	**Chocolate vine**	—	—	Deer, Heavy Shade, Erosion	Prune as needed in late spring after flowers appear. May be cut to the ground to renovate	Fruits are edible.

Climbers that need non-sturdy structural supports:

Table 4.21: Climbers that need non-sturdy structural supports and their performances in “growth rate”, “good coverage”, “climbing type” and “seasonal changing”

Non-sturdy structural support								
Species name	**English name**	**USDA Zones**	**Structural support**	**Overall size/ft**	**Growth rate**	**Coverage overall score (1-5)**	**Climbing type**	**Seasonal changing**
Passiflora incarnata	**Wild passion flower**	5-9	Trellises, arbors, walls or fences.	6-8	Fast	4	Root suckers and tendrills	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature
Passiflora caerulea	**Passion Flower**	7-9	Trellis, pergola and beams	30-45	Fast	4	Leaf tendrils	Evergreen; Bloom from March to April; blue-white flower
Bignonia capreolata **'Tangerine Beauty'**	**Cross-vine**	5-9, apply winter mulch in zone 5	Fences, arbors, walls, pillars, large trellises and other structures	20-30	Fast	5	Branched tendrils with adhesive disks	Deciduous; Bloom from May to June; tangerine color flowers, reddish-purple foliage in fall
Lonicera heckrottii	**Flame Honeysuckle**	5-9	Trellises or espaliers; fences	10-15	Fast	5	Twining vine	Deciduous; Bloom from June to August; rose pink with yellow interior flowers
Lonicera sempervirens	**Trumpet honeysuckle**	4-9	Trellises, arbors, or fences.	8-15	Fast	5	Twining vine	Semi-evergreen; Bloom from May to June; Scarlet/orange with yellow inside flower
Rosa **‘Zephirine Drouhin’**	**Zephirine Drouhin' Climbing Rose**	5-9	Trellises or arbors; fences	15-20	Fast	5	Thornless twining stems	Deciduous; Bloom from June to Oct; pink flowers with fragrance
Rosa **‘Strawberry Hill’**	**English rose**	5-10	Trellises or arbors; fences	3-4	Fast	5	Thorny twining stems	Deciduous; Bloom from April to frost; pink with yellow stamen at the center flowers with fragrance
Rosa **‘Paul’s Himalayan Musk’**	**Hybrid Musk Rose**	4-9	Fences, trellises, arbors and arches	20-30	Fast	5	Twining stems	Deciduous; bloom time May to June; pink-white flower
Rosa **‘Chevy Chase’**	**—**	5-9	Need to be tied as near horizontal as possible on to wires, trellis or similar	9-15	Slow	4	Twining stems	Deciduous; bloom time June to Sep; red flower
Rosa **'Dortmund'**	**Kordesii rose**	4-10	Walls, arbors, trellises, along fences or around pillars	6-10	Fast	5	Thorny stem	Deciduous; bloom time May to frost, scarlet with white eyes flowers
Phaseolus coccineus	**Scarlet runner bean**	7-11, serve as annual in colder zones	Sunny porch or split rail fence, or train on tripods, trellises or pergolas	8-12	Medium	5	Twining vine	Deciduous; Bloom from June to Oct; red flowers

Table 4.21 (cont.): Climbers that need non-sturdy structural supports and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance”, “maintenance” and “special value”

Non-sturdy structural support

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance	Special value
Passiflora incarnata	**Wild passion flower**	Butterflies, bees, birds	Roots can spread aggressively. Root rot can occur in wet, poorly-drained soils, particularly in winter.	Drought	Prune to control it growing	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.
Passiflora caerulea	**Passion Flower**	Butterflies	A few aphids outdoor; Indoor or conservatory grown plants can be infested with whitefly, scale insects and red spider mite.	Not lower than 10 °F; Drought	Regular pruning to avoid compact branches and allow more flowers	Flowers can make tea; plant can make medicine.
Bignonia capreolata **'Tangerine Beauty'**	**Cross-vine**	Hummingbirds	—	Heavy Shade	Prune after flowering if needed.	—
Lonicera heckrottii	**Flame Honeysuckle**	Hummingbirds, Butterflies	Powdery mildew and leaf spots may occur.	Deer, Black Walnut, needs good air circulation	—	—
Lonicera sempervirens	**Trumpet honeysuckle**	Birds, Hummingbirds, Butterflies	—	Deer, Clay Soil, Black Walnut	Prune as needed immediately after flowering.	—
Rosa **‘Zephirine Drouhin’**	**Zephirine Drouhin' Climbing Rose**	Butterflies	—	Full sun, well-drained; poor soil	Remove spent flowers to encourage rebloom. Prune as needed in late winter to early spring.	Flowers can be made fragrance.
Rosa **‘Strawberry Hill’**	**English rose**	Butterflies	—	Full sun	—	Flowers can be made fragrance.
Rosa **‘Paul’s Himalayan Musk’**	**Hybrid Musk Rose**	Butterflies	Watch for thorny stems	Full sun	Prune after flowering	Flowers can make perfume oil
Rosa **‘Chevy Chase’**	**—**	Bees	Watch for thorny stems	Full sun	Pruning needed for newly planted rose; prune in October or November again	Flowers can make perfume oil
Rosa **'Dortmund'**	**Kordesii rose**	Butterflies	Disease: Black spot, powdery mildew, rust and rose rosette; Pest: aphids, beetles, borers, scale, thrips, rose midges, leafhoppers and spider mites	Full sun; poor soil	Water deeply and regularly (mornings are best); no pruning in the first two years	Flowers can be made fragrance.
Phaseolus coccineus	**Scarlet runner bean**	Hummingbirds, butterflies, birds and bees	Mosaic viral disease, bacterial blight, and anthracnose may appear.	—	Pick beans when ripe to encourage new flowers	Produce beans as vegetables

Table 4.21 (cont.): Climbers that need non-sturdy structural supports and their performances in "growth rate", "good coverage", "climbing type" and "seasonal changing"

Species name	English name	USDA Zones	Structural support	Overall size/ft	Growth rate	Coverage overall score (1-5)	Climbing type	Seasonal changing
***Clematis* 'Hagley Hybrid'**	**Large-Flowered Clematis 'Hagley Hybrid'**	4-11	Trellises, arbors, walls or fences.	7-10	Fast	5	Twisting petioles	Deciduous; bloom time June to Sep; shell pink flowers with a touch of lavender flowers with deep-red anthers
Clematis viticella	**Etoile Violette Clematis**	4-9	Arbor, fence, or trellis, or allow to climb through shrubbery	10-15	Fast	5	Twining stems	Deciduous; Bloom from July to Sep; violet-purple flowers
Clematis terniflora	**Sweet autumn clematis**	4-9	Trellises, arbors, posts, fences	15-30	Fast	5	Twining vine	Deciduous; Bloom from Aug to Sep; white flowers
***Clematis* 'Frances Rivis'**	**Clematis alpina or Old Man's Beard**	3-9	Trellises, arbors, posts, fences	6-8	Fast	5	Twining leaf-stalks	Deciduous; Bloom time April to May; blue flower
***Clematis* 'Bill MacKenzie'**	**Clematis alpina 'Frankie'**	5-9	Tall fences, arbors or unsightly buildings	6-8	Fast	4	Twining leaf-stalks	Deciduous; bloom time June to November; yellow flowers;
***Clematis* 'Alba Luxurians'**	**Clematis viticella 'Alba Luxurians'**	3-9	Structure support for climbing. No structure support serve as cascading groundcover	8-12	Fast	5	Twining leaf-stalks	Deciduous; bloom time July to Sep; white flower
Lathyrus grandiflorus	**two-flowered Everlasting pea**	3-8	Arbors, trellises, along fences or around pillars	5-6	Fast	5	Branched tendrils	Deciduous; Bloom from June to Aug; magenta-pink, purple-red flower;
Antigonon leptopus	**Coral vine**	8-11, annual in colder zones	Trellises, arbors or fences	8-10	Fast	5	Tendril-climbing	Deciduous (evergreen in 9-11 zones); seasonal bloomer; pink to white flowers
Jasminum mesnyi	**Chinese jasmine**	8-10, annual in colder zones	Trellises, arbors or fences	5-10	Medium	5	Twining stems	Deciduous (evergreen in 8-10 zones); seasonal bloomer spring and winter; yellow flowers
Jasminum officinale	**Summer Jasmine; Common Jasmine**	7-10	Trellis, pergola and beams	15-30	Fast grower	5	Climbing stems	Semi-evergreen or deciduous; Seasonal bloom; white-yellow flower
Trachelospermum jasminoides	**Confederate jasmine**	8-10	Fences, trellises, arbors and arches	3-6	Fast	4	Twining stems	Evergreen; bloom time May to June; yellow-green flower; willowy green stems in the late winter
Wisteria frutescens	**American wisteria**	5-9	Freestanding arbors, pergolas, posts, trellises, fences or terrace walls.	15-30	Fast; Produce flowers second or third year after planting	5	Twining vine	Deciduous; bloom time April to May; lilac-purple flowers
Humulus lupulus	**Common hop**	4-8	Various support structures	15-20	Fast	5	Stiff downward facing hairs that provide stability and allow them to climb	Deciduous; Bloom from Sep to Oct; yellow-green flower

Table 4.21 (cont.): Climbers that need non-sturdy structural supports and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "maintenance" and "special value"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance	Special value
***Clematis* 'Hagley Hybrid'**	**Large-Flowered Clematis 'Hagley Hybrid'**	Butterflies, hummingbirds	—	Deer, Black Walnut	Hard prune in late winter or early spring	—
Clematis viticella	**Etoile Violette Clematis**	Butterflies, hummingbirds	—	Deer	Water weekly, or more often in extreme heat or containers.	—
Clematis terniflora	**Sweet autumn clematis**	—	Clematis wilt is a potentially fatal fungal disease.	Deer, Black Walnut	Prune hard in fall after flowering or in early spring.	—
***Clematis* 'Frances Rivis'**	**Clematis alpina or Old Man's Beard**	Butterflies, hummingbirds	Young shoots may be troubled by aphids and caterpillars; petals can be eaten by earwigs	Deer	Prune lightly after flowering	—
***Clematis* 'Bill MacKenzie'**	**Clematis alpina 'Frankie'**	Hummingbirds, Butterflies	Aphids. Watch for thorns	Deer	Hard pruning in late winter or early spring	
***Clematis* 'Alba Luxurians'**	**Clematis viticella 'Alba Luxurians'**	—	Wilt, powdery mildew, rust, fungal spots, and stem cankers are common.	Full sun	Weekly watering or more often in extreme heat; prune every spring	—
Lathyrus grandiflorus	**two-flowered Everlasting pea**	Butterflies	May be attacked by aphids, slugs and snails	Cold (down to -4°F or -20°C)	—	—
Antigonon leptopus	**Coral vine**	Hummingbirds	—	Drought	Prune annually in late winter to early spring to remove frost damaged foliage and to maintain desired size	—
Jasminum mesnyi	**Chinese jasmine**				Prune after flowering to keep in control	—
Jasminum officinale	**Summer Jasmine; Common Jasmine**	Butterflies and hummingbirds	Aphids but not troublesome; watch for mealybugs, scale and whitefly	Deer	Pruning is required carried out right after flowering	Flowers can make tea or fragrance.
Trachelospermum jasminoides	**Confederate jasmine**	Bees	—	Heavy shade, drought	Prune in early spring	Flowers can make perfume oil; Stems can produce a bast fibre.
Wisteria frutescens	**American wisteria**	Butterflies, bees	Watch for aphids, leaf miners, Japanese beetles, scale insects, and mealybugs	Deer	Regular pruning(s) in order to control size and shape of the plant and to encourage flowering	—
Humulus lupulus	**Common hop**	Butterflies	Skin contact may cause dermatitis.	Drought	—	Brewing for bittering beer

Table 4.21 (cont.): Climbers that need non-sturdy structural supports and their performances in "growth rate", "good coverage", "climbing type" and "seasonal changing"

Species name	English name	USDA Zones	Structural support	Overall size/ft	Growth rate	Coverage overall score (1-5)	Climbing type	Seasonal changing
Vitis coignetiae	**Crimson Glory Vine**	5-9	Fence, trellis, wires, frameworks, and smaller branches of trees or shrubs	30-60	Fast	4	Woody stem with tendrils and wrap themselves around any firm support	Deciduous; Bloom from July to Aug; heart-shaped leaves with gold, orange and red color in autumn; light green flower
***Vitis vinifera* 'Purpurea'**	**Grape Vine**	6-9	Pergola, cages and ladders or fence	15-30	Fast	5	Branched tendrils	Deciduous; Bloom from May to June; burgundy leaves in late summer; white-green flower; fruits are purple clusters of grapes
Lathyrus latifolius	**Everlasting pea**	3-8	Arbors, trellises, along fences or around pillars	6-9	Fast	5	Rhizomes and twining tendrils	Deciduous; Bloom from June to Sep; pink-white flower;
Lathyrus odoratus	**Sweet Pea**	2-11	Trellis net, fence, strings, stakes or bamboo pyramid	6-8	Fast	5	Tendrils at the leaf apex	Deciduous; Bloom from May to July; any color except yellow flower;
Ipomoea purpurea	**Morning Glory**	2-11	Trellis, fence or arbor	6-10	Fast	5	Twining stems	Deciduous; Bloom from June to Oct; purple with white throat flower;
Tropaeolum peregrinum	**Canary-creeper, or canarybird flower**	10-11	Trellis or fence	10-12	Fast	5	Twining petioles	Deciduous; Bloom from May to Sep; yellow flower;
Celastrus scandens	**American bittersweet**	3-8	Fences, arbors, trellises, posts	15-20	Fast	5	Twining woody vine	Deciduous; bloom time May to June, greenish white-yellow flowers, orange-colored fruits in fall and winter
Ipomoea alba	**Moonflower**	4-7 annual; 8-12 perennial	Fences, decks, trellises or other structures	10-15	Fast	5	Twining stems	Deciduous; bloom time July to Oct; white flower; heart-shaped leaves
***Bignonia capreolata* 'Tangerine Beauty'**	**'Tangerine Beauty' Crossvine**	5-9; annual in winter in Zone 5 and evergreen in warmer zones	Fences, arbors, walls, pillars, large trellises	20-30	Fast	4	Branched tendrils with adhesive disks	Deciduous; Bloom from May to June; Tangerine-orange trumpet flower; Foliage turns reddish-purple in fall.
Gelsemium sempervirens	**Carolina jessamine**	6-10, insulated from winter winds in cold zones	Trellis, arbor, pergola, fence or wall	12-20	Medium	5	Twining vine	Deciduous; Bloom from Feb to April; yellow flower; yellow to purple leaves in winter

Table 4.21 (cont.): Climbers that need non-sturdy structural supports and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "maintenance" and "special value"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance	Special value
Vitis coignetiae	**Crimson Glory Vine**	—	Attract Japanese beetles but not serious	Heat, cold and wind	Restrictive pruning in winter and realise the extent of growth when first planting.	Medicinal plant; brewing for wines
***Vitis vinifera* 'Purpurea'**	**Grape Vine**	—	May be affected by powdery mildew and botrytis; Pests are phylloxera, grape berry moth, Japanese beetle, leaf hopper, leaf roller, mealy bugs and flea beetles	—	Lightly pruned in winter; Frequently pruning ongoing attention to insect and disease pests for better fruit production	Grape fruit; wine, vineagr and juice; dried to produce raisins
Lathyrus latifolius	**Everlasting pea**	Bumblebees, butterflies, hummingbirds	Slugs and snails are attracted to young plants	Full sun; Drought	Provide even moisture and regular fertilizer throughout the growing season	—
Lathyrus odoratus	**Sweet Pea**	Bees, butterflies and/or birds	Aphids, pollen beetle, caterpillars, thrips, slugs and snails; All parts of plant are poisonous if ingested.	Full sun, deer	—	—
Ipomoea purpurea	**Morning Glory**	Butterflies and hummingbirds	—	Full sun, deer	—	—
Tropaeolum peregrinum	**Canary-creeper, or canarybird flower**	Butterflies	Keep an eye out for aphids, caterpillars and flea beetles	Full sun, deer; drought, poor soil	—	Leaves, buds, flowers, pods and seeds are edible and may be used in salads.
Celastrus scandens	**American bittersweet**	Birds, bees, butterflies	Euonymus scale and two-marked treehoppers may cause significant damage in some areas	Full sun; deer, drought	Prune in late winter to early spring; one male plant need 6-9 female plants to produce fruits	—
Ipomoea alba	**Moonflower**	Night-flying moths	—	Deer	—	—
***Bignonia capreolata* 'Tangerine Beauty'**	**'Tangerine Beauty' Crossvine**	Hummingbirds, bees, butterflies	—	Heavy shade	Water regularly - weekly, or more often in extreme heat; Prune annually after flowering to reduce size.	—
Gelsemium sempervirens	**Carolina jessamine**	Butterflies and bumblebees	—	Full sun; drought	Yearly cutting in late spring after flowering	—

Table 4.21 (cont.): Climbers that need non-sturdy structural supports

Species name	English name	USDA Zones	Structural support	Overall size/ft	Growth rate	Coverage overall score (1-5)	Climbing type	Seasonal changing
Ampelopsis brevipedunculata	**Porcelain vine**	4-8	Trellises, arbors, walls or fences.	15-20	Fast	4	Tendril climbing	Deciduous; Bloom from July to Aug; greenish flower; light-blue berries in fall
Aristolochia macrophylla	**Dutchman's Pipe**	4-8	Trellises, arbors, wires or chain-link fences	20-30	Slow	5	Twining stem	Deciduous; bloom time May to June; Yellow, green, purple flower
Clematis tangutica	**Golden Clematis**	5-9	Trellises, arbors, posts, fences	12-15	Medium	5	Twining leaf axles	Deciduous; Bloom from July to Sep; Bell-shaped, bright yellow flower
Jasminum nudiflorum	**Winter jasmine**	6-10 2-11; colder zones grow as annual	Fences, trellises, arbors and arches	10-15	Medium	5	Twining stems	Deciduous; bloom time March to April; yellow flower; willowy green stems in the late winter
Rhodochiton atrosanguineus	**Purple bell vine**		Fences, trellises, arbors and arches	5-12	Fast	5	Twining stems	Deciduous; bloom time May to Sep; red-purple flower

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance	Special value
Ampelopsis brevipedunculata	**Porcelain vine**	Birds, mammals	Watch for Japanese beetles. Fruits are not edible.	—	Trim stems as needed to maintain desired shape	—
Aristolochia macrophylla	**Dutchman's Pipe**	—	—	Black Walnut, shade	Cut back in late winter to control growth.	—
Clematis tangutica	**Golden Clematis**	Butterflies and hummingbirds	Watch for Clematis wilt, spider mites	Deer, Black Walnut, shade	Pruned back hard (to approximately 8-12" from the ground) to strong leaf buds in late winter to early spring	—
Jasminum nudiflorum	**Winter jasmine**	—	—	Hard pruning; heavy shade	Prune in early spring right after flowering is completed	—
Rhodochiton atrosanguineus	**Purple bell vine**	—	May be attacked by glasshouse whitefly and glasshouse red spider mite	Cold	—	—

Climbers that don't need structural supports necessarily:

Table 4.22: Climbers that don't need structural supports necessarily and their performances in "growth rate", "good coverage", "climbing type" and "seasonal changing"

No need structural support (besides walls)							
Species name	**English name**	**USDA Zones**	**Overall size/ft**	**Growth rate**	**Coverage overall score (1-5)**	**Climbing type**	**Seasonal changing**
Schizophragma hydrangeoides	**Japanese hydrangea vine**	5-8	20-30	Fast	5	Stem-borne adhesive rootlets	Deciduous; bloom time June to July; white flower; Reddish-brown stems provide some interest in winter.
Passiflora incarnata	**Purple passionflower Maypop**	5-9	6-8	Fast	4	Root suckers and tendrills	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature
Parthenocissus quinquefolia	**Virginia Creeper**	3-9	60-90	Fast	5	Sucker pads	Deciduous; Bloom from May to Aug; red leaves in autumn; white-green flower
Parthenocissus tricuspidata	**Boston Ivy**	4-8	60-90	Fast	5	Sucker pads	Deciduous; Bloom from June to July; red-purple leaves in autumn; yellow-green flower
Parthenocissus henryana	**Silver vein creeper**	6-9	20-30	Fast	4	Sucker pad	Deciduous; bloom time April-June; green flower; leaves with silver veins and turn to burgundy in autumn
Parthenocissus dalzielii	**—**	6-9	10-15	Medium	5	Sucker pad	Deciduous; bloom time April-June; white-blue flower
Tecoma stans	**Yellow bell**	9-11; In cooler climates, the plant is often grown as an annual	8-15	Fast	5	Climbing vines	Evergreen; bloom time May to Sep; Trumpet-shaped bright golden-yellow flowers
Pyracantha	**Firethorn**	6-9	6-18	Fast	5	Climbing shrub	Evergreen in warm winter climates but semi-evergreen to deciduous in the St. Louis area; Bloom from March to April; white flower; bright orange-red berries in early autumn through winter
Solanum jasminoides	**White Potato vine**	7-11	12-30	Fast	5	Stems climbing by rhizomes	Evergreen or semi-evergreen; Bloom year-roundc; white flower
Campsis radicans	**Trumpet Vine**	4-9	20-40	Fast	5	Aerial rootlets	Deciduous; bloom time July; red and orange flower

Table 4.22 (cont.): Climbers that don't need structural supports necessarily and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "maintenance" and "special value"

No need structural support (besides walls)

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance	Special value
Schizophragma hydrangeoides	**Japanese hydrangea vine**	—	—	Heavy shade	—	—
Passiflora incarnata	**Purple passionflower Maypop**	Butterflies, bees	—	Drought	Prune to control it growing	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.
Parthenocissus quinquefolia	**Virginia Creeper**	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Black Walnut	—	—
Parthenocissus tricuspidata	**Boston Ivy**	Birds	Susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut	—	—
Parthenocissus henryana	**Silver vein creeper**	Birds	Keep an eye out for glasshouse red spider mite and vine weevil	Deer, clay soil	—	—
Parthenocissus dalzielii	**—**	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems. Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut	—	—
Tecoma stans	**Yellow bell**	Hummingbirds, bees, birds, butterflies	Watch for spider mites and whiteflies	Drought, heat	Prune as needed after flowering	—
Pyracantha	**Firethorn**	Blackbirds; wood pigeons	Caterpillars; Fireblight, Aphids; thorns may cause injures easily	Drought; heavy pruning	Annually pruning	—
Solanum jasminoides	**White Potato vine**	—	Vegetative parts are poisonous as are the fruits	Deer, drought; not lower than 10 °F	Need pruning every spring	—
Campsis radicans	**Trumpet Vine**	Hummingbirds	—	Heat, cold, drought, deer, clay soil	Prune in late winter to early spring	—

Table 4.22 (cont.): Climbers that don't need structural supports necessarily

Species name	English name	USDA Zones	Overall size/ft	Growth rate	Coverage overall score (1-5)	Climbing type	Seasonal changing
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	Climbing hydrangea	4-9	30-50	Fast	5	Aerial roots	Deciduous; bloom time May to June; white flower
Pileostegia viburnoides	Climbing hydrangea	7-9	12-20	Slow	5	Aerial roots	Evergreen; bloom time July to Dec; white flower;
Hedera algeriensis 'Gloire de Marengo'	Algerian ivy 'Gloire de Marengo'	6-11	7-12	Fast	5	Aerial roots	Evergreen; bloom time May to June; white flower; grey-green leaves margined with creamy-white
Tropaeolum speciosum	Flame flower	7-10	8-12	Medium	5	Rhizomes	Deciduous; bloom time June-Sep; red flower
Clematis 'Alba Luxurians'	Clematis viticella 'Alba Luxurians'	3-9	8-12	Fast	5	Twining leaf-stalks	Deciduous; bloom time July to Sep; white flower

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance	Special value
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	Climbing hydrangea	—	—	Heavy shade, drought	Prune after flowering	Flowers are used as bouquets.
Pileostegia viburnoides	Climbing hydrangea	Bees, butterflies	—	Not lower than 14°F	Prune in early spring	—
Hedera algeriensis 'Gloire de Marengo'	Algerian ivy 'Gloire de Marengo'	Birds	—	Deer, drought	—	—
Tropaeolum speciosum	Flame flower	—	May be attacked by caterpillars, flea beetles and blackfly	Not lower than 10°F; not long periods of snow cover	Prune every spring; difficult to establish	—
Clematis 'Alba Luxurians'	Clematis viticella 'Alba Luxurians'	—	Wilt, powdery mildew, rust, fungal spots, and stem cankers are common.	Full sun	Weekly watering or more often in extreme heat; prune every spring	—

Maintenance methods

Comparably, climbers are easier to maintain than herbaceous plants and grass plants are easier than flowering plants. More tolerances, easier maintenance. The herbaceous plants suggested here are divided into three maintenance levels based on the pruning and watering frequency they need: 1) low maintenance—pruning is not required necessarily unless for growth control, and low watering requirement (rainfall is enough); 2) medium maintenance—pruning once in a year for more blooming and medium watering requirement (rainfall plus occasionally manual watering); and 3) high maintenance—pruning several times in a year, high watering requirement (water regularly to promise moist soil), or plus any other additional fertilizer.

Climbers are only divided into “low” and “medium” two maintenance levels since they normally grow very rigorously and can tolerate various growing conditions. The most common maintenance for climbers is annually pruning to control the growth. All climber mentioned in this research are relatively easy to grow and good choices for various types of green façades. In order not to provide too many repetitious plant information, just several typical climbers for low and medium maintenance, as an example, will be mentioned in this part. People may don’t like high-maintenance plants, but here my division is only based on the frequency of pruning and irrigation. Most of them still belong to easy-care plants because, for example, they are disease and pest resistance, poor soil tolerance or vigorously growing when established. Besides, considering the amazing landscape they will achieve, people could apply those plants in a small scale outdoor combining with easy-care plants or indoor vertical greenings.

Low-maintenance climbers and Herbaceous plants:

Climbers

Figure 4.47: Left to right: *Actinidia kolomikta; Aristolochia macrophylla; Clematis montana; Clematis tangutica; Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris*

Figure 4.48: Left to right: *Schizophragma hydrangeoides; Lonicera sempervirens; Campsis radicans; Parthenocissus quinquefolia; Parthenocissus quinquefolia*

Figure 4.49: Left to right: *Rosa* ‘Radrazz’; *Celastrus scandens; Passiflora incarnata; Bignonia capreolata* ‘Tangerine Beauty; *Humulus lupulus*

Table 4.23: Climbers that require low maintenance and their performances in “growth rate”, “good coverage”, “climbing type” and “seasonal changing”

Low maintenance--Climbers

Species name	English name	USDA Zones	Maintenance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Actinidia kolomikta	**Variegated-leaf hardy kiwi**	4-8	Prune before flowering complete if expect more fruits	15-20	Fast	5	Hardy twining climbers	Deciduous; bloom time April; white flower; white-pink leaves when older
Aristolochia macrophylla	**Dutchman's Pipe**	4-8	Cut back in late winter to control growth.	20-30	Slow	5	Twining stem	Deciduous; bloom time May to June; Yellow, green, purple flower
Clematis montana	**Anemone Clematis**	5-9	Prune after flowering; regularly water during the first year; mulch to keep soil cool	20-40	Fast	5	Twining leaf axles	Deciduous; Bloom from May to June; white flower and many golden stamens
Clematis tangutica	**Golden Clematis**	5-9	Pruned back hard (to approximately 8-12” from the ground) to strong leaf buds in late winter to early spring	12-15	Medium	5	Twining leaf axles	Deciduous; Bloom from July to Sep; Bell-shaped, bright yellow flower
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	4-9	Prune after flowering	30-50	Slow to get started but grows rapidly	5	Aerial roots	Deciduous; bloom time May to June; white flower
Schizophragma hydrangeoides	**False Hydrangea Vine or Japanese hydrangea vine**	5-9	Prune in late winter to early spring as needed	30-40	Fast but slow to establish	5	Stem-borne adhesive rootlets	Deciduous; bloom time June to July; white, pink flower; the dark green leaves have a noticeable silvery overlay; Reddish-brown stems in winter
Lonicera sempervirens	**Trumpet Honeysuckle**	4-9	Prune right after flowering	10-20	Fast	5	Twining vine	Deciduous; bloom time May to June; Scarlet/orange with yellow inside flower; red berries in late summer to early fall
Campsis radicans	**Trumpet Vine**	4-9	Prune in late winter to early spring	20-40	Fast	5	Aerial rootlets	Deciduous; bloom time July; red and orange flower
Parthenocissus quinquefolia	**Virginia Creeper**	3-9	—	60-90	Fast	5	Sucker pads	Deciduous; Bloom from May to Aug; red leaves in autumn; white-green flower
Parthenocissus quinquefolia	**Boston Ivy**	4-8	—	60-90	Fast	5	Sucker pads	Deciduous; Bloom from June to July; red-purple leaves in autumn; yellow-green flower

Table 4.23 (cont.): Climbers that require low maintenance and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "maintenance" and "special value"

Low maintenance--Climbers

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Special value
Actinidia kolomikta	**Variegated-leaf hardy kiwi**	Bees, butterflies and/or birds	—	Cold down to −40 °F	Strong structures such as a robust pergola or well supported trellis framework	Fruits are edible.
Aristolochia macrophylla	**Dutchman's Pipe**	—	—	Black Walnut, shade	sun porches, verandas, pillars, posts, trellises, arbors, fences or walls	—
Clematis montana	**Anemone Clematis**	Butterflies and hummingbirds	—	Shade; Resistant to clematis wilt	Sturdy trellis or arbor	Root and stem can be used as medicine.
Clematis tangutica	**Golden Clematis**	Butterflies and hummingbirds	Watch for Clematis wilt, spider mites	Deer, Black Walnut, shade	Wall, trellis, fence, arbor, porch, lamppost or other stationary structure	—
Hydrangea petiolaris-Hydrangea anomala subsp. Petiolaris	**Climbing hydrangea**	—	—	Heavy shade, drought	Sturdy arbors, fences or the trunks of large trees, or sprawled over low stone walls, unsightly tree stumps or rock piles	Flowers are used as bouquets.
Schizophragma hydrangeoides	**False Hydrangea Vine or Japanese hydrangea vine**	—	—	Heavy shade, drought	Walls, arbors or trees	—
Lonicera sempervirens	**Trumpet Honeysuckle**	Birds, Hummingbirds, Butterflies	Watch for aphids	Deer, Clay Soil, Black Walnut	Trellises, arbors and fences	—
Campsis radicans	**Trumpet Vine**	Hummingbirds	—	Heat, cold, drought, deer, clay soil	Sturdy trellises, fences or arbors (using structural supports if want to protect the façade)	—
Parthenocissus quinquefolia	**Virginia Creeper**	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Black Walnut	—	—
Parthenocissus quinquefolia	**Boston Ivy**	Birds	Susceptible to a number of insect pests including beetles, scale and leaf hoppers.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut	—	—

Table 4.23 (cont.): Climbers that require low maintenance

Species name	English name	USDA Zones	Maintenance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
***Rosa* 'Radrazz'**	**Knock Out Roses**	5-11; need some winter protection	A good early spring pruning is highly recommended. Self-cleaning to the deadhead	3-4	Medium	4	Twining stems	Deciduous; Bloom from June to July cherry red, pink, yellow-cream, orange, white flower
Celastrus scandens	**American bittersweet**	3-8	Prune in late winter to early spring; Mature vines require little pruning other than removal of dead or excess growth.	15-20	Fast	5	Twining woody vine	Deciduous; bloom time May to June, greenish white-yellow flowers, orange-colored fruits in fall and winter
Passiflora incarnata	**Wild passion flower**	5-9	Prune to control it growing	6-8	Fast	4	Root suckers and tendrils	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature
***Bignonia capreolata* 'Tangerine Beauty'**	**Cross-vine**	5-9, apply winter mulch in zone 5	Prune after flowering if needed.	20-30	Fast	5	Branched tendrils with adhesive disks	Deciduous; Bloom from May to June; tangerine color flowers, reddish-purple foliage in fall
Humulus lupulus	**Common hop**	4-8	Stems may be pruned to the ground in autumn after a hard frost.	15-20	Fast	5	Stiff downward facing hairs that provide stability and allow them to climb	Deciduous; Bloom from Sep to Oct; yellow-green flower

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Special value
***Rosa* 'Radrazz'**	**Knock Out Roses**	Bees, butterflies and/or other pollinators	—	Heat, full sun, drought	Need to be tied as near horizontal as possible on to wires, trellis or similar	Flowers can be made essential oil and fragrance.
Celastrus scandens	**American bittersweet**	Birds, bees, butterflies	Euonymus scale and two-marked treehoppers may cause significant damage in some areas	Full sun; deer, drought	Fences, arbors, trellises, posts	—
Passiflora incarnata	**Wild passion flower**	Butterflies, bees, birds	Roots can spread aggressively. Root rot can occur in wet, poorly-drained soils, particularly in winter.	Drought	Trellises, arbors, walls or fences.	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.
***Bignonia capreolata* 'Tangerine Beauty'**	**Cross-vine**	Hummingbirds	—	Heavy Shade	Fences, arbors, walls, pillars, large trellises and other structures	—
Humulus lupulus	**Common hop**	Butterflies	Skin contact may cause dermatitis.	Drought	Various support structures	Brewing for bittering beer

Herbaceous plants

Figure 4.50: Left to right: *Trillium recurvatum; Hosta; Zinnia haageana* ‘Orange Star’; *Heuchera; Coreopsis lanceolate*

Figure 4.51: Left to right: *Sedum; Senecio cineraria; Stachys byzantine; Stachys officinalis* 'Big Ears'; *Epimedium*

Figure 4.52: Left to right: *Sempervivum; Delosperma; Phalaris arundinacea; Tagetes; Vinca minor* (Periwinkle)

Figure 4.53: Left to right: *Bergenia; Ajuga; Dianthus; Pachysandra; Liriope muscari*

Figure 4.54: Left to right: *Armeria maritima; Lamium galeobdolo; Pachysandra terminalis; Salvia nemorosa* ‘New Dimension’; *Anemone multifida*

Table 4.24: Herbaceous plants that require low maintenance and their performances in "growth rate" and "seasonal changing"

Low maintenance--Herbaceous						
Species name	**English name**	**USDA Zones**	**Maintenance**	**Overall size/in**	**Growth rate**	**Seasonal changing**
Trillium recurvatum	**Purple Prairie Trillium; wood lily**	4-9	—	12-18	Medium	Deciduous; bloom time mid summer; purple to wine-red flowers. Dark green leaves with mottled appearance
Hosta	**—**	2-10	Wet, Well Draining soil; Divide plants as needed in spring or autumn.	6-24	Slow	Evergreen; bloom time summer, white with a lavender tinge flowers, purple; blue/green, chartreuse/gold leaves
***Zinnia haageana* 'Orange Star'**	**Zinnia angustifolia**	2-11; 2-9 annual, 10-11 perennial	—	6-10	Fast	Deciduous; bloom time from April to August; orange-yellow flowers.
Heuchera	**Coralbells**	3-9	Remove stems of faded flowers to encourage additional bloom.	12-20	Medium	Deciduous. Spring Bloom Fall Bloom Summer Bloom Colorful Fall Foliage Winter Interest; Green, Red, White, Pink flowers, purple, gold, sliver foliage retained in winter
Coreopsis lanceolata	**Lanceleaf coreopsis**	4-9	Cut back hard in summer if foliage sprawls or becomes unkempt	12-20	Fast	Deciduous; Bloom from May to July; yellow flowers
Sedum	**Creeping Sedum or stonecrop**	2-11	Medium to good-drained soil	Range from mat-forming ground covers to 18ft	Fast	Mats of succulent leaves ranging from green to bluegray to reddish bronze are topped with five-petaled flowers in yellow, white, or pink. The leaves of evergreen species turn shades of red and russet in winter

Table 4.24 (cont.): Herbaceous plants that require low maintenance and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", and "special value"

		Low maintenance--Herbaceous			
Species name	**English name**	**Increase biodiversity**	**Pest promotion or other problems**	**Climate tolerance**	**Special value**
Trillium recurvatum	**Purple Prairie Trillium; wood lily**	—	May attract carrion beetles and flesh flies	Full shade	—
Hosta	**—**	Hummingbirds	Slugs and snails are attracted to the foliage.	Full shade, drought	—
***Zinnia haageana* 'Orange Star'**	**Zinnia angustifolia**	Bees, butterflies	—	Resistant to Alternaria and powdery mildew; drought, heat	—
Heuchera	**Coralbells**	Butterflies, hummingbirds, birds	—	Heavy shade, deer	—
Coreopsis lanceolata	**Lanceleaf coreopsis**	Butterflies	Can be an aggressive self-seeder. Tends to sprawl, particularly if grown in moist and/or fertile soils.	Deer, Drought, Dry Soil, Shallow-Rocky Soil, Poor soil, Heat, Humidity	—
Sedum	**Creeping Sedum or stonecrop**	—	As long as they're not over-watered, they rarely suffer from any diseases or pests.	Drought, poor soil, shade	—

Table 4.24 (cont.): Herbaceous plants that require low maintenance and their performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Maintenance	Overall size/in	Growth rate	Seasonal changing
Senecio cineraria	**Dusty Miller**	7-10, annual in colder zones	Care is minimal when the plant is established	6-12	Medium	Annual; bloom in mid-summer; yellow flowers; The lacy, silver-gray leaves contrast with vibrant green foliage
Stachys byzantina	**Lamb's Ear**	4-7	Every three or four years you can divide the plants in the spring or just remove the dead centers if you prefer to maintain the clumps	12-18	Fast	Evergreen; bloom time summer, pink to purple flowers, purple; silver grey-green color leaves with a soft velvety texture and a shape like the ear of a lamb
Stachys officinalis **'Big Ears'**	**'Helene von Stein'**	3-10	Well-drained soils are essential.	8-10	Fast	Evergreen; rarely blooming; purple flowers, purple; silver grey-green color leaves with a soft velvety texture and a shape like the ear of a lamb
Epimedium	**Barrenwort**	3-9	Cutback if they become leggy and flop open; well-drained soil	6-8	Fast	Evergreen and deciduous; bloom time spring; spider-like pink, red, red-orange, creamy yellow, or white flowers; Leaflets usually have spiny margins
Sempervivum	**Houseleek**	6-9	Well-drained soils are essential.	4-12	Fast	Evergreen; bloom time summer; white, yellowish, pink, red, or greenish flowers, purple; leaves spread by little offsets that cluster around parent rosette
Delosperma	**Hardy ice plant**	5-9	Well-drained soils are essential.	3-6	Fast	Evergreen; bloom time summer and fall; white, yellowish, pink, purple daisy-like flowers
Phalaris arundinacea	**Ribbon Grass**	4-9; mulch roots in winter	Well-drained soils are essential. Prune as needed to control the spreading	8-12	Fast	Evergreen; seldom blooms; green-pink flowers; strappy leaves that begin with pink or white tinged variegation, become striped with green and white when mature

Table 4.24 (cont.): Herbaceous plants that require low maintenance and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance”, and “special value”

Species name	English name	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Special value
Senecio cineraria	**Dusty Miller**	—	Soil must be well draining to avoid root rot.	Deer, drought, heat, frost, shade	—
Stachys byzantina	**Lamb's Ear**	—	Soil must be well draining to avoid root rot.	Shade, deer, drought, poor soil	Can be used an alternative to toilet paper and medicinally to treat wounds; leaves are also edible and can be made into a tea
Stachys officinalis **'Big Ears'**	**'Helene von Stein'**	—	Soil must be well draining to avoid root rot.	Deer, Drought, Dry Soil, Shallow-Rocky Soil, Black Walnut, Air Pollution, shade	—
Epimedium	**Barrenwort**	—	Vine weevil and mosaic virus	Deer, full shade, poor soil, dry soil	—
Sempervivum	**Houseleek**	—	Soil must be well draining to avoid root rot.	Deer, drought, shade, poor soil	The leaf of the non-flowering plant is used to make medicine. People apply them directly to the skin for burns; ulcers; warts; and itchy, burning skin and swelling associated with insect bites
Delosperma	**Hardy ice plant**	Bees	May be invasive	Deer, drought, shade, poor soil, heat, rocky soil	—
Phalaris arundinacea	**Ribbon Grass**	—	May be invasive	Deer, drought, shade, poor soil, heat, rocky soil	—

Table 4.24 (cont.): Herbaceous plants that require low maintenance and their performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Maintenance	Overall size/in	Growth rate	Seasonal changing
Tagetes	**Marigold**	2-11	Pinch off the tops of the plants to encourage them to grow bushier	6-12 (selected for vertical greening)	Medium	Annual; bloom from March to Oct; Multicolor, Orange, Red, White, Yellow flowers; daisy- or carnation-like flowerheads
Vinca minor (Periwinkle)	**Vinca Minor; dwarf periwinkle**	4-8	Unpretentious care	3-6	Fast	Evergreen; bloom time May to June; Blue, lavender, purple, white flowers
Bergenia	**—**	3-8	Protect from strong, cold winter winds to prevent its evergreen leaves from losing moisture	6-12	Slow	Evergreen; bloom time April to May; red, pink, white flowers; large rosettes of glossy, leathery, gently toothed green/blue, purple/burgundy (winter) leaves
Ajuga	**—**	4-10	—	Under 6	Fast	Semi-evergreen; bloom spring and summer; bright blue, purple, pink or white blossoms; various foliage colors usually in the rich deep burgundy realm, and sometimes cream and pink edges
Dianthus	**Pinks**	3-10	Remove any spent blooms	Under 6; 6-12	Medium	Deciduous; Bloom from March to Aug; starry flowers with purple, red, white, pink, yellow colors; grasslike, blue-green foliage
Pachysandra	**—**	4-9	Well-established plants need almost zero care	6-12	Medium	Deciduous; Bloom from spring to summer; white flowers; blue-green foliage; winter interest
Liriope muscari	**Liriope; lilyturf or blue lily turf**	5-10	Cut foliage to the ground in late winter to early spring in preparation for new growth	12-18	Fast	Deciduous; Bloom from Aug to Sep; blue-violet flowers

Table 4.24 (cont.): Herbaceous plants that require low maintenance and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", and "special value"

Species name	English name	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Special value
Tagetes	**Marigold**	Bees and other pollinators	Powdery mildew If planted in shade and cool, moist areas; mites and aphids sometimes infest the plants	Drought, heat	—
Vinca minor (Periwinkle)	**Vinca Minor; dwarf periwinkle**	—	Most often chokes out competing plants and weeds	Full shade, drought	—
Bergenia	**—**	Bees and other pollinators	Keep an eye out for slug damage	Full shade, deer, drought	—
Ajuga	**—**	—	Crown rot when get too wet	Full shade, deer, drought	—
Dianthus	**Pinks**	Birds	Crown rot when get too wet	Deer, drought; full sun	Flowers are ideal for bonquet.
Pachysandra	**—**	—	Root rot when soils are too wet; leaf blight commonly appears; watch for euonymus scale	Heavy shade, deer, drought, poor soil	—
Liriope muscari	**Liriope; lilyturf or blue lily turf**	—	Watch for slugs and snails. Leaf rot and crown rot may occur if soils are too wet.	Shade, deer, drought, poor soil, erosion, air Pollution	—

Table 4.24 (cont.): Herbaceous plants that require low maintenance and their performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Maintenance	Overall size/in	Growth rate	Seasonal changing
Armeria maritima	**Sea Thrift**	4-9	—	6-12	Slow	Evergreen; bloom time April to Aug; Blue, azure flowers
Lamium galeobdolo	**Yellow archangel**	4-9	If plants become leggy, shear back to 4-6" or to new fresh basal leaves in order to shape plants and to promote new foliage growth.	9-15	Fast	Deciduous. Bloom time June; Yellow, flecked brown flowers, variegated with silver-gray markings
Pachysandra terminalis	**Japanese Spurge**	3-10	—	4-12	Slow	Evergreen. Bloom time March to April; White flowers
Salvia nemorosa **'New Dimension'**	**Sage**	5-8	—	8-10	Medium	Deciduous. Bloom from June to Sep, violet-blue flowers
Anemone multifida	**Anemone**	5-9	Easily divided in fall or early spring.	8-12	Slow	Deciduous; bloom time May to July; butter-yellow flower; fern-like, sliver-green foliage

Table 4.24 (cont.): Herbaceous plants that require low maintenance and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance”, and “special value”

Species name	English name	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Special value
Armeria maritima	**Sea Thrift**	Bees, butterflies	—	Drought, salt, dry soil, poor soil, rocky soil, deer; full sun	—
Lamium galeobdolo	**Yellow archangel**	—	Slugs and snails are occasional visitors. Leaf blight. Mites. Can spread invasively.	Deer, Drought, Heavy Shade, Erosion, Dry Soil, Shallow-Rocky Soil, Air Pollution	—
Pachysandra terminalis	**Japanese Spurge**	—	Leaf blight; Root/stem rot may also occur. Watch for scale and mites.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil	—
Salvia nemorosa **‘New Dimension’**	**Sage**	Butterflies, bees, hummingbirds	Some susceptibility to powdery mildew, leaf spot and rust.	Deer, Drought, Dry Soil, Air Pollution	—
Anemone multifida	**Anemone**	Bees	Heavy shade	—	—

Medium-maintenance climbers and Herbaceous plants:

Climbers

Figure 4.55: Left to right: *Passiflora caerulea; Akebia; Lathyrus latifolius; Wisteria sinensis; Wisteria frutescens*

Figure 4.56: Left to right: *Actinidia arguta; Rosa* ‘Chevy Chase’; *Rosa* 'Dortmund'; *Clematis viticella; Clematis* ‘Alba Luxurians’

Table 4.25: Climbers that require medium maintenance and their performances in “growth rate”, “good coverage”, “climbing type” and “seasonal changing”

Medium maintenance--Climbers

Species name	English name	USDA Zones	Maintenance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Passiflora caerulea	**Passion Flower**	7-9	Regular pruning to avoid compact branches and allow more flowers	30-45	Fast	4	Leaf tendrils	Evergreen; Bloom from March to April; blue-white flower
Akebia	**Chocolate vine**	5-8	Irrigating during periods of hot, dry weather; cut it back significantly in winter if it grows out of bounds	8-20	Fast	5	Twining stems	Deciduous; Bloom from Spring; purple or white flowers that smell of chocolate; blue-green leaves are divided into leaflets
Lathyrus latifolius	**Everlasting pea**	3-8	Provide even moisture and regular fertilizer throughout the growing season	6-9	Fast	5	Rhizomes and twining tendrils	Deciduous; Bloom from June to Sep; pink-white flower;
Wisteria sinensis	**Chinese wisteria**	5-9	Regular prunning to control size and shape of plants to promote flowering; water weekly	60-90	Medium Fast; Produce flowers second or third year after planting	5	Twisting stems	Deciduous; bloom time May to June; blue drooping clusters of flower
Wisteria frutescens	**American wisteria**	5-9	Regular pruning(s) in order to control size and shape of the plant and to encourage flowering	15-30		5	Twining vine	Deciduous; bloom time April to May; lilac-purple flowers
Actinidia arguta	**Hardy kiwi**	3-8	Needs frequent pruning, including an annual winter pruning of each stem back to 8-10 buds and an annual summer pruning of excessively long shoots.	25-30	Fast	5	Twining vine	Deciduous; bloom time May; greenish white flower; white-pink leaves when older
Rosa **‘Chevy Chase’**	**—**	5-9	Pruning needed for newly planted rose; prune in October or November again	9-15	Slow	4	Twining stems	Deciduous; bloom time June to Sep; red flower
Rosa **'Dortmund'**	**Kordesii rose**	4-10	Water deeply and regularly (mornings are best); no pruning in the first two years	6-10	Fast	5	Thorny stem	Deciduous; bloom time May to frost, scarlet with white eyes flowers
Clematis viticella	**Etoile Violette Clematis**	4-9	Water weekly, or more often in extreme heat or containers.	10-15	Fast	5	Twining stems	Deciduous; Bloom from July to Sep; violet-purple flowers
Clematis **‘Alba Luxurians’**	**Clematis viticella 'Alba Luxurians'**	3-9	Weekly watering or more often in extreme heat; prune every spring	8-12	Fast	5	Twining leaf-stalks	Deciduous; bloom time July to Sep; white flower

Table 4.25: Climbers that require medium maintenance and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance”, “structural support” and “special value”

Medium maintenance--Climbers

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Special value
Passiflora caerulea	**Passion Flower**	Butterflies	A few aphids outdoor; Indoor or conservatory grown plants can be infested with whitefly, scale insects and red spider mite.	Not lower than 10 °F; Drought	Trellis, pergola and beams	Flowers can make tea; plant can make medicine.
Akebia	**Chocolate vine**	—	—	Deer, Shade, Erosion	Sturdy structural supports	Can produce edible, sausage-shape fruits
Lathyrus latifolius	**Everlasting pea**	Bumblebees, butterflies, hummingbirds	Slugs and snails are attracted to young plants	Full sun; Drought, shade	Arbors, trellises, along fences or around pillars	—
Wisteria sinensis	**Chinese wisteria**	Butterflies, bees	Invasive plants	Drought; deer	Sturdy arbor, pergola, trellise, fence	—
Wisteria frutescens	**American wisteria**	Butterflies, bees	Watch for aphids, leaf miners, Japanese beetles, scale insects, and mealybugs	Deer	Freestanding arbors, pergolas, posts, trellises, fences or terrace walls.	—
Actinidia arguta	**Hardy kiwi**	Bees, butterflies and/or birds	—	Shade	Trellis, arbor, patio overhead, fence, or wall Need to be tied as near horizontal as possible	Fruits are edible.
Rosa **‘Chevy Chase’**	**—**	Bees	Watch for thorny stems	Full sun	on to wires, trellis or similar	Flowers can make perfume oil
Rosa **'Dortmund'**	**Kordesii rose**	Butterflies	powdery mildew, rust and rose rosette; Pest: aphids, beetles, borers, scale, thrips, rose midges, leafhoppers and spider mites	Full sun; poor soil	Walls, arbors, trellises, along fences or around pillars	Flowers can be made fragrance.
Clematis viticella	**Etoile Violette Clematis**	Butterflies, hummingbirds	—	Deer	Arbor, fence, or trellis, or allow to climb through shrubbery	—
Clematis **‘Alba Luxurians’**	**Clematis viticella 'Alba Luxurians'**	—	Wilt, powdery mildew, rust, fungal spots, and stem cankers are common.	Full sun	Structure support for climbing. No structure support serve as cascading groundcover	—

Herbaceous plants

Figure 4.57: Left to right: *Thymus; Mentha balsamea; Ophiopogon japonicus; Festuca glauca; Cranesbill geraniums*

Figure 4.58: Left to right: *Tiarella cordifolia; Asplenium scolopendrium; Scilla siberica; Pulmonaria; Helleborus orientalis*

Table 4.26: Herbaceous plants that require medium maintenance and their performances in "growth rate" and "seasonal changing"

Medium maintenance--Herbaceous						
Species name	**English name**	**USDA Zones**	**Maintenance**	**Overall size/in**	**Growth rate**	**Seasonal changing**
Thymus	**Creeping Thyme**	4-9	Prune creeping thyme ground cover in the spring to maintain a compact appearance and again after the small white flowers are spent if additional shaping is preferred.	3-5	Fast	Evergreen; bloom time May to July, light purple, white, orange, red, yellow flowers; evergreen with lightly haired foliage
Mentha balsamea	**Peppermint**	3-10	Constantly moist soil with adequate drainage	12-18	Fast	Evergreen; Bloom time summer; purple, pink or white flowers; fragrant leaves
Ophiopogon japonicus	**Mondo Grass**	5-10	Keep the soil moist for the first 3 to 6 months, watering only when the soil is dry after established	2-10	Fast	Evergreen; bloom time summer; white flowers, bright blue berries in fall; green, black foliage
Festuca glauca	**Fescue 'Elijah Blue'**	3-8	Only need watering during periods of extreme heat; Plants are short lived and require frequent division	6-10	Fast	Evergreen; bloom time June to July; Green with purple tinge flowers; blue foliage
Cranesbill geraniums	**Hardy Geranium**	4-8	Only require well-drained, fertile and moist soil	12-18	Fast	Deciduous; bloom time from March to Sep; white, blue, pink and other colors flowers
Tiarella cordifolia	**Foam Flower**	3-9	Wet, Well Draining soil	8-12	Medium	Semi-evergreen; Bloom May; white/pink flowers; maple-like leaves
Asplenium scolopendrium	**Hart's tongue fern**	5-9	Require medium moisture, well-drained, alkaline to slightly acidic soils	12-18	Fast	Evergreen; no flowering; tongue-shaped, leathery, bright green leaves

Table 4.26 (cont.): Herbaceous plants that require medium maintenance and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance” and “special value”

Medium maintenance--Herbaceous					
Species name	**English name**	**Increase biodiversity**	**Pest promotion or other problems**	**Climate tolerance**	**Special value**
Thymus	**Creeping Thyme**	Butterflies, bees	Susceptible to root rot in soil that is too moist	Deer, drought, shade, dry soil, rocky soil, salt	Edible with a flavor and aroma akin to mint when crushed or steeped for teas or tinctures
Mentha balsamea	**Peppermint**	—	—	Repel mosquitoes	Salads, essential oil, herb medicine
Ophiopogon japonicus	**Mondo Grass**	Birds	—	Full shade, deer	—
Festuca glauca	**Fescue 'Elijah Blue'**	—	Plant foliage may decline considerably in hot, humid summers.	Drought, Dry Soil, Shallow-Rocky Soil, Black Walnut, Air Pollution	—
Cranesbill geraniums	**Hardy Geranium**	Butterflies	—	Shade, deer	—
Tiarella cordifolia	**Foam Flower**	Bees, butterflies, and other pollinators	—	Full shade, deer	—
Asplenium scolopendrium	**Hart's tongue fern**	—	Root rot can be a problem in poorly drained soils.	Heavy shade	—

Table 4.26 (cont.): Herbaceous plants that require medium maintenance and their performances in “growth rate” and “seasonal changing”

Species name	**English name**	**USDA Zones**	**Maintenance**	**Overall size/in**	**Growth rate**	**Seasonal changing**
Scilla siberica	**Siberian Squill**	2-8	Wet, Well-draining soil	3-6	Medium	Deciduous; bloom time March to April; intense blue bell-shaped nodding flowers; grassy foliage
Pulmonaria	**Lungwort**	3-9	Some require regular watering; Cut back hard immediately after blooming to prompt more blooming	12-14	Medium	Evergreen; Bloom time April to May; blue, deep-purple bells flowers; hairy dark-green leaves are heavily spotted in silver
Helleborus orientalis	**Hellebore, Lenten rose**	4-9	A rugged and easy-to-grow plant.	12-18	Fast	Evergreen; Bloom time late winter to spring; blue, White to pink to rose-purple with yellow stamens flowers; winter interest

Table 4.26 (cont.): Herbaceous plants that require medium maintenance and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance” and “special value”

Species name	English name	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Special value
Scilla siberica	**Siberian Squill**	Butterflies	—	Deer	—
Pulmonaria	**Lungwort**	Bees and other pollinators	—	Heavy shade, deer, urban pollution, black walnut	Some can be used as herb medicine.
Helleborus orientalis	**Hellebore, Lenten rose**	—	Leaf spot and crown rot are occasional problems.	Deer, Heavy Shade, Dry Soil, Shallow-Rocky Soil, Air Pollution	—

High-maintenance Herbaceous plants:

Figure 4.59: Left to right: *Brunnera macrophylla* ‘Silver Heart’; *Lysimachia; Cornus canadensis; Phlox subulate; Nepeta* × *faassenii*

Figure 4.60: Left to right: *Teucrium chamaedrys; Lamium maculatum; Galium odoratum; Anemone Americana; Lithodora diffusa* 'Grace Ward'

Table 4.27: Herbaceous plants that require relatively high maintenance and their performances in “growth rate” and “seasonal changing”

		High maintenance--Herbaceous				
Species name	**English name**	**USDA Zones**	**Maintenance**	**Overall size/in**	**Growth rate**	**Seasonal changing**
Brunnera macrophylla ‘ **Silver Heart’**	**Silver Heart Bugloss**	4-9	Water deeply, regularly in first growing season to establish root system; once established, water regularly to maintain evenly moist soil.	6-12	Slow	Deciduous; bloom time spring; deep blue flowers. Very thick, heart-shaped leaves that are silver with green edging and veining
Lysimachia	**Creeping Jenny**	3-9	Water regularly and apply mulch or organic compost around plants to help with moisture retention; Cut back to control the growth	4-8	Fast	Deciduous; bloom time May; yellow flowers. yellow-green, coin-like foliage that turns bronze in the winter

Table 4.27 (cont.): Herbaceous plants that require relatively high maintenance and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance" and "special value"

High maintenance--Herbaceous					
Species name	**English name**	**Increase biodiversity**	**Pest promotion or other problems**	**Climate tolerance**	**Special value**
***Brunnera macrophylla* 'Silver Heart'**	**Silver Heart Bugloss**	—	—	Full shade, full sun	—
Lysimachia	**Creeping Jenny**	—	Spread so rapidly	Shade	—

Table 4.27 (cont.): Herbaceous plants that require relatively high maintenance and their performances in "growth rate" and "seasonal changing"

Species name	**English name**	**USDA Zones**	**Maintenance**	**Overall size/in**	**Growth rate**	**Seasonal changing**
Cornus canadensis	**Bunchberry**	2-6	Regular water to keep soil medium moisture; Can be difficult to establish	3-8	Medium	Deciduous; bloom time from May to July; white flowers with four petals.
Phlox subulata	**Creeping phlox**	3-9	Regular water to keep medium moist soil, well-drained soil; Cut back stems after flowering by 1/2 to maintain form and promote denser growth	4-6	Medium	Deciduous; bloom time from March to May; Red-purple to violet-purple to pink to white flowers.
Nepeta × faassenii	**Nepeta**	3-8	Regular water to keep medium moist soil, well-drained soil; cut back before first flowering to promote more compact size. Shear flower spikes after initial flowering to promote continued bloom.	12-20	Medium	Deciduous; bloom time from May to Sep; Blue/violet flowers; Gray-green leaves
Teucrium chamaedrys	**Wall germander**	5-9	Regular water to keep medium moist soil, well-drained soil; Pinch (or shear if leggy or scraggly) stems after flowering to promote bushy, compact growth	8-12	Medium	Evergreen; bloom time from July; Rosy lavender to pinkish purple flowers; winter interest
Lamium maculatum	**Spotted deadnettle**	3-8	Regular water to keep medium moist soil, well-drained soil; mulch roots to keep moist	6-8	Fast	Deciduous; bloom time from May to July; white flowers; Colorful leaves

Table 4.27 (cont.): Herbaceous plants that require relatively high maintenance and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance" and "special value"

Species name	English name	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Special value
Cornus canadensis	**Bunchberry**	Butterflies, birds	—	Shade, cold, deer	Fruits are edible.
Phlox subulata	**Creeping phlox**	Butterflies and other insect pollinators	Spider mites can be a problem, particularly in hot, dry conditions. Foliar nematodes can cause damage in wet/humid conditions.	Deer, Hot, Drought, Erosion, Air Pollution; Full sun	—
Nepeta × faassenii	**Nepeta**	—	—	Deer, Dry Soil, Shallow-Rocky Soil, Air Pollution, Shade	—
Teucrium chamaedrys	**Wall germander**	—	Susceptible to mildew, leaf spot, rust and mites. Cold temperature injury, die-back to the ground or death may occur in harsh winters.	Deer, poor Soil; full sun	—
Lamium maculatum	**Spotted deadnettle**	—	Foliage may decline (melt out) in hot and humid summer climates; Leaf scorch may occur, if soils are allowed to dry out	Deer, Heavy Shade	—

Table 4.27 (cont.): Herbaceous plants that require relatively high maintenance and their performances in "growth rate" and "seasonal changing"

Species name	English name	USDA Zones	Maintenance	Overall size/in	Growth rate	Seasonal changing
Galium odoratum	**Sweetscented bedstraw**	4-8	Regular water to keep medium to wet soil, well-drained soil	6-12	Fast	Deciduous; bloom time from April to May; white flowers
Anemone americana	**Roundleaf Liverleaf**	3-8	Require humusy, medium moisture, well-drained soils in part shade. Needs consistently moist soils which do not dry out.	6-8	Medium	Evergreen; bloom time from March; Blue to lavender or white flowers; leaves turn brown/burgundy in winter
Lithodora diffusa **'Grace Ward'**	**Grace Ward Lithodora**	6-9; need to mulch or protect in Zone 5	Weekly water to keep medium to wet soil, or more often in extreme heat; well-drained soil; Pruning every summer after flowering	6-12	Slow	Evergreen; bloom time from April to Aug; deep blue flowers

Table 4.27 (cont.): Herbaceous plants that require relatively high maintenance and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance” and “special value”

Species name	English name	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Special value
Galium odoratum	**Sweetscented bedstraw**	—	—	Heavy Shade, Black Walnut	Leaves are sometimes used to flavor teas and cold fruit drinks. Leaves are also used to make May wine.
Anemone americana	**Roundleaf Liverleaf**	—	—	Shade	—
***Lithodora diffusa* 'Grace Ward'**	**Grace Ward Lithodora**	Pollinators, butterflies	—	Shade, deer	—

Special value

This is not an indispensable criterion for vertical greening but it indeed can make VG more interesting or aesthetical pleasing. Climbers and Herbaceous plants that bear edible fruit add another item to the long list of useful purposes served by these plants. We may develop VG to be not only a landscape but also a new opportunity for urban farmland. The fruit and vegetable production of VG’s plants may be largely needed in the future. Besides, even the fruits are not edible, they could bring more seasonal interests to the whole landscape. Various birds and pollinators would be attracted, leading to an increase in urban biodiversity at the same time. Pay attention to the configuration of how many male plants should pollinate the female one if we want the largest fruit production, also it commonly requires careful maintenance. We should also keep in mind that poisonous fruit-produce plants should be avoided in the children’s garden or places with a large human flow especially when the fruits are quite eye-catching, or at least plant them highly so we don’t get anyone poisoned because of our landscape. According to my previous research, the common special values of VG’s plants are edibility (fruits, leaves, medicine) and as materials for fragrance and essential oil. For the latter one, the common plant species are Rosa, Clematis and Jasmine which are known for their fragrant flowers and long blooming time. Here, we just talk about edible fruit or foliage-bearing plants.

Edible fruit or foliage-bearing climbers:

Figure 4.61: Left to right: *Actinidia arguta; Actinidia kolomikta; Akebia quinate; Passiflora edulis; Passiflora edulis f. flavicarpa*

Figure 4.62: Left to right: *Passiflora incarnata; Vitis vinifera* 'Flame Seedless'; *Vitis labrusca* 'Himrod'; *Rubus idaeus* 'Canby Red'; *Phaseolus coccineus*

Figure 4.63: Left to right: *Apois Americana; Lathyrus tuberosus; Basella alba; Tropaeolum majus; Jasmine*

Table 4.28: Edible fruit or foliage-bearing climbers and their performances in "growth rate", "good coverage", "climbing type" and "seasonal changing"

Edible fruit or foliage bearing Climbers

Species name	English name	USDA Zones	Special value	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Actinidia arguta	**The Chinese Gooseberry or Kiwi vine**	4-8	Furry fruit with a high consentration of Vitamin C; at least one male pollinator needed for fruit set on female vines	8-shrubs; 30-climbers	Fast	5	Hardy twining climbers	Deciduous; Bloom in late summer; white-yellow flower; leaves turn to pink-white when getting old; grape-sized fruit ripens in early fall
Actinidia kolomikta	**Variegated-leaf hardy kiwi**	4-8	Fruits are edible; at least one male pollinator needed for fruit set on female vines	15-20	Fast	5	Hardy twining climbers	Deciduous; bloom time April; white flower; white-pink leaves when older
Akebia quinate	**Chocolate vine**	4-8	The whitish pulp of the fruit is edible; plant more than one vine to facilitate good cross-pollination. Many experts recommend hand-pollination.	20-40	Fast	4	Twining stems	Evergreen; Bloom from March to April; chocolate-purple flower
Passiflora edulis	**Purple granadilla**	10-12; Where winter hardy, grow this vine outdoors on a pergola, trellis, arch or fence.	Edible, ovoid, purple passionfruits; Ripe fruits are incorporated into a variety of food products such as beverages, jellies, fruit salads and sherbets.	10-15	Medium	5	Coiled tendrils	Evergreen in zones 10-12; Bloom time early spring; White with pruple based flowers; purple fruits from May to July; Young stems are tinged with red or purple

Table 4.28 (cont.): Edible fruit or foliage-bearing climbers and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", "structural support" and "maintenance"

Edible fruit or foliage bearing Climbers

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance
Actinidia arguta	**The Chinese Gooseberry or Kiwi vine**	Bees, butterflies and/or birds	—	Easily get frost damage	Strong structures such as a robust pergola or well supported trellis framework	Training and pruning are necessary
Actinidia kolomikta	**Variegated-leaf hardy kiwi**	Bees, butterflies and/or birds	—	Cold down to −40 °F	Strong structures such as a robust pergola or well supported trellis framework	Prune before flowering complete if expect more fruits
Akebia quinate	**Chocolate vine**	—	—	Deer, Heavy Shade, Erosion	Canes or sturdy trellis	Prune as needed in late spring after flowers appear. May be cut to the ground to renovate
Passiflora edulis	**Purple granadilla**	Bees and other pollinators, butterflies	Requires good air circulation to discourage fungal diseases	—	Pergola, trellis, arch or fence	Water evenly and consistently during the growing season. Vines produce flowers on new growth, so they may be pruned as needed early in the growing season.

Table 4.28 (cont.): Edible fruit or foliage-bearing climbers and their performances in "growth rate", "good coverage", "climbing type" and "seasonal changing"

Species name	English name	USDA Zones	Special value	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Passiflora edulis f. flavicarpa	**Yellow Passionfruit**	10-12; Where winter hardy, grow this vine outdoors on a pergola, trellis, arch or fence.	Egg-shaped yellow passionfruits; Ripe fruits are incorporated into a variety of food products such as beverages, jellies, fruit salads and sherbets.	15-20	Medium	5	Coiled tendrils	Evergreen in zones 10-12; Bloom time April to Sep; White to tinged purple flower; yellow to orange pulp surrounding black seeds
Passiflora incarnata	**Wild passion flower**	5-9	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.	6-8	Fast	4	Root suckers and tendrils	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature
***Vitis vinifera* 'Flame Seedless'**	**Flame Seedless Grape**	7-10	One of the most popular grapes, prized for its excellent flavor; for wine making	20-25	Fast; start bearing fruit within two to four years of planting	5	Tendrill stems	Deciduous; Bloom from July to Sep; green flower; clusters of round, red, seedless fruit with a firm, crisp texture in Aug; bold-textured, yellow, orange, red, copper, and bronze foliage in fall
***Vitis labrusca* 'Himrod'**	**Himrod Grape**	5-8	Excellent for fresh eating as a sweet dessert grape; for wine making	15-20	Fast	5	Climb by tendrils	Deciduous; Bloom from May to June; green flower; clusters of small, entirely seedless, crispy sweet, early season fruit that turns golden yellow when fully ripe in the summer

Table 4.28 (cont.): Edible fruit or foliage-bearing climbers and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance”, “structural support” and “maintenance”

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance
Passiflora edulis f. flavicarpa	**Yellow Passionfruit**	Bees and other pollinators, butterflies	Requires good air circulation to discourage fungal diseases	—	Pergola, trellis, arch or fence	Water evenly and consistently during the growing season. Vines produce flowers on new growth, so they may be pruned as needed early in the growing season.
Passiflora incarnata	**Wild passion flower**	Butterflies, bees, birds	Roots can spread aggressively. Root rot can occur in wet, poorly-drained soils, particularly in winter.	Drought	Trellises, arbors, walls or fences.	Prune to control it growing
***Vitis vinifera* 'Flame Seedless'**	**Flame Seedless Grape**	Birds	May be attacked by bacterial or viral pathogens and insect pests, particularly during periods of heavy rain and humidity.	Full sun, deer	Sturdy trellises, arbors, espalier or fences.	Once established, water deeply, occasionally; more in extreme heat; Prune annually in winter to control size
***Vitis labrusca* 'Himrod'**	**Himrod Grape**	Birds	Susceptible to anthracnose, black rot, downy and powdery mildew, gray mold, crown gall and botrytis bunch rot. Insect pests include phylloxera, grape berry moth, Japanese beetle, leaf hopper, leaf roller, mealy bugs, spotted wing drosophila and flea beetles.	Full sun, deer	Arbor or trellis or trailing along fences	Once established, water deeply, occasionally; more in extreme heat; Prune annually in winter to control size; require regular chemical spraying

Table 4.28 (cont.): Edible fruit or foliage-bearing climbers and their performances in “growth rate”, “good coverage”, “climbing type” and “seasonal changing”

Species name	English name	USDA Zones	Special value	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
***Rubus idaeus* 'Canby Red'**	**"Canby Red" raspberry**	4-8	Produces large, tasty, good quality, bright red berries; edible nuts	5-6	Fast; bears fruit in summertime on second year growth	5	Twining vines	Deciduous; Bloom time Spring; white flower; thornless canes; Luscious red berries ripen in summer.
Phaseolus coccineus	**Scarlet runner beans**	7-11	Produce vegetable-edible pods (green beans) and seeds (fresh or dried beans); young leaves are also edible.	8-12	Medium	5	Twining vines	Annual; Bloom time June to Oct; red flower; Luscious red berries ripen in summer.
Apios americana	**Potato bean**	3-10	Edible Fruits and Nuts; The legumes are also edible	15-20	Fast	5	Twining vines	Deciduous; Bloom time July to Oct; pink, purple, or red-brown flower; bean pods that will persist until winter
Lathyrus tuberosus	**Tuberous sweet pea**	3-8	Edible pea; tubers are edible; increases soil fertility	3-5	Fast	5	Tendrils at the leaf apices	Deciduous; Bloom time June to July; purple to pinkish-red flowers

Table 4.28 (cont.): Edible fruit or foliage-bearing climbers and their performances in “increase biodiversity”, “pest promotion and other issues”, “climate tolerance”, “structural support” and “maintenance”

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance
***Rubus idaeus* 'Canby Red'**	**"Canby Red" raspberry**	Birds, butterflies	Can get aphids, glasshouse red spider mite, raspberry leaf and bud mite, leafhoppers and raspberry beetle	Deer, shade	Plant near a fence or wall for support or allow to ramble	Water weekly, or more often in extreme heat; After harvest, cut the old canes to the ground and leave the new canes in place for next year's crop.
Phaseolus coccineus	**Scarlet runner beans**	Hummingbirds, butterflies and bees	Mexican bean beetles and Japanese beetles may chew holes in foliage. Watch for aphids, leafhoppers and maggots.	Full sun, deer	Ornamental for supports on a sunny porch or split rail fence, or train on tripods, trellises or pergolas	Consistent moisture throughout the growing season is important. Pick beans when ripe to encourage new flowers.
Apois americana	**Potato bean**	Butterflies	—	Shade	Arbor or trellis or trailing along fences	Requires consistently moist soil
Lathyrus tuberosus	**Tuberous sweet pea**	Butterflies	May be attacked by aphids, slugs and snails	Full sun, deer	Arbors, trellises, along fences or around pillars	—

Table 4.28 (cont.): Edible fruit or foliage-bearing climbers

Species name	English name	USDA Zones	Special value	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Seasonal changing
Basella alba	**Climbing spinach; Malabar spinach**	7-11; annual in colder zones	Edible spinach-like stems and leaves	2-6	Medium	5	Twining vines	Deciduous; Bloom time July to frost; white, pinkish, purplish, red flowers
Tropaeolum majus	**Climbing Nasturtium**	2-11	Edible flowers and leaves; flower buds contain mustard oil	6-8	Fast	5	Twining vines	Deciduous; Bloom time summer and fall; white, orange, mahogany, red and yellow flowers; rounded, parasol-like leaves
Jasmine	**—**	6-10	Flowers are made essential oil; tea	3-8; 8-20	Fast	5	Twining stems	Deciduous; Bloom time various all season; white, pink

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Structural support	Maintenance
Basella alba	**Climbing spinach; Malabar spinach**	—	—	Heat, shade, humidity, full sun	Sturdy trellis or posts, fences, hanging baskets	Requires consistently moist soil
Tropaeolum majus	**Climbing Nasturtium**	Butterflies	—	Full sun, shade, poor soil	Arbors, trellises, along fences or around pillars	Water regularly throughout the growing season; Cutting off the faded/dead flowers will prolong blooming.
Jasmine	**—**	—	—	Hard pruning; heavy shade	Fences, trellises, arbors and arches	Prune in early spring right after flowering is completed; prune regularly to control the size

Edible fruit or foliage-bearing Herbaceous plants:

Figure 4.64: Left to right: *Arachis hypogaea; Mentha; Melissa officinalis; Ocimum basilicum; Allium tuberosum*

Figure 4.65: Left to right: *Allium sativum; Origanum vulgare; Petroselinum crispum; Thymus; Chamaemelum nobile*

Figure 4.66: Left to right: *Sanguisorba minor; Rumex acetosa; Coriandrum sativum; Origanum majorana; Viola sororia*

Table 4.29: Edible fruit or foliage-bearing Herbaceous plants

Edible fruit or foliage-bearing Herbaceous						
Species name	**English name**	**USDA Zones**	**Special value**	**Overall size/in**	**Growth rate**	**Seasonal changing**
Arachis hypogaea	**Peanut**	2-11	Delicious roots produce peanut	8-18	Fast	Annual; Bloom time July to Sep; Orange-veined yellow flowers; roots with a nutty
Mentha	**Mint**	3-10	Spice up a fruit salad, lamb or fish dish, or even a glass of iced tea or a cocktail	4-20	Fast	Deciduous; Bloom time July to Sep; blue-purple, white, or pink flowers.
Melissa officinalis	**lemon balm**	3-7	Edible leaves that have a mild lemon scent similar to mint; tea, flavouring, essential oil, alternative medicine	12-18	Fast	Deciduous; Bloom time June to Aug; white to pale yellow flowers.
Ocimum basilicum	**Sweet basil**	2-11	Leaves can be medicine; edible leaves	12-18	Medium	Annual; Bloom time June to frost; magenta flowers; succulent green or purple leaves

Table 4.29 (cont.): Edible fruit or foliage-bearing Herbaceous plants and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", and "maintenance"

Edible fruit or foliage-bearing Herbaceous					
Species name	**English name**	**Increase biodiversity**	**Pest promotion or any other problems**	**Climate tolerance**	**Maintenance**
Arachis hypogaea	**Peanut**	—	Peanuts are particularly susceptible to contamination during growth and storage. Poor storage can lead to infection by mold fungus Aspergillus flavus.	Sandy soil	Add calcium as needed to the top 3-4" of soil. Do not allow soils to dry out.
Mentha	**Mint**	—	Verticillium wilt, mint rust, mint anthracnose, and insects such as spider mites, flea beetles, root borers, cutworms, and root weevils.	Shade	Water regularly to have moist, well-drained soil; Frequent cutting keeps mint looking attractive
Melissa officinalis	**lemon balm**	Bees	Powdery mildew, leaf spot, leaf blight and gray mold may occur	Shade, full sun, deer	Require dry to medium, well-drained soils; Frequent pruning
Ocimum basilicum	**Sweet basil**	—	May be skeletonized by Japanese beetles	Full sun	Root cuttings in water since they are extremely sensitive to frost

Table 4.29 (cont.): Edible fruit or foliage-bearing Herbaceous plants and their performances in "growth rate", and "seasonal changing"

Species name	**English name**	**USDA Zones**	**Special value**	**Overall size/in**	**Growth rate**	**Seasonal changing**
Allium tuberosum	**Garlic chives**	3-9	Leaves can be used in cooking; onion family	9-18	Fast	Deciduous; Bloom time Aug to Sep; white flowers.
Allium sativum	**Cultivated garlic**	4-9	Its segmented bulbs are commonly used in cooking.	12-18	Medium	Annual; Bloom time April to May; Pinkish-white flowers; fragrant leaves
Origanum vulgare	**Oregano**	4-8	Leaves with good flavor may be clipped fresh as needed or dried for year-round use.	12-20	Medium	Annual; Bloom time July to Oct; Pinkish-purple or white flowers
Petroselinum crispum	**Parsley**	2-11	Aromatic edible leaves which may be used fresh or dried in soups, salads and a wide variety of other food dishes	8-12	Germination is slow	Annual; Bloom time seasonal bloomer; Greenish-yellow flowers

Table 4.29 (cont.): Edible fruit or foliage-bearing Herbaceous plants and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", and "maintenance"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance
Allium tuberosum	**Garlic chives**	Butterflies		Shade, Deer, Drought, Black Walnut	Deadhead flowers before seed set to control unwanted spread.
Allium sativum	**Cultivated garlic**	Butterflies	Root/bulb rot may occur in wet, poorly-drained soils. Potential insect pests include nematodes, thrips, bulb mites, onion maggots and wireworms.	Deer, Black Walnut	Need winter mulch in colder zones
Origanum vulgare	**Oregano**	Butterflies	Root rot may occur in wet, poorly drained soils. Watch for fungal diseases. Aphids, leaf miners and spider mites may appear.	Deer, Drought, Erosion, Dry Soil, Shallow-Rocky Soil	Best to shear plants back regularly before flowering to keep the planting tidy and to induce growth of new leaves.
Petroselinum crispum	**Parsley**	—	Septoria leaf spot and stem rot. Carrot weevil, flea beetles, leafhoppers and tarnished plant bugs.	Shade	—

Table 4.29 (cont.): Edible fruit or foliage-bearing Herbaceous plants and their performances in "growth rate", and "seasonal changing"

Species name	English name	USDA Zones	Special value	Overall size/in	Growth rate	Seasonal changing
Thymus	**Creeping Thyme**	4-9	Edible with a flavor and aroma akin to mint when crushed or steeped for teas or tinctures	3-5	Fast	Evergreen; bloom time May to July, light purple, white, orange, red, yellow flowers; evergreen with lightly haired foliage
Chamaemelum nobile	**Chamomile**	4-9	Finely-dissected, fern-like foliage emits a fruity scent when bruised. Flower heads may be dried to make chamomile tea and medicine	3-6	Fast	Evergreen; Bloom time June to September; White rays with yellow centers flowers
Sanguisorba minor	**Burnet**	4-8	Young leaves have the best taste (reminiscent of cucumber). Leaves are used fresh off the plant in salads, soups, herbal butters, vinegars or cold drinks.	9-20	Medium	Annual in colder zones; Bloom time July; Greenish with purple-tinged styles flowers
Rumex acetosa	**Sorrel**	3-7	Leaves have a tangy, acidic, sour-lemony flavor and are commonly used in salads, soups, omelets and sauces.	12-20	Fast	Annual; Bloom time June to Aug; Green turning reddish with age flowers

Table 4.29 (cont.): Edible fruit or foliage-bearing Herbaceous plants and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", and "maintenance"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance
Thymus	**Creeping Thyme**	Butterflies, bees	Susceptible to root rot in soil that is too moist	Deer, drought, shade, dry soil, rocky soil, salt	Prune creeping thyme ground cover in the spring to maintain a compact appearance and again after the small white flowers are spent if additional shaping is preferred.
Chamaemelum nobile	**Chamomile**	—	Can spread aggressively	Shade, drought	—
Sanguisorba minor	**Burnet**	—	—	Full sun, deer	Regularly cut back older leaves to promote growth of young leaves which have the best taste; Remove flower stalks immediately after bloom
Rumex acetosa	**Sorrel**	—	It is considered by many to be an aggressive weed.	Full sun	Remove flowers immediately to promote leaf growth.

Table 4.29 (cont.): Edible fruit or foliage-bearing Herbaceous plants and their performances in "growth rate", and "seasonal changing"

Species name	English name	USDA Zones	Special value	Overall size/in	Growth rate	Seasonal changing
Coriandrum sativum	**Cilantro/Coriander**	2-11	Cilantro leaves are used for flavoring a number of food dishes including salads, salsas, meats, sauces and soups. Stems are also edible when young. Mature seeds have a pleasantly sweet-spicy fragrance and are used for flavoring sauces, meats, sausages, stews, chutneys, pies and cakes.	12-18	Fast	Annual; Bloom time seasonal bloomer; White to pink to pale lavender flowers
Origanum majorana	**Sweet marjoram**	9-10; annual in other zones	Popular herb (fresh or dried) for seasoning soups, sauces, salads, stuffings, stews, roasts, vegetables and meats.	12-20	Medium	Annual; Bloom time July to Aug; White to pale pink flowers; reddish, square stems
Viola sororia	**Common Blue Viola**	3-7	Leaves can be used in salads or cooked as greens. The flowers can be made into candies, cupcakes, frozen in ice cubes and jellies	6-10	Medium	Deciduous; Bloom time April to Aug; blue-violet flowers with white throats; heart-shaped leaves

Table 4.29 (cont.): Edible fruit or foliage-bearing Herbaceous plants and their performances in "increase biodiversity", "pest promotion and other issues", "climate tolerance", and "maintenance"

Species name	English name	Increase biodiversity	Pest promotion or any other problems	Climate tolerance	Maintenance
Coriandrum sativum	**Cilantro/Coriander**	—	Potential disease problems include damping off, rot, wilt and bacterial blight, blossom blight and aster yellows. Potential insect pests include grasshoppers, leafhoppers and cabbage loopers.	Full sun, shade	Best growth occurs in cool and dry summer climates.
Origanum majorana	**Sweet marjoram**	—	Root rot may occur in wet, poorly drained soils.	Deer, Drought, full sun, heat	Cut back stems before flowers appear to encourage bushy growth
Viola sororia	**Common Blue Viola**	Butterflies and bees.	Watch for slugs, snails, aphids, glasshouse red spider mite, violet gall midge, powdery mildews and pansy leaf spot	Shade, clay soil, wet soil, deer, black walnut	—

Conclusion

Plants are the most interesting part of vertical greening. They make every expectation come true, at the same time they function to benefit human society and urban ecosystem. Up to date, vertical greening is still a relatively new idea for urban landscape—one of the reasons is that concerns about it are more than convincement. The nine criteria focused in this research are summarized from current people's concerns and expectations which could be solved and achieved through suitable plant selection. For some plants, they are able to satisfy more than one criterion, making them popular utilizations through all types of proposed VG, climbers such as Clematis, Lathyrus, Actinidia, Wisteria and Parthenocissus; Herbaceous plants such as Pulmonaria, Heuchera, Hosta, Bergenia and Mentha.

In the real projects, designers should take as much as plant-selection criteria into consideration to have a more functional and sustainable vertical greening. In the next chapter, we will apply this knowledge into a real-world design—adding VG to downtown Chicago—and have a better understanding of how to coordinate these criteria into different proposed VG.

References

[1] A. M. Hathaway, W. F. Hunt, & G. D. Jennings. (2008). A Field Study of Green Roof Hydrologic and Water Quality Performance. *Transactions of the ASABE*, *51*(1), 37–44. https://doi.org/10.13031/2013.24225

[2] Andrew Fletcher, & Nick Pecker. (2020). *Actinidia kolomikta (Variegated Kiwi Vine)*. Gardenia.Net. https://www.gardenia.net/plant/actinidia-kolomikta

[3] ARCHITEK. (2020). Green Facades. *Architek*. http://architek.com/products/green-facades/

[4] Armitage, A. M. (c1989.). *Herbaceous perennial plants: A treatise on their identification, culture, and garden attributes /*. Varsity Press,.

[5] Avent, T. (2012). *Pulmonaria—The World of Lungworts*. Plant Delights Nursery. https://www.plantdelights.com/blogs/articles/pulmonaria-lungworts

[6] Balick, M. J., Kronenberg, F., Ososki, A. L., Reiff, M., Fugh-Berman, A., Bonnie, O., Roble, M., Lohr, P., & Atha, D. (2000). Medicinal plants used by latino healers for women's health conditions in New York City. *Economic Botany*, *54*(3), 344–357. https://doi.org/10.1007/BF02864786

[7] Ballyrobert Gardens. (2020). *Tropaeolum speciosum*. Ballyrobert Gardens. https://www.ballyrobertgardens.com/products/tropaeolum-speciosum

[8] Blanc, P. (2008). *The vertical garden: From nature to the city /*. W.W. Norton,.

[9] Boeri, S., & Insulza, F. (2009). The Vertical Forest and New Urban Comfort. *Harvard Design Magazine*, *31*, 60–65.

[10] Boisset, C. (c1988.). *Vertical gardening: Climbing plants, hanging plants, trellises, wall planting, terrace steps, window boxes /* (1st ed.). Weidenfeld & Nicolson,.

[11] Boltz, H. O. (c1958). *The landscape use of shrubs and vines, according to form, color, and texture, soil and culture.* (1st ed.). Educational Publishers,.

[12] Chan, C. T. W. (2018). Promoting Vertical Greening in High-rise Residential Buildings within Urban Areas. *Pacific International Journal*, *1*(2), 29–38.

[13] Chan, P., & Chu, C. (2005). Hong kong building environmental assessment method. In *Tall Buildings* (Vol. 1–0, pp. 979–986). WORLD SCIENTIFIC. https://doi.org/10.1142/9789812701480_0144

[14] Chew, M. Y. L., Conejos, S., & Azril, F. H. B. (2019). Design for maintainability of high-rise vertical green facades. *Building Research & Information*, *47*(4), 453–467. https://doi.org/10.1080/09613218.2018.1440716

[15] Coghlan, R. (1975). *Landscape gardening in the tropics /*. Hart-Davis, MacGibbon,.

[16] Cullina, W. (2002). *Native trees, shrubs, & vines: A guide to using, growing, and propagating North American woody plants /*. Houghton Mifflin,.

[17] Darwin, F. (1880). Climbing Plants. *The Popular Science Review; London*, *4*(13), 213–229.

[18] David Beaulieu. (2019a). *Japanese Forest Grass Is a Great Perennial Ornamental Grass for Shade*. The Spruce. https://www.thespruce.com/golden-hakone-grass-2132482

[19] David Beaulieu. (2019b). *Japanese Honeysuckle Is Often an Invasive Vine*. The Spruce. https://www.thespruce.com/japanese-honeysuckle-vines-2132890

[20] Department of Environment, Water and Natural Resources. (2013). *Factsheet—*Solanum laxum (prev. S. jasminoides)*. http://www.flora.sa.gov.au/efsa/lucid/Solanaceae/Solanum%20species/key/Australian%20Solanum%20species/Media/Html/Solanum_laxum_%28prev._S._jasminoides%29.htm

[21] Dunnett, N. (2008). *Planting green roofs and living walls /* (Rev. and updated ed., [2nd ed.]). Timber Press,.

[22] Flora of North America. (2018). *Akebia quinata in Flora of North America @ efloras.org*. http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=200008288

[23] Gardenia. (2019a). *Campsis radicans (Trumpet Vine)*. Gardenia.Net. https://www.gardenia.net/plant/campsis-radicans-trumpet-vine

[24] Gardenia. (2019b). *Clematis "Hagley Hybrid" (Late Large-Flowered Clematis)*. Gardenia.Net. https://www.gardenia.net/plant/clematis-hagley-hybrid
[25] Gardenia. (2019c). *Dianthus deltoides "Arctic Fire" (Maiden Pink)*. Gardenia.Net. https://www.gardenia.net/plant/dianthus-deltoides-arctic-fire
[26] Gardenia. (2019d). *Hardy Geraniums (Cranesbill)*. Gardenia.Net. https://www.gardenia.net/guide/hardy-geraniums-cranesbill
[27] Gardenia. (2019e). *Heuchera "Electra" (Coral Bells)*. Gardenia.Net. https://www.gardenia.net/plant/heuchera-electra-coral-bells
[28] Gardenia. (2019f). *Monarda "Balmy Purple" (Bee Balm)*. Gardenia.Net. https://www.gardenia.net/plant/monarda-balmy-purple
[29] Gardenia. (2019g). *Tropaeolum majus (Nasturtium)*. Gardenia.Net. https://www.gardenia.net/plant/tropaeolum-majus-nasturtium
[30] Gardenia. (2020a). *Dianthus gratianopolitanus "Firewitch" (Cheddar Pink)*. Gardenia.Net. https://www.gardenia.net/plant/dianthus-gratianopolitanus-firewitch-cheddar-pink
[31] Gardenia. (2020b). *Eranthis hyemalis (Winter Aconite)*. Gardenia.Net. https://www.gardenia.net/plant/eranthis-hyemalis-winter-aconite
[32] Gardenia. (2020c). *Oxalis triangularis subsp. Papilionacea (Purple Shamrock)*. Gardenia.Net. https://www.gardenia.net/plant/oxalis-triangularis-subsp-papilionacea
[33] Gardenia. (2020d). *Rosa "Zephirine Drouhin" (Bourbon Rose)*. Gardenia.Net. https://www.gardenia.net/plant/rose-zephirine-drouhin
[34] Gardenvisit. (2013). *A treatise on the theory and practice of landscape gardening, adapted to North America,1841 Section VI. Vines and Climbing Plants Virginia Creeper Ampelopsis hederacea Parthenocissus quinquefolia*. https://www.gardenvisit.com/book/a_treatise_on_the_theory_and_practice_of_landscape_gardening_adapted_to_north_america1841/section_vi_vines_and_climbing_plants/virginia_creeper_ampelopsis_hederacea_parthenocissus_quinquefolia
[35] Ghazalli, A. J., Brack, C., Bai, X., & Said, I. (2019). Physical and Non-Physical Benefits of Vertical Greenery Systems: A Review. *Journal of Urban Technology*, *26*(4), 53–78. https://doi.org/10.1080/10630732.2019.1637694
[36] Gilman, E. F. (1999). *Trachelospermum jasminoides*. 3.
[37] Gou, Z., & Lau, S. S.-Y. (2014). Contextualizing green building rating systems: Case study of Hong Kong. *Habitat International*, *44*, 282–289. https://doi.org/10.1016/j.habitatint.2014.07.008
[38] Haaland, C., & van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening*, *14*(4), 760–771. https://doi.org/10.1016/j.ufug.2015.07.009
[39] Hogan, S. (Ed.). (2003). *Flora: A gardener's encyclopedia: over 20,000 plants*. Timber Press.
[40] *Humulus lupulus—Plant Finder*. (n.d.). Retrieved March 5, 2020, from http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=f191
[41] Ip, K., Lam, M., & Miller, A. (2010). Shading performance of a vertical deciduous climbing plant canopy. *Building and Environment*, *45*(1), 81–88. https://doi.org/10.1016/j.buildenv.2009.05.003
[42] Iwatsuki, K. (Ed.). (1995). *Pteridophyta and gymnospermae* (1. print). Kodansha.
[43] Jason Canon. (2012, May 30). *Virginia Nature Hills Nursery—The Ivy League*. Archive.Is. http://archive.is/HrOF
[44] Jim, C. Y. (2015). Assessing growth performance and deficiency of climber species on tropical greenwalls. *Landscape and Urban Planning*, *137*, 107–121. https://doi.org/10.1016/j.landurbplan.2015.01.001
[45] Ken Woolfenden. (2020). *Growing Clematis Queries—International Clematis Society*. http://clematisinternational.com/growing.html
[46] Kenny, H. T. (1945). *West Virginia place names, their origin and meaning, including the nomenclature of the streams and mountains,*. Piedmont, W.Va.,. http://hdl.handle.net/2027/mdp.39015009099824

[47] Kibbel, W. (2019). *Ivy and Vines: Attribute or Detriment? | Old House Web*. http://www.oldhouseweb.com/how-to-advice/ivy-and-vines-attribute-or-detriment.shtml
[48] Köhler, M., & Ksiazek-Mikenas, K. (2018). Green Roofs as Habitats for Biodiversity. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 239–249). Elsevier. https://doi.org/10.1016/B978-0-12-812150-4.00022-7
[49] Kotzen, B. (2018). Green Roofs Social and Aesthetic Aspects. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 273–281). Elsevier. https://doi.org/10.1016/B978-0-12-812150-4.00025-2
[50] Kubba, S. (2017). Water Efficiency and Sanitary Waste. In *Handbook of Green Building Design and Construction* (pp. 413–441). Elsevier. https://doi.org/10.1016/B978-0-12-810433-0.00008-3
[51] Li, K. (2018). Analysis of Barrier Factors in Vertical Planting of Old Housing Estates. *Advances in Applied Sociology*, *08*(07), 562–574. https://doi.org/10.4236/aasoci.2018.87033
[52] M. RooV, H. M. Kuypers, & Sanda LenzholzerSanda Lenzholzer. (2010). *The green city guidelines: Techniques for a healthy liveable city | Request PDF*. ResearchGate. https://www.researchgate.net/publication/254838421_The_green_city_guidelines_techniques_for_a_healthy_liveable_city
[53] Manso, M., & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews*, *41*, 863–871. https://doi.org/10.1016/j.rser.2014.07.203
[54] Menlo Park, Calif., Lane Pub. Co. (1954). *Sunset western garden book*, ([1st ed.].). Lane Pub. Co.
[55] Meyer, F. N. (1911). *Chinese plant names,*. Chinese & Japanese Pub. Co.,.
[56] Missouri Botanical Garden. (2017a). *Pachysandra terminalis—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=e430
[57] Missouri Botanical Garden. (2017b). *Parthenocissus quinquefolia—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=l490
[58] Missouri Botanical Garden. (2018a). *Allium schoenoprasum—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=j270
[59] Missouri Botanical Garden. (2018b). *Anemone blanda 'White Splendour'—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=242824
[60] Missouri Botanical Garden. (2018c). *Antigonon leptopus—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a486
[61] Missouri Botanical Garden. (2018d). *Hedera helix—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=r450
[62] Missouri Botanical Garden. (2018e). *Impatiens omeiana—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a774
[63] Missouri Botanical Garden. (2018f). *Scabiosa 'Butterfly Blue'—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=f490
[64] Missouri Botanical Garden. (2019a). *Ampelopsis brevipedunculata—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=b270
[65] Missouri Botanical Garden. (2019b). *Bignonia capreolata 'Tangerine Beauty'—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=273223
[66] Missouri Botanical Garden. (2019c). *Campanula poscharskyana—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=278835
[67] Missouri Botanical Garden. (2019d). *Celastrus scandens—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a151
[68] Missouri Botanical Garden. (2019e). *Gelsemium sempervirens—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=c519
[69] Missouri Botanical Garden. (2019f). *Geum 'Mrs. J. Bradshaw'—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=c900
[70] Missouri Botanical Garden. (2019g). *Humulus lupulus 'Aureus'—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=j440

[71] Missouri Botanical Garden. (2019h). *Hydrangea anomala subsp. Petiolaris—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=d370
[72] Missouri Botanical Garden. (2019i). *Ipomoea alba—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=c801
[73] Missouri Botanical Garden. (2019j). *Lamium galeobdolon—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=d710
[74] Missouri Botanical Garden. (2019k). *Lobelia erinus—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a592
[75] Missouri Botanical Garden. (2019l). *Lonicera × heckrottii 'Gold Flame'—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=b839
[76] Missouri Botanical Garden. (2019m). *Schizophragma hydrangeoides—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=f520
[77] Missouri Botanical Garden. (2019n). *Trillium recurvatum—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=r850
[78] Missouri Botanical Garden. (2020a). *Asplenium scolopendrium—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=b244
[79] Missouri Botanical Garden. (2020b). *Brunnera macrophylla 'Jack Frost'—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=m800
[80] Missouri Botanical Garden. (2020c). *Calamintha nepeta subsp. Nepeta—Plant Finder*. http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=264462
[81] Molly Allman. (2018). *Care for a Flowering Maple*. https://homeguides.sfgate.com/care-flowering-maple-38511.html
[82] Monrovia. (2019). *Alba Luxurians Clematis—Monrovia—Alba Luxurians Clematis*. Alba Luxurians Clematis. https://www.monrovia.com/plant-catalog/plants/881/alba-luxurians-clematis/
[83] Murray, Johan Andreas. (1784). *Lonicera japonica Thunb. —The Plant List*. http://www.theplantlist.org/tpl1.1/record/kew-2339716
[84] Murrill, W. A. (1945). *A guide to Florida plants*. The author,.
[85] Naczi, R. F. C. (2016). New Manual of Vascular Plants of Northeastern United States and Adjacent Canada. *Brittonia*, *68*(3), 238–244. https://doi.org/10.1007/s12228-016-9416-6
[86] NC Extension Gardener. (2019). *Celastrus scandens (American Bittersweet, Bittersweet, Climbing Bittersweet, False Bittersweet, Shrubby Bittersweet, Waxwork) | North Carolina Extension Gardener Plant Toolbox*. https://plants.ces.ncsu.edu/plants/celastrus-scandens/
[87] Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., & Mihalakakou, G. (2001). Analysis of the green roof thermal properties and investigation of its energy performance. *Energy and Buildings*, *33*(7), 719–729. https://doi.org/10.1016/S0378-7788(01)00062-7
[88] Nikki Tilley. (2019a). *Coleus Care – Information On Growing Coleus*. Gardening Know How. https://www.gardeningknowhow.com/ornamental/foliage/coleus/coleus-plant-care.htm
[89] Nikki Tilley. (2019b). *Growing Primrose – Primrose Plants In Your Garden*. Gardening Know How. https://www.gardeningknowhow.com/ornamental/flowers/primrose/growing-primrose-primrose-plants-in-your-garden.htm
[90] Nikki Tilley. (2019c). *Growing Wisteria – Proper Wisteria Vine Care*. Gardening Know How. https://www.gardeningknowhow.com/ornamental/vines/wisteria/growing-wisteria-proper-wisteria-vine-care.htm
[91] Nikki Tilley. (2019d). *Trumpet Vine Plant: How To Grow Trumpet Vine*. Gardening Know How. https://www.gardeningknowhow.com/ornamental/vines/trumpet-vine/growing-trumpet-vines.htm
[92] Othman, A. R., & Sahidin, N. (2016). Vertical Greening Façade as Passive Approach in Sustainable Design. *Procedia - Social and Behavioral Sciences*, *222*, 845–854. https://doi.org/10.1016/j.sbspro.2016.05.185
[93] Pandey, A. K., Pandey, M., & Tripathi, B. D. (2015). Air Pollution Tolerance Index of climber plant species to develop Vertical Greenery Systems in a polluted tropical city. *Landscape and Urban Planning*, *144*, 119–127. https://doi.org/10.1016/j.landurbplan.2015.08.014

[94] Paul Pilon. (2002). *Lamium "Orchid Frost" Spotted Deed Nettle*. Greenhouse Product News. https://gpnmag.com/article/lamium-orchid-frost-spotted-deed-nettle/
[95] Paxton, J. P. (1836). *Paxton's Magazine of Botany, and Register of Flowering Plants*.
[96] Perennials.com. (2020). *Plant Profile for Aquilegia vulgaris 'Clementine Red'—Clematis-flowered Columbine Perennial*. http://www.perennials.com/plants/aquilegia-vulgaris-clementine-red.html
[97] Perini, K., Ottelé, M., Giulini, S., Magliocco, A., & Roccotiello, E. (2017a). Quantification of fine dust deposition on different plant species in a vertical greening system. *Ecological Engineering*, *100*, 268–276. https://doi.org/10.1016/j.ecoleng.2016.12.032
[98] Perini, K., Ottelé, M., Giulini, S., Magliocco, A., & Roccotiello, E. (2017b). Quantification of fine dust deposition on different plant species in a vertical greening system. *Ecological Engineering*, *100*, 268–276. https://doi.org/10.1016/j.ecoleng.2016.12.032
[99] Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2011). Greening the building envelope, facade greening and living wall systems. *Open Journal of Ecology*, *01*(01), 1–8. https://doi.org/10.4236/oje.2011.11001
[100] Perini, K., & Roccotiello, E. (2018). Vertical Greening Systems for Pollutants Reduction. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 131–140). Elsevier. https://doi.org/10.1016/B978-0-12-812150-4.00012-4
[101] Peter Kirland. (2020). *PlantFile*. http://plantfileonline.net/plants/plant_details/32
[102] Rakhshandehroo, M., Mohd Yusof, M. J., & Deghati Najd, M. (2015). Green Façade (Vertical Greening): Benefits and Threats. *Applied Mechanics and Materials*, *747*, 12–15. https://doi.org/10.4028/www.scientific.net/AMM.747.12
[103] RHS. (2018). *Lonicera henryi | Henry's honeysuckle/RHS Gardening*. https://www.rhs.org.uk/Plants/10471/Lonicera-henryi/Details
[104] RHS. (2019a). *Campanula carpatica "Blaue Clips" | tussock bellflower 'Blaue Clips'/RHS Gardening*. https://www.rhs.org.uk/Plants/114489/i-Campanula-carpatica-i-Blaue-Clips/Details
[105] RHS. (2019b). *Pileostegia viburnoides | climbing hydrangea/RHS Gardening*. https://www.rhs.org.uk/Plants/13019/Pileostegia-viburnoides/Details
[106] RHS. (2019c). *Rosa "Danse du Feu" (ClF) | rose 'Danse du Feu'/RHS Gardening*. https://www.rhs.org.uk/Plants/126246/Rosa-Danse-du-Feu-(ClF)/Details
[107] Sargent, C. S. (1894). *Forest flora of Japan.Notes on the forest flora of Japan;* Boston,. http://hdl.handle.net/2027/uc2.ark:/13960/t3rv0fp1w
[108] Smith, James Edward. (2018). *International Plant Names Index*. https://www.ipni.org/n/501740-1
[109] Snodgrass, E. C. (2006). *Green roof plants: A resource and planting guide /*. Timber Press,.
[110] Sun, L. (2005). *Vertical neighborhoods/ sky garden architecture/ landscape architecture design response /*.
[111] Susan. (2017). *Sweet Autumn Clematis, Clematis terniflora*. Master Gardener Program. https://wimastergardener.org/article/sweet-autumn-clematis-clematis-terniflora/
[112] The Sunday Gardener. (2020). *Fallopia Russian Vine Mile a minute plant*. https://www.sundaygardener.co.uk/fallopia-russian-vine-mile-a-minute-plant.html
[113] Thornbush, M. J. (2013). Tracking the Use of Climbing Plants in the Urban Landscape through the Photoarchives of Two Oxford Colleges, 1861–1964. *Landscape Research*, *38*(3), 312–328. https://doi.org/10.1080/01426397.2011.647897
[114] Tian, Y., & Jim, C. Y. (2012). Development potential of sky gardens in the compact city of Hong Kong. *Urban Forestry & Urban Greening*, *11*(3), 223–233. https://doi.org/10.1016/j.ufug.2012.03.003
[115] Tolderlund, L., Ap, L., & GRP. (2010). *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*. 59.
[116] Tom Oder. (2019). *16 plants that repel unwanted insects*. MNN - Mother Nature Network. https://www.mnn.com/your-home/organic-farming-gardening/stories/12-plants-that-repel-unwanted-insects

[117] Wong, N. H., Tan, A. Y. K., Tan, P. Y., Sia, A., & Wong, N. C. (2010). Perception Studies of Vertical Greenery Systems in Singapore. *Journal of Urban Planning and Development*, *136*(4), 330–338. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000034

[118] Ye, L., Cheng, Z., Wang, Q., Lin, W., & Ren, F. (2013). Overview on Green Building Label in China. *Renewable Energy*, *53*, 220–229. https://doi.org/10.1016/j.renene.2012.11.022

[119] Zhao, X., Zuo, J., Wu, G., & Huang, C. (2019). A bibliometric review of green building research 2000–2016. *Architectural Science Review*, *62*(1), 74–88. https://doi.org/10.1080/00038628.2018.1485548

CHAPTER 5: ADDING VERTICAL GREENING IN DOWNTOWN CHICAGO

Abstract

Based on the suitability calculation in the previous chapter, a detail research of the land use, buildings attribute, suitable walls and major users in the two suitable areas was conducted. According to so, three prototypes have been decided and responsive proposals for types of VG and expectations have been come up with. Afterward, prototypes had been designed using three particular walls as an example. Plants were selected based on the criteria I proposed previously and there was a planting list for each design. In order to help proposed VGs come true, there are big brokers recommended in which people can get all the plants I used. This chapter is a practical contemplation of what should be considered when applying VG in cities and how to use suitable-plant criteria in the real-world project.

Introduction

Chicago as the most populous city in the U.S. state of Illinois and the third-most-populous city in the United States, has a tremendous population density of approximately 11,841/square miles (USGS, 2018). Downtown Chicago is the most populous area in Chicago which is suffering increasingly competitive land use and a compact urban living environment. Urbanization and densification processes have led to a loss of urban green space (UGS) and biodiversity within cities. With the increasing frequency and severity of environmental hazards and climate change such as heat, green space will play an important role in reducing vulnerability, promoting health and building resilience (Stone et al., 2010). In response to these environmental hazards and urban densification (i.e., via rapid population growth and rural to urban migration), there is a growing need to multiply the volume of greenspaces and plan them sustainability for resilient urban environments. Besides, Chicago, renowned as an advanced metropolis around the world, deserves creative types of green spaces such as vertical greening which is regarded as one type of smart landscape. It is always worthy to approach strategies for adding VG in Downtown Chicago creatively and sustainably. To date, Chicago is known for owning the largest green roof in the world—Millenium Park which is built above a public garage (Gilfoyle, 2006). While, there is barely any outdoors living wall system or green façade. Therefore the opportunities to add these two types of VG in downtown Chicago are mainly

discussed in this research. The area of downtown Chicago focused is consisted of neighborhoods Armour Square Chinatown, Gold Coast, Grant Park, Loop, Millenium Park, Museum Campus, Near South Side, Old Town, Printers Row, River North, Rush & Division, Magnificent Mile, and Streeterville (Figure 1).

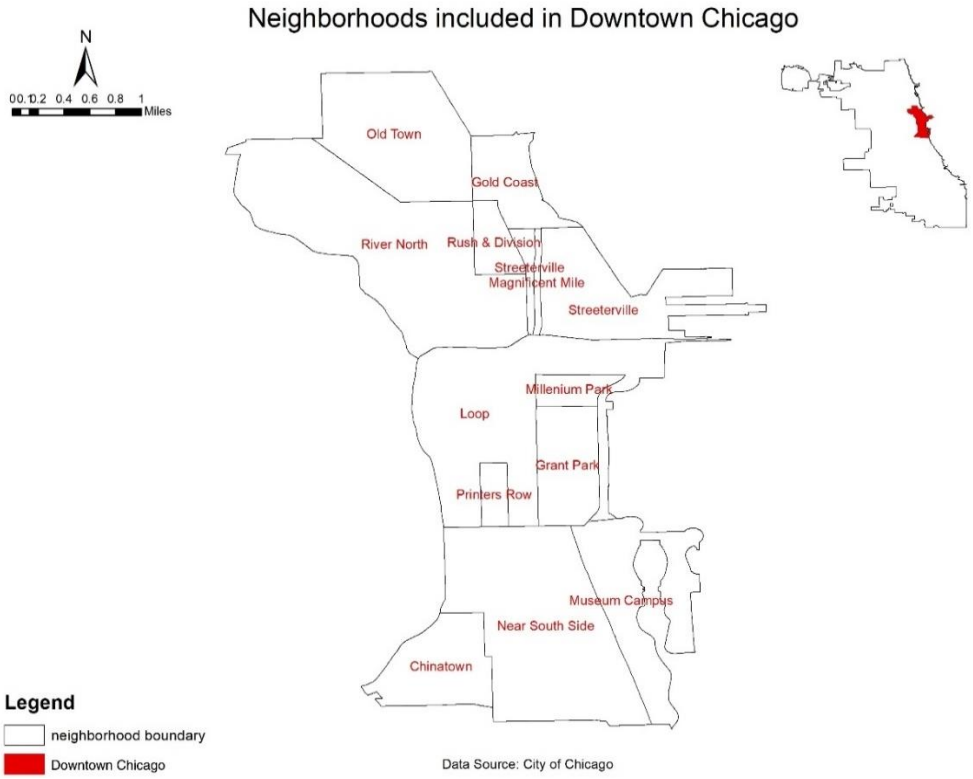

Figure 5.1: Neighborhoods in downtown Chicago

To locate where are the suitable sites for VG applications, we need first to go back and see what benefits VG can bring. Those places need to have issues in aspects such as urban heat-island effect and green space insufficiency, then adding VG could be an effective strategy to solve these issues and help to perform better in urban ecology and social living. VG can reduce urban heat island effect by cooling down the surrounding environment (Chan, 2018). The building would not need to turn on the air conditioners, saving energy for the whole society (Coma et al., 2014). So my first analysis was to spot where are the "hot" areas in downtown Chicago—analyzing Land Surface Temperature (LST). I found the higher LST happens in areas far away from the Michigan Lake. VG full of numerous plants can serve as noise insulation (Rakhshandehroo et al., 2015). I analyzed the noise distribution in downtown Chicago and found noise is mainly concentrated along the transportation network. VG is powerful to filter air by absorbing contaminative dust in the surrounding atmosphere (Perini & Roccotiello, 2018). VG

also functions to manage rainwater by purifying and slowly releasing it back into the environment, which aids in reducing pollutants flowing into soil and alleviates peak discharge fundamentally (Kubba, 2017). Based on these two functions, I analyzed the pollution level (air and soil) in downtown Chicago and concluded the relatively heavier polluted areas are in the north-west and south-west corners. The last VG benefit that could be quantified is to reintroduce biodiversity to the urban area by providing more natural habitats (Wong et al., 2010). Accordingly, I analyzed Normalized Difference Vegetation Index (NDVI) in downtown Chicago, which is a widely used parameter to detect the abundance of vegetation and evaluate ecosystem services, vegetation greenness, drought vulnerability, etc. (Zha et al., 2003). I found the areas next to Michigan Lake and northern downtown Chicago have a higher NDVI.

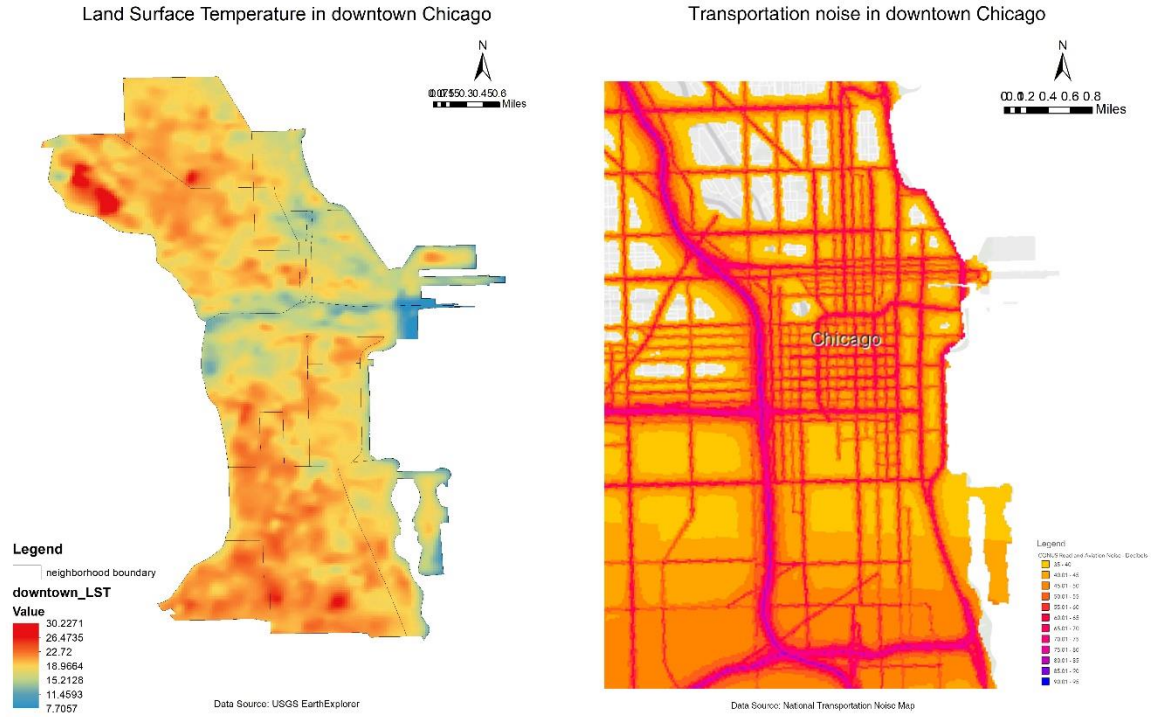

Figure 5.2: LST and noise distribution in downtown Chicago

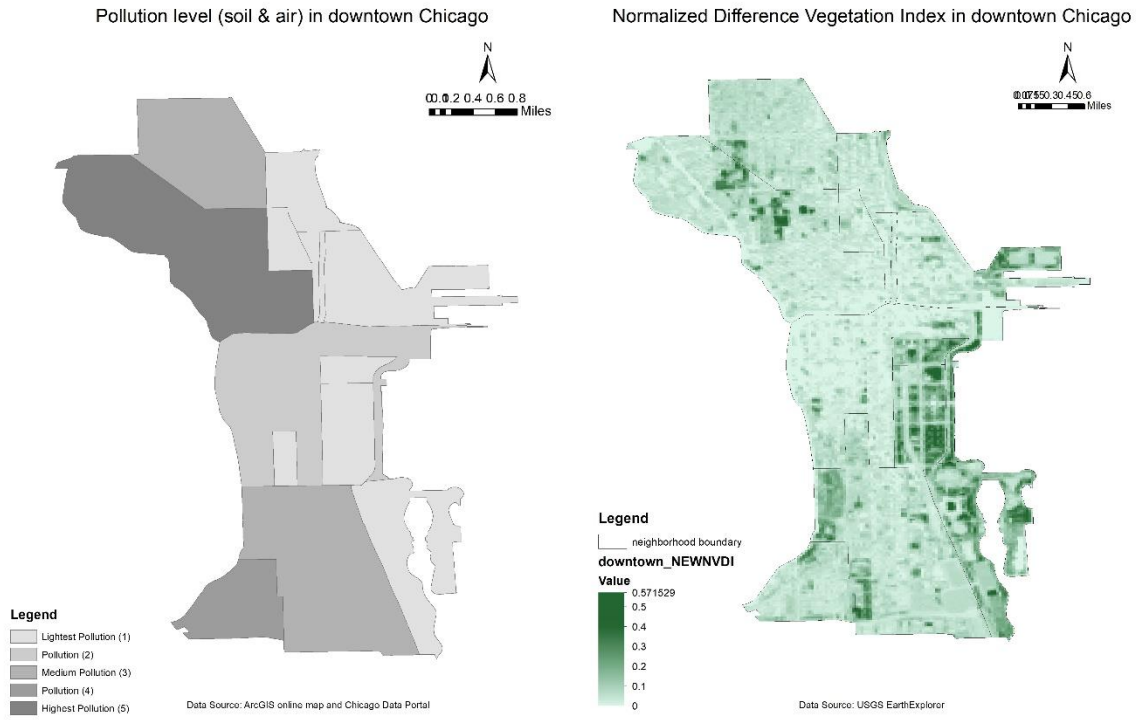

Figure 5.3: Pollution distribution and NDVI in downtown Chicago

Together with some demographic data such as population density and income distribution, the suitability for VG applications in downtown Chicago had been calculated. The weights for each determinant are LST *30%, NDVI *30%, Noise *20%, Pollution *10%, Population *5% and Income *5%. Based on the analyses, the differences between population density and income distribution in the researched area are not extreme relatively, since downtown Chicago is not a large area and mainly dominated by more affluent people. So I think the population and income distribution may be the least influential determinants. Considered the functionality of limited areas of VG, the LST, NDVI and noise will have the most obvious change after VG's installation, so they have larger weights. Comparably, pollution is more likely to be influenced by various factors and VG may play a limited role in alleviating it, so 10% weight was given to pollution. After the calculation, there are two areas with a higher suitability score located. Suitable site 1 contains Millenium Park and Grant Park neighborhood, and suitable site 2 contains Armour Square Chinatown and the southwest part of Near South Side neighborhood. To suggest effective and sustainable vertical landscapes, outdoor VGs will be proposed based on land use, major users, surface materials and final expectations.

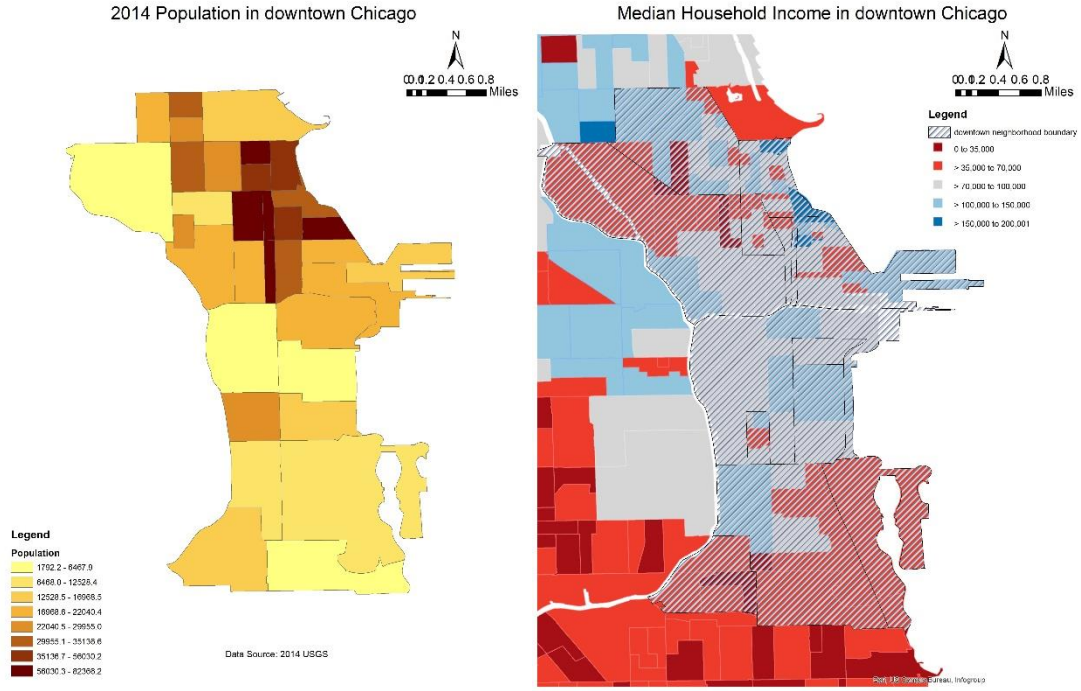

Figure 5.4: Population density and income variation in downtown Chicago

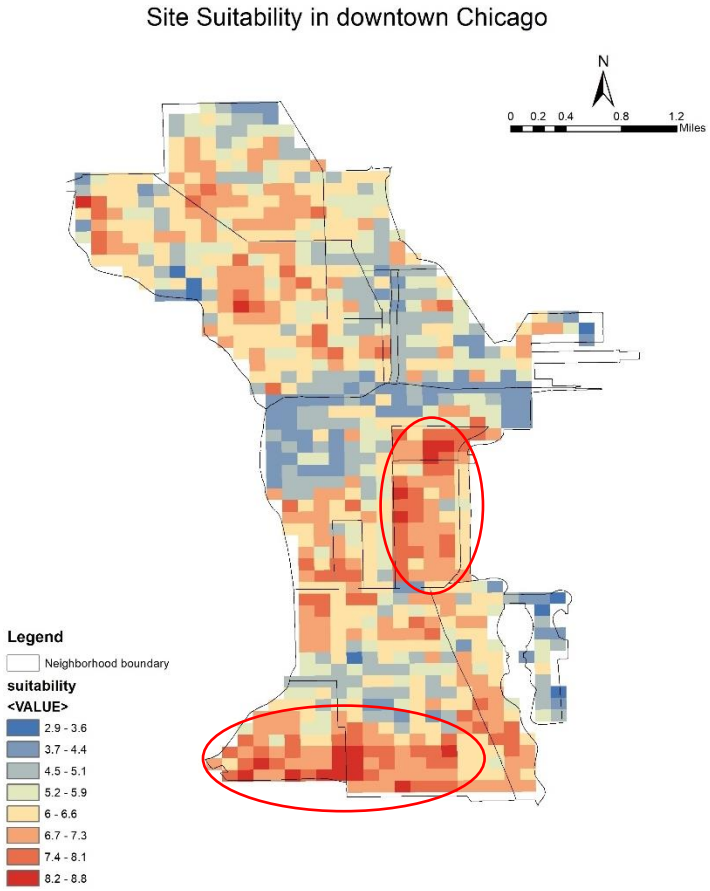

Figure 5.5: Suitability score for VG application in downtown Chicago and two suitable sites

Suitable site 1— Millenium Park and Grant Park neighborhood

Millennium Park neighborhood is a highly commercial area in Downtown Chicago that features a prominent collection of public art and gardens surrounded by the skyscrapers of the Loop. The park is a popular destination for tourists and features some of Chicago's most famous landmarks. During the day, especially during warmer weather, the area will be populated by tourists enjoying the park and professionals taking a break from work. Permanent residents of the area enjoy a vibrant and active urban lifestyle. Downtown Chicago hosts exciting events and festivals throughout the year and residents of Millennium Park are in a prime location to see it all (Gilfoyle, 2006). High-rises offering luxury condominiums and apartments overlook this iconic park. Along Michigan Avenue and Randolph Street, high-rises and notable skyscrapers that hold office space as well as upscale condominiums and penthouses can be found. At the ground level of many of these tall buildings are the neighborhood's restaurants. Grant park neighborhood is south next to Millennium park neighborhood and is called "Chicago's front yard". This neighborhood is renowned by having the most notable features which are Buckingham Fountain, the Art Institute of Chicago, School of the Art Institute of Chicago and the Museum Campus. Because of that, it owns performance venues, gardens, art work, sporting, and harbor facilities, and it hosts public gatherings and several large annual events (Kinzer, 2004). To summarize, these two neighborhoods are highly public sites with commercial, educational and open space land uses.

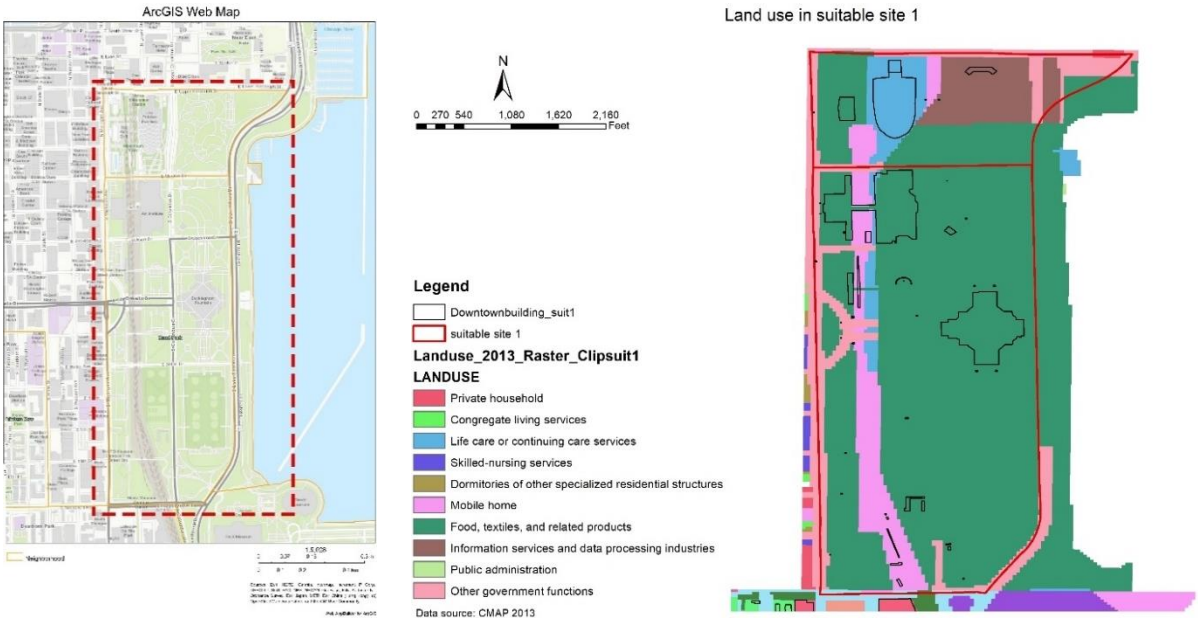

Figure 5.6: Buildings in suitable site 1 (left), land use and building footprint in suitable site 1 (right)

To increase the effectiveness of the proposed VG, there are two appropriate buildings—The Art Institute of Chicago and School of the Art Institute of Chicago. They are next to each other and both locate in the core area of Grant Park neighborhood. At the same time they bridge the two neighborhoods, making an extremely high human flowrate there every day. The Art Institute of Chicago already has a 154-year history (Augustyn et al., 2019) with a material of brick and stone on outside walls. For the preservation of historic buildings and its originally cultural sense, this building is not suitable to build a VG on the outside walls.

Figure 5.7: The Art Institute of Chicago. Source: arctic.edu

The School of the Art Institute of Chicago (SAIC), named the "most influential art school" in the United States, is a private university associated with the Art Institute of Chicago (AIC) and has been accredited since 1936 (George H. & Roeder, Jr., 2005). Although it has been 84 years old, the exterior walls are glass facades together with simple concrete and the interiors are full of modern ideas, too. Besides, VG can have an educational value for the public, such as plant identification, aesthetical design or serving as a spot for outside sketching. These two reasons make it a more suitable choice for a proposed VG which would not only match with the artistic atmosphere surrounded but also function to inspire people.

Figure 5.8: School of the Art Institute of Chicago. Source: Google Streetmap

Prototype 1: Commerce, Culture, Transportation, City Center, West-facing

Proposal: Living Wall System, High Seasonal Changing, Increasing Biodiversity, Climate Tolerance, Special Values

Figure 5.9: The VG-proposed stone wall and the bridge connecting it to Millennium Park (left and middle); The wall faces the east side of AIC and a rail transportation between them (right). Source: Google Streetmap

Because this building locates in the core area of downtown Chicago and is also directly connected to Millennium Park through a viaduct named Nichols Bridgeway, it is a hot spot for visitors. From the image 5.9 you can see the wall contains an entrance of the Modern Wing which is next to the school and usually included in the educational system by holding exhibitions, so it is educational to students and public. It deserves a more delicate and elegant VG to be more aesthetical pleasing. Therefore VG's type should be a living wall system instead of green façade. For more various landscapes during different times all year round, plant species should characterize more seasoning changing. It should also be attractive to different pollinators and birds which could make it more dynamic. Considering the wall's direction which is facing west, with less light on the morning and strong light in the afternoon, plants should be able to tolerate partial shade to full sun. It faces the rail transportation which would generate lots of urban pollution and dust, so plants should have a tolerance to urban pollution. Plants could also have some special values such as interesting fruits or strong fragrance. Students may help to harvest fruits and learn more about plant characters. Fragrant plants can please mental health and help to alleviate the unpleasing smell from the transportation.

The wall is approximately 100' W x 27' H. Area of the entrance is about 70 square feet (10' W x 7' H). There is also a glass façade where proposed VG is inapplicable. Its area is about 434 square feet (62' W x 7' H). In total, the area for proposed VG is 3796 square feet. Based on Google Streetmap, site visit and discussions with architecture experts, its structure is either a thin limestone layer outside with support of a real concrete wall behind, or a stone-like concrete wall. For both structures, the wall is able to afford the attachments of VG modules. The wall is safe enough to hold a living wall system. For the construction, there are two main ways to attach

modules—Clip-on modules and Hook-on modules. Clip-on allows for smooth installation and secure hold on the modules. This also means no drilling of green wall directly into wall to allow for maintenance of plants. This is suitable for high height green walls. Hook-on allows for mounting onto any size of fence, BRC or wire mesh. The easy hook-on system allows for easy installation and maintenance. This is suitable for low height green walls. Prototype 1 is a high-heights wall so we should use Clip-on method for installation. Mostly used modules are in size 12”x12” called standard planters (Outdoor Applications Only) and 16”x16” called large planters (Indoor or Outdoor Applications) (Weinmaster, 2009).

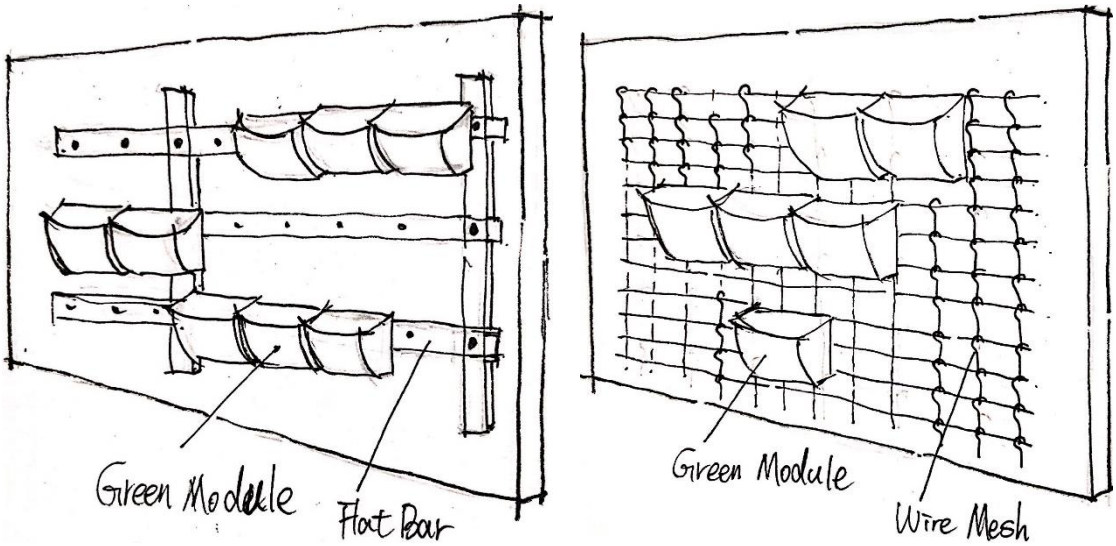

Figure 5.10: Clip-on modules (left) and Hook-on modules (right)

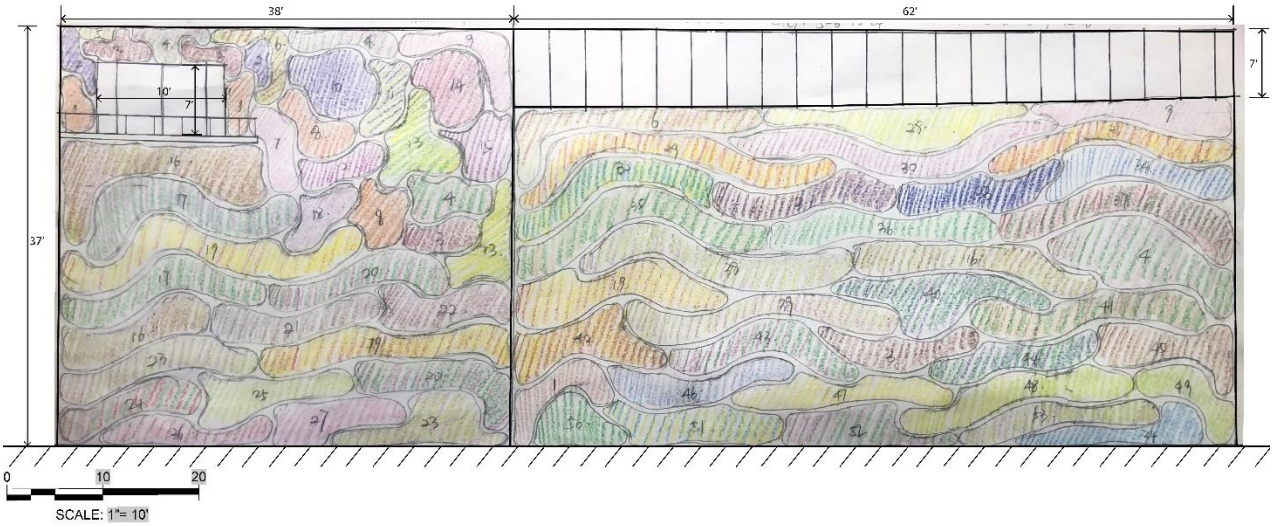

Figure 5.11: Master plan of the proposed VG; Colors show what the plants look like in blooming seasons. Plants are planted based on the module’s network which is a 1’x1’ grid system.

Table 5.1: Planting list of prototype 1

Planting list for prototype 1

Plant number	Species name	English name	Seasonal changing	Overall size/in	Growth rate	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Maintenance	Special value
1	***Tropaeolum majus***	**Common Nasturtium**	Annual. Bloom from May to Sep, orange-red flowers	6-8	Fast	Butterflies	—	Deer	Trellises, arbors, walls or fences.	Flower buds contain mustard oil and are used for seasonings; peppery flavor or the unripe seed pods can be used in salads.
2	***Campanula carpatica* 'Deep Blue Clips'**	**Carpathian Bellflower**	Deciduous. Bloom from May to Sep, blue, upturned, bell shaped flowers.	6-8	Medium	Hummingbirds	May be damaged by slugs and snails	Full sun; Drought	—	—
3	***Heuchera* 'Melting Fire'**	**Coral Bells Melting Fire**	Deciduous. Bloom from June to July, white flowers, purple foliage retained in winter	10-18	Medium	Butterflies, hummingbirds	—	Deer, shade	Remove stems of faded flowers to encourage additional bloom.	—
4	***Begonia grandis***	**Hardy Begonia**	Deciduous. Bloom from July to Oct, pink flowers, heart-shaped leaves with green above and red beneath	15-24	Medium	—	Winter hardiness is a concern in St. Louis.	Heavy Shade, Black Walnut	Keep soil moist	—
5	***Impatiens flaccida***	**Jewelweed**	Annual. Bloom from May to frost, pinkish lavender with bright magenta flowers	10-18	Fast	—	—	Drought, Dry Soil	It prefers moist, well draining soil of good fertility. Bright, indirect light or filtered sun is best.	—
6	***Geum* 'Mrs J. Bradshaw'**	**Avens**	Evergreen; Bloom from May to June; massed scarlet orange flower	23-29	Medium	Butterflies	May be short-lived in heavy clay soils and/or hot summer climates	Deer	Prune hard after blooming	—
7	***Scabiosa columbaria Pink Mist***	**Pincushion Flower**	Deciduous. Bloom from April to frost, pink flowers	12-18in	Medium	Butterflies, bees, birds	Watch for aphids and whiteflies.	Deer, drought	Cut off dead outer leaves in spring; cut back old flowering stems in winter	—
8	***Begonia sutherlandii***	**Hardy Orange Begonia**	Annual. Bloom from June to July, orange flowers	8-15	Medium	—	—	Not lower than 2 degree F	Keep soil moist	—
9	***Lathyrus latifolius***	**Sweat Pea or everlasting pea**	Deciduous; Bloom from June to Sep; pink-white flower	6-9ft	Fast	Bumblebees, butterflies, hummingbirds	Slugs and snails are attracted to young plants	Full sun; Drought	Walls, arbors, trellises, along fences or around pillars	—
10	***Salvia nemorosa* 'New Dimension'**	**Sage**	Deciduous. Bloom from June to Sep, violet-blue flowers	8-10	Medium	Butterflies, bees, hummingbirds	Some susceptibility to powdery mildew, leaf spot and rust.	Deer, Drought, Dry Soil, Air Pollution	Cut plants back after flowering	—

Table 5.1 (cont.): Planting list of prototype 1

Plant number	Species name	English name	Seasonal changing	Overall size/in	Growth rate	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Maintenance	Special value
11	***Campanula glomerata*** **'Superba'**	**Clustered bellflower**	Deciduous. Bloom from June to July, violet blue-deep purple bell shaped flowers.	12-18	Fast	—	—	Full sun	Needs regular moisture, Promptly remove spent flower stems to encourage additional bloom.	—
12	***Heuchera*** **'Obsidian'**	**Coral Bells 'Obsidian'**	Evergreen; Bloom from March to June; dark-purple foliage; cream-colored flowers	6-10	Medium	Butterflies	—	Heat, humidity, deer	Apply a protective winter mulch once the ground has frozen.	—
13	***Impatiens omeiana***	**Hardy impatiens**	Annual. Winter protection; Bloom from Sep to Oct, yellow flowers	9-18	Fast	—	—	Heavy shade	—	—
14	***Impatiens balsamina***	**Garden balsam**	Annual. Bloom from May to frost, pink, rose, red, purple, white and bicolor flowers	6-15	Fast	—	—	Drought, Dry Soil	—	—
15	***Petunia Supertunia Priscilla***	**Petunia**	Annual. Bloom from June to July, purple shades flowers	6-10	Medium	Butterflies, Hummingbirds, bees	—	Drought, Dry Soil	Perform best with regular watering	—
16	***Ajuga reptans*** **'Burgundy Glow'**	**Bugleweed**	Deciduous. Bloom from May to June, blue-purple flowers; green-purple-sliver foliage	8-15	Fast	—	Crown rot can be a problem, particularly in the humid conditions	Deer, Black Walnut	Avoid planting in wet, heavy soils, provide good air circulation and divide when clumps become overcrowded.	—
17	***Heuchera micrantha*** **'Palace Purple'**	**Alum root 'Palace Purple'**	Evergreen; Bloom from March to April; star-shaped foliage, deep olive green, purple-bronze, and brilliant deep purple leaves; yellowish-white flowers	8-12	Medium	Butterflies	—	Deer, salt	Divide clumps in spring every 3-4 years; apply winter mulch aftre the ground freezes	—
18	***Campanula poscharskyana***	**Serbian Bellflower**	Deciduous. Bloom from May to June, blue-lilac bell shaped flowers. Foliage is semi-evergreen to evergreen in warm winter.	8-12	Fast	—	—	—	Needs regular moisture, clumps may be divided in spring.	—

Table 5.1 (cont.): Planting list of prototype 1

Plant number	Species name	English name	Seasonal changing	Overall size/in	Growth rate	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Maintenance	Special value
19	***Heuchera Electra***	**Coral Bells 'Electra'**	Semi-evergreen; bloom time June to July; white flowers; yellow with blood-red veins leaves in spring	8-12	Fast	Butterflies, hummingbirds, bees	—	Vigor, heat, humidity, deer	Remove stems of faded flowers; winter mulch	—
20	***Trillium recurvatum***	**Purple Prairie Trillium; wood lily**	Deciduous; bloom time mid summer; purple to wine-red flowers. Dark green leaves with mottled appearance	12-18	Medium	Butterflies, bees	May attract carrion beetles and flesh flies	Full shade	—	—
21	***Heuchera* 'Glitter'**	**Coral Bells 'Glitter'**	Semi-evergreen; bloom time June to Sep; fuchsia-pink flowers; mirror-bright silver foliage with black veins	10-16	Fast	Butterflies, hummingbirds	—	Drought, full shade	Remove stems of faded flowers; winter mulch	—
22	***Heuchera* 'Wild Rose' PPAF**	**Wild Rose Heuchera**	Deciduous; bloom time mid summer; pink flowers. Rosy purple leaves with deep gray veining	8-10	Fast	Butterflies, hummingbirds	—	Full shade, deer	Container Planting; Hanging Baskets	—
23	***Phlox paniculata* 'Cosmopolitan'**	**Cosmopolitan Phlox**	Deciduous; bloom time from May to Sep; bright pink flowers.	12-16	Medium	Butterflies, hummingbirds	—	Good mildew resistance; Sandy and clay soil; good air circulation	Cut back by 1/2 in late spring/early summer	—
24	***Aquilegia vulgaris* 'Clementine Red'**	**Clementine Red Aquilegia**	Deciduous; bloom time April to June; red flowers. Lacy green foliage	12-18	Medium	Butterflies, hummingbirds	Leaf miners or sawfly may disfigure the leaves around flowering time.	Drought, deer, shade	Simply trim off the ugly foliage	—
25	***Calamintha nepeta subsp. nepeta***	**Calamint**	Deciduous; bloom time Aug to Oct; lavender and white flowers, flowers and leaves are fragrant	12-18	Medium	Butterflies, bees	Foliage may decline in hot and humid summer; Watch for powdery mildew.	Drought, Erosion, Dry Soil, Shallow-Rocky Soil, deer	Prefers well-drained soil	—
26	***Stachys* 'Lilac Falls'**	—	Deciduous; bloom time June to Sep; carpet of lavender flowers that add color to borders	8-12	Medium	Butterflies, bees	Aphids, spider mites and whiteflies; Watch for root rot	Hanging baskets and works well as a cascading plant in combination planters.	—	—
27	***Monarda* 'Balmy Purple'**	**Bee Balm 'Balmy Purple'**	Deciduous; bloom time from May to August; bright purple flowers.	10-12	Fast	Birds, butterflies, hummingbirds	Powdery mildew	Clay soil, deer	Cut to the ground after flowering; divide every 3 years; good air circulation	—
28	***Lathyrus ochroleucus***	**Cream Pea**	Deciduous; Bloom from May to July; White-yellow flower	2.7-3.6ft	Fast	Bumblebees, butterflies, hummingbirds	All parts of plant are poisonous if ingested	Full sun	Walls, arbors, trellises, along fences or around pillars	—

Table 5.1 (cont.): Planting list of prototype 1

Plant number	Species name	English name	Seasonal changing	Overall size/in	Growth rate	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Maintenance	Special value
29	***Zinnia elegans* 'Dreamland Series'**	**Bedding zinnia**	Annual; bloom time from May to August; flowers are in apricot, ivory, red, yellow, pink, and many shades in between.	8-12	Medium	Bees, butterflies	Bacterial and fungal spots, bacterial wilt, powdery mildew, caterpillars, mealybugs, spider mites	well-draining soil; Full sun	Deadhead spent blossoms to continue flowering	—
30	***Monarda* 'Balmy Purple'**	**Bee Balm 'Balmy Purple'**	Deciduous; bloom time from May to August; bright purple flowers.	10-12	Fast	Birds, butterflies, hummingbirds	Powdery mildew	Clay soil, deer	Cut to the ground after flowering; divide every 3 years; good air circulation	—
31	***Zahara™ Zinnia***	**Zinnia marylandica Zahara™ Series Patented**	Annual; bloom time from March to July; muticolored flowers	12-18	Medium	Butterflies	—	Highly mildew resistant; urban polution; well-draining soil; Full sun	Occasional watering; Trim off the flower heads after they fade to encourage more blooms	—
32	***Primula acaulis* 'Zebra Blue'**	**Blue Zebra™ Primrose**	Semi-evergreen; winter protection; bloom time March to Sep; blue and white striped petals with a bright yellow center flowers	6-8	Medium	Hummingbirds, butterflies, bees	—	Full shade, deer	Crown of plant should rest just at or above the soil surface after watering in.	—
33	***Lobelia erinus***	**Edging lobelia**	Annual; bloom time from April to June; Blue to violet with yellow to white throat flowers	6-9	Medium	Butterflies	Mid-summer die back is usually the most serious problem.	Deer	Cut back after summer blooming to encourage a fall bloom	—
34	***Hosta sieboldiana* 'Elegans'**	**Hosta**	Evergreen; bloom time May to June, white with a lavender tinge; large smoky-blue rounded leaves	12-24	Slow	Hummingbirds	Slugs and snails are attracted to the foliage.	Full shade	Wet, Well Draining soil; Divide plants as needed in spring or autumn.	—
35	***Dianthus deltoides* 'Arctic Fire' (Maiden Pink)**	**Maiden Pink 'Arctic Fire'**	Evergreen; bloom time April to August; white serrated petals surrounding a deep fiery red eye	6-8	Medium	Butterflies, bees	—	Sandy soil, deer, humidity, drought	—	Flowers are perfect for small bouquets
36	***Hepatica acutiloba***	**Sharp-lobed hepatica**	Evergreen; bloom time March to May; white to lavender blooms with an occasional pink bloom.	4-8	Slow	Butterflies, bees	—	Shade, deer	Prefers well-drained soil	Leaves can be made herbal remedy.
37	***Lakota Fire Echinacea***	**Lakota Fire Echinacea Coneflower**	Deciduous; bloom time June to Sep; colorful coneflower with reddish-orange and pinkish red flowers	12-16	Medium	Butterflies, hummingbirds, bees	—	Drought, deer	Need Good Drainage	—

Table 5.1 (cont.): Planting list of prototype 1

Plant number	Species name	English name	Seasonal changing	Overall size/in	Growth rate	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Maintenance	Special value
38	***Phlox stolonifera* 'Sherwood Purple'**	**Sherwood Purple Woodland Phlox**	Evergreen; bloom time April to June; purple flowers	6-10	Medium	Butterflies	—	Shade, drought	Occasional shearing to stimulate growth. After flowering or late summer.	—
39	***Lamium maculatum* 'Orchid Frost'**	**Spotted Deed Nettle**	Deciduous. Bloom time April to June; orchid-pink flowers; Scalloped blue-green margins and shimmering silvery centers	4-6	Fast	Butterflies	—	Heavy shade, deer, urban pollution	They may be trimmed to shape growth or cut back if desired; Water regularly to maintain evenly moist soil	—
40	***Athyrium niponicum* Red Beauty**	**Japanese Painted Fern Red Beauty**	Evergreen; silver-tinged green fronds that sport deep-burgundy stems and veins	12-18	Medium	—	—	Heavy shade, deer	Mulch the plants to maintain consistent soil moisture.	—
41	***Geranium Cranesbill***	**Hardy Geraniums**	Deciduous. Bloom time May to Sep; blue-purple blooms; bright orange to red color foliage	15-18	Medium	Butterflies, hummingbirds	—	Shade, deer, drought	Moist but well-drained soil	—
42	***Coleus blumei***	**Coleus**	Evergreen. Bloom time summer; White flowers; colored foliage—in combinations of green, yellow, pink, red, maroon, etc.	6-12	Fast	—	—	Heavy shade, deer	Keep the soil evenly moist, but never soggy.	—
43	***Primula polyantha***	**Primrose**	Deciduous. Bloom time spring; Blue Green Red Orange White Pink Yellow flowers; blue/green foliage	6-12	Medium	Hummingbirds, butterflies, bees, birds	—	Shade, deer	Prefer consistent moisture, well-drained soil is a must	—
44	***Pulmonaria***	**Lungwort**	Evergreen; Bloom time April to May; blue, deep-purple bells flowers; hairy dark-green leaves are heavily spotted in silver	12-14	Medium	Bees and other pollinators	—	Heavy shade, deer, urban pollution, black walnut	Cut back hard immediately after blooming	Some can be used as herb medicine.
45	***Heucherella* 'Sweet Tea'**	—	Evergreen. Bloom time spring; white flowers; Bronze, Brown, Burgundy, Copper, Gold, Orange, Red, Rose, Variegated foliage	12-20	Medium	Butterflies	—	Drought, Heat, Humidity, shade, deer	Well-drained soil is critical	—
46	***Mertensia virginica***	**Virginia Bluebells**	Deciduous. Bloom time March to July; pink buds that later mature into lavender-blue flowers	10-18	Medium	Hummingbirds, bees	—	Heavy shade, deer	Water plants regularly during the first year after planting	—

Table 5.1 (cont.): Planting list of prototype 1

Plant number	Species name	English name	Seasonal changing	Overall size/in	Growth rate	Increase biodiversity	Pest promotion or other problems	Climate tolerance	Maintenance	Special value
47	*Pachysandra terminalis*	Japanese Spurge	Evergreen. Bloom time March to April; White flowers	4-12	Slow	—	Leaf blight; Root/stem rot may also occur. Watch for scale and mites.	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil	—	—
48	*Hakonechloa macra* 'Aureola'	Golden Japanese Forest Grass	Evergreen; bloom time from July to Aug, yellow-green flowers; Slender stems holding bright yellow leaves with thin green stripes	12-18	Slow	—	—	Shade, deer, urban pollution	Water regularly to maintain evenly moist soil	—
49	*Hosta* 'Captain's Adventure'	Hosta	Evergreen. Bloom time spring; Mauve/Lilac flowers; Chartreuse, Deep Green, White foliage	14-16	Medium	Hummingbirds	Slugs and snails are attracted to the foliage.	Heavy shade, drought, urban pollution		—
50	*Helleborus niger*	Black hellebore	Evergreen; Bloom from Feb to March; White fading to blush pink with yellow stamens flowers	8-12	Slow	—	Crown rot and leaf spot are occasional problems. Watch for aphids and slugs.	Deer, Dry Soil, polluted air, full shade	Protect them from cold winter winds; remove faded flowers stem to promote new growth	—
51	*Hosta* 'Popcorn'	Hosta	Evergreen. Bloom time July; Pale lavender flowers; bright yellow with a nice blue margin foliage	10-12	Medium	Hummingbirds	—	Heavy shade, drought, urban pollution	Cleaned up in early spring before it resumes active growth for the season.	—
52	*Geranium endressii*	Cranesbill Geranium	Semi-evergreen; Bloom from April to Aug; deep-pink flower; heart-shaped leaves	12-20	Medium	—	—	Shade, polluted air, clay soil	Cut back hard in midsummer to encourage fresh new foliage	—
53	*Lamium Shell Pink*	Spotted Dead Nettle	Evergreen. Bloom time April to July; snapdragon-like, pink flowers; heart-shaped green leaves with a white stripe down the middle	10-12	Fast	Butterflies	—	Heavy shade, deer, urban pollution, clay soil	Shear back to 4 to 6" if it gets leggy or cut back to new leaves at base of plant in midsummer	—

Design concept is basically based on the analysis of people's view. Closer to people, more colorful and vivid plants selected. Broader view, more organized pattern. Plant configuration near the entrance is made up of small groups of plants because I want more various plant species for people to observe closely. In the farther area, the south part of the wall, I used streamlined pattern with more organized and larger groups of plants to coordinate with the rail transportation beside. Also, with a farther distance, people will appreciate more of plants order and neat configuration, which is similar to an earth landscape. Besides, I considered the blooming time of different groups and coordinated them to achieve a year-round blooming for the whole green wall. To let every group of plants be viewed entirely, I put higher plants more southern of the wall so they won't block the view of shorter plants and can serve as a green

background. In the middle part of the wall, plant's height is varied slightly from 8 inches to 15 inches so the wall will be more topographical and interesting. Fifty-three plants are selected based on the criteria of high seasonal changing, increasing biodiversity, shade and pollution tolerance, and special values. Closer to the ground, more groups of plants are pollution tolerant.

Normally people would like to have one complete plant orders from one broker. After learning from some experts, there are nine big brokers recommended which also release information about planting guides, tools and accessories for plants. People can easily get a quote for their entire plant order.

1) Mountain Crest Gardens™, https://mountaincrestgardens.com/, has been focusing on succulent nursery since 1995. It offers affordable assorted trays with no minimum order or wholesale account requirements.
2) Ball Seed, https://www.ballseed.com/CatalogsBrochures/, supports category searching such as plants selected by class, color, use, or blooming season. Besides it also provides landscape inspirations such as plant placing tools and plant trials.
3) Hummert International, https://www.hummert.com/, focuses more on greenhouse equipment and irrigation system. It also provides chemicals indispensable for plants.
4) Germania, http://germaniaseed.com/index.tpl, a good broker for plant seeds.
5) BFG Supply, https://www.bfgsupply.com/, also supplies gardening equipment such as irrigation system and plants container. It also has instructions for pest management and invasive plants control.
6) Griffin, https://www.griffins.com/, can provide ready-to-install plants.

Figure 5.12: Perspective of the proposed VG in blooming season

Suitable site 2—Chinatown and the southwest part of Near South Side neighborhood

The Chinatown neighborhood is on the South Side (located in the Armour Square community area), centered on Cermak and Wentworth Avenues, and is an example of an American Chinatown, or ethnic-Chinese neighborhood. It is home to a number of banks, Chinese restaurants, gift shops, grocery stores, Chinese medicine stores, as well as a number of services that cater to people interested in Chinese culture, including those speaking varieties of Chinese, especially Cantonese. It is a community hub, a business center, as well as a popular destination for tourists and locals alike (Laffey, 2009). Although the major land use in Chinatown neighborhood is commerce, there are several residential communities scattered on the margin areas. Because it is kind of the south entrance of downtown Chicago, there are numerous rail trails, viaducts and highways in its southwest area connecting downtown Chicago with southern cities. The land use of transportation also takes up a large part. For Near South Side neighborhood, it contains a major of residential land use and others are mixed-use. There is basically no specialty of this neighborhood, in other words, commercial, educational, governmental and transportation land uses can all be found there. Given that the more suitable place is the southwest part of this neighborhood which is mainly residential land use, VGs proposed in suitable site 1 and Chinatown neighborhood would also be applicable there. As a result, there is no new VG's prototype in this neighborhood.

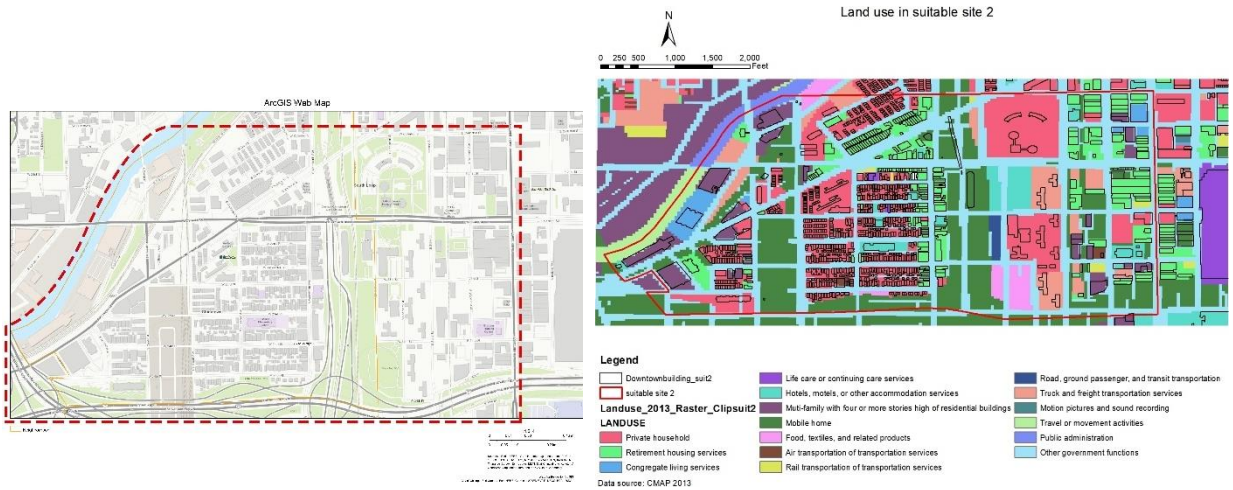

Figure 5.13: Buildings in suitable site 2 (left), land use and building footprint in suitable site 2 (right)

Figure 5.14: Chinatown commerce (left) and the common residential buildings in these two neighborhoods. Source: welltraveled.com and Google Streetmap

Prototype 2: Residence, Healthcare, Activity Center, North-Facing

Proposal: Various Types Of VG, Shade tolerance, Low Pest Promotion and Other Problems, Vigorous Foliage, High Seasonal Changing, Special Values

Figure 5.15: The activity center where the proposed VG is (left), Proposed wall with red CMU materials (right)

As a gathering place in a residential community, the activity center shoulders the responsibility to unite residence, educate children, share newest information and take care of the

elderly. VG is a precious opportunity that can enlarge those functions. Proposed VG could be either living wall system or green façade but a vigorous foliage is a fundamental requirement to cover the red wall. Low pest promotion is another indispensable requirement for a residential area. Plants should not be pest attractive at the same time repel mosquitoes and flies which annoy people so much. Given that there is a north-facing wall, plants should have a good tolerance to partial shade and heavy shade. Plants with special values such as fruits are favored by residence since people are willing to take care of interesting plants near their home and witness the bearing moment with a sense of achievement. Plants with various seasonal changing and unique shapes could be exciting to enlarge people's knowledge and let them cherish this green infrastructure more in their daily life.

This wall is made up of two different-height buildings. The shorter and western one is about 10.5' H x 17' W and the higher eastern one is about 14' H x 60' W. Material used of this wall is the rough concrete masonry unit (CMU), which is safe enough to be drilled holes and hold the weight of vertical greening. Since this is not a large wall, Hook-on module is an appropriate way for living wall system. For a green façade, we could select adhesive plants and let them attach the wall by themselves, or add a wire system first and have more choices than only adhesive plants. For this prototype, I combined living wall system and green façade together to create a more varied landscape.

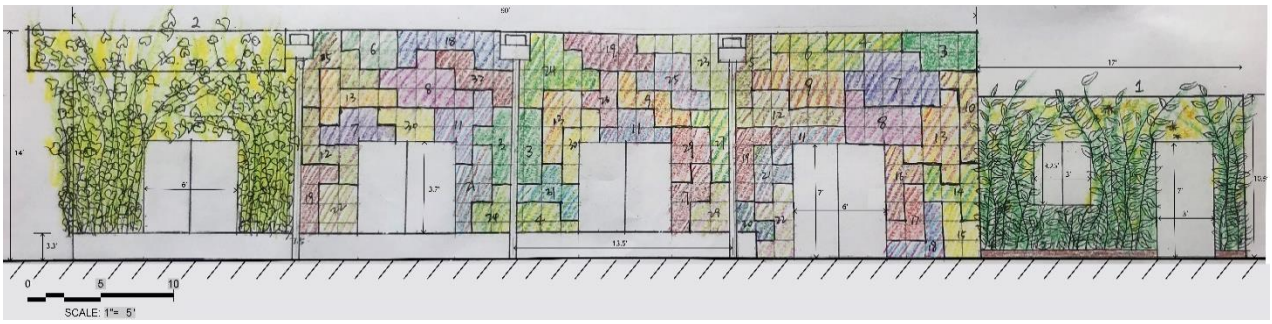

Figure 5.16: Master plan of the proposed VG; Colors show what the plants look like in blooming seasons. Plants are planted based on the module's network which is a 1'x1' grid system.

Table 5.2: Planting list of prototype 2-Climbers

Planting list for prototype 2-Climbers

Plant number	Species name	English name	Climate tolerance	Pest promotion or any other problems	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type
1	***Pileostegia viburnoides***	**Climbing hydrangea**	Heavy shade, drought	—	12-24	Slow	5	Aerial roots
2	***Hedera colchica***	**Bullock's heart ivy**	Drought, Heavy Shade, Dry Soil	Leaf spots and mites can be significant problems. Slugs and snails will sometimes hide and breed in the thick foliage.	30-50	Fast	5	Aerial rootlets

Planting list for prototype 2-Climbers

Species name	English name	Seasonal changing	Increase biodiversity	Structural support	Maintenance	Special value
Pileostegia viburnoides	**Climbing hydrangea**	Evergreen; bloom time May to June; white flower	—	Sprawled over low stone walls, or sturdy arbors, fences or the trunks of large trees	Prune after flowering	—
Hedera colchica	**Bullock's heart ivy**	Evergreen; bloom time Sep to Oct; greenish-white flower	Bees, birds	—	Trim plants in early spring to control growth and maintain attractive appearance.	—

Table 5.3: Planting list of prototype 2-Herbaceous plants

Planting list for prototype 2-Herbaceous plants

Plant number	Species name	English name	Climate tolerance	Pest promotion or other problems	Overall size/in	Growth rate	Seasonal changing	Increase biodiversity	Maintenance	Special value
3	***Convallaria majalis***	**Lily of the valley**	Deer, Heavy Shade, Erosion, Clay Soil, Dry Soil	—	8-12	Medium	Deciduous; bloom time April; white flower	Bees	Needs regular watering in pots	—
4	***Hosta* 'El Niño'**	**Plantain lily**	Deer	—	16-18	Medium	Evergreen; Bloom from July to Aug; Pale lavender flowers; pointy powder-blue leaves with streaky white margins	Bees	Needs regular watering in pots	—
5	***Asplenium scolopendrium***	**Hart's tongue fern**	Heavy shade	—	12-18	Fast	Evergreen; no flowering; tongue-shaped, leathery, bright green leaves	—	Require medium moisture, well-drained, alkaline to slightly acidic soils	—
6	***Anemone multifida***	**Anemone**	Heavy shade	—	8-12	Slow	Deciduous; bloom time May to July; butter-yellow flower; fern-like, sliver-green foliage	Bees	Easily divided in fall or early spring.	—
7	***Pulmonaria angustifolia***	**Blue Lungwort**	Full shade	—	9-12	Medium	Semi-evergreen; bloom time seasonal blooming spring, bright deep blue, funnel-shaped flowers; roughly hairy, ovate dark green basal leaves	Bees	Requires consistently moist soil	—

Table 5.3 (cont.): Planting list of prototype 2-Herbs

Plant number	Species name	English name	Climate tolerance	Pest promotion or other problems	Overall size/in	Growth rate	Seasonal changing	Increase biodiversity	Maintenance	Special value
8	***Pulmonaria* 'Dark Vader'**	**Dark Vader Lungwort**	Full shade, deer, clay soil, Black Walnut	—	10-12	Medium	Evergreen; Bloom time April to May; deep-purple bells flowers; hairy dark-green leaves are heavily spotted in silver	Bees and other pollinators	Cut back hard immediately after blooming	—
9	***Heuchera Electra***	**Coral Bells 'Electra'**	Vigor, heat, humidity, shade, deer	—	8-12	Fast	Semi-evergreen; bloom time June to July; white flowers; yellow with blood-red veins leaves in spring	Butterflies, hummingbirds, bees	Remove stems of faded flowers; winter mulch	—
10	***Lamium galeobdolo***	**Yellow archangel**	Deer, Drought, Heavy Shade, Erosion, Dry Soil, Shallow-Rocky Soil, Air Pollution	Slugs and snails are occasional visitors. Leaf blight. Mites. Can spread invasively.	9-15	Fast	Deciduous. Bloom time June; Yellow, flecked brown flowers, variegated with silver-gray markings	—	If plants become leggy, shear back to 4-6" or to new fresh basal leaves in order to shape plants and to promote new foliage growth.	—
11	***Lamium maculatum* 'Orchid Frost'**	**Spotted Deed Nettle**	Heavy shade, deer, urban pollution	—	4-6	Fast	Deciduous. Bloom time April to June; orchid-pink flowers; Scalloped blue-green margins and shimmering silvery centers	Butterflies	They may be trimmed to shape growth or cut back if desired; Water regularly to maintain evenly moist soil	—
12	***Tiarella cordifolia***	**Foamflower**	Heavy shade, deer	—	6-12	Medium	Deciduous. Bloom time spring; white-pink flowers; colorful fall foliage	Birds	Prefer well-drained soil with consistent moisture	—
13	***Coleus blumei***	**Coleus**	Heavy shade, deer	—	6-12	Fast	Evergreen. Bloom time summer; White flowers; colored foliage—in combinations of green, yellow, pink, red, maroon, etc.	—	Keep the soil evenly moist, but never soggy.	—
14	***Alchemilla mollis***	**Lady's mantle**	Shade, deer, drought	—	10-12	Fast	Deciduous. Bloom time June to Sep; Yellow flowers; fuzzy, cup-like leaves	—	Require supplemental water in high heat or full sun areas to prevent leaves from turning brown	Used in making lotions and soaps
15	***Hakonechloa macra* 'Aureola'**	**Golden Japanese Forest Grass**	Shade, deer, urban pollution	—	12-18	Slow	Evergreen; bloom time from July to Aug, yellow-green flowers; Slender stems holding bright yellow leaves with thin green stripes	—	Water regularly to maintain evenly moist soil	—
16	***Primula polyantha***	**Primrose**	Shade, deer	—	6-12	Medium	Deciduous. Bloom time spring; Blue Green Red Orange White Pink Yellow flowers; blue/green foliage	Hummingbirds, butterflies, bees, birds	Prefer consistent moisture, well-drained soil is a must	—
17	***Abutilon spp.***	**Flowering Maple**	Shade	Watch out for whiteflies and scale insects	6-12	Fast	Evergreen. Bloom time June to Oct; orange-red flowers; maple-like leaves	—	Keep the soil evenly moist, but never soggy.	—
18	***Geranium* Cranesbill**	**Hardy Geraniums**	Shade, deer, drought	—	15-18	Medium	Deciduous. Bloom time May to Sep; blue-purple blooms; bright orange to red color foliage	Butterflies, hummingbirds	Moist but well-drained soil	—
19	***Heucherella* 'Sweet Tea'**	—	Drought, Heat, Humidity, shade, deer	—	12-20	Medium	Evergreen. Bloom time spring; white flowers; Bronze, Brown, Burgundy, Copper, Gold, Orange, Red, Rose, Variegated foliage	Butterflies	Well-drained soil is critical	—

Table 5.3 (cont.): Planting list of prototype 2-Herbs

Plant number	Species name	English name	Climate tolerance	Pest promotion or other problems	Overall size/in	Growth rate	Seasonal changing	Increase biodiversity	Maintenance	Special value
20	***Strobilanthes dyerianus***	**Persian shield**	Heavy shade	—	12-24	Medium	Deciduous. Bloom time Sep to Oct; cone-shaped blue flowers; neon shades of purple, veined with green foliage	—	Prune it after blooming to keep compact foliage	—
21	***Brunnera macrophylla* 'Jack Frost'**	**Jack Frost Siberian Bugloss**	Deer, full shade	—	10-12	Slow	Evergreen; Bloom time April to May; blue flowers; heart-shaped, dark green, basal foliage	—	Water regularly during the hot summer	—
22	***Hosta* 'Raspberry Sundae'**	**Hosta**	Heavy shade	—	10-20	Medium	Evergreen. Bloom time Aug to Sep; lavender-purple flowers; Creamy yellow leaves that turn white quickly, the red of the petioles goes into the white center of the leaf	Hummingbirds	Humus-rich, moist but well-drained soil.	—
23	***Hosta undulata* var. *undulata***	**Wavy Plantain Lily**	Deer, clay soil	—	13-17	Medium	Evergreen; Bloom from April to Sep; tubular flowers; variegated leaves with a narrow cream-colored centre and a broad green margin	Bees	Cut off the stems after blooming to encourage the plant's growth	—
24	***Hosta* 'Popcorn'**	**Hosta**	Heavy shade, drought, urban pollution	—	10-12	Medium	Evergreen. Bloom time July; Pale lavender flowers; bright yellow with a nice blue margin foliage	Hummingbirds	Cleaned up in early spring before it resumes active growth for the season.	—
25	***Mertensia virginica***	**Virginia Bluebells**	Heavy shade, deer	—	10-18	Medium	Deciduous. Bloom time March to July; pink buds that later mature into lavender-blue flowers	Hummingbirds, bees	Water plants regularly during the first year after planting	—
26	***Impatiens***	**Busy Lizzie**	Shade	Watch out for Spider mites Impatiens Downy Mildew (IDM)	6-18	Medium	Deciduous. Bloom time May to Sep; Orange, Pink, Purple, Red, White, Yellow blooms	Birds	Humus-rich, moist but well-drained soil.	—
27	***Melissa officinalis***	**lemon balm**	Shade, full sun, deer	Powdery mildew, leaf spot, leaf blight and gray mold may occur	12-18	Fast	Deciduous; Bloom time June to Aug; white to pale yellow flowers.	Bees	Require dry to medium, well-drained soils; Frequent pruning	Edible leaves that have a mild lemon scent similar to mint; tea, flavouring, essential oil, alternative medicine
28	***Coriandrum sativum***	**Cilantro/Coriander**	Full sun, shade	Potential disease problems include damping off, rot, wilt and bacterial blight, blossom blight and aster yellows. Potential insect pests include grasshoppers, leafhoppers and cabbage loopers.	12-18	Fast	Annual; Bloom time seasonal bloomer; White to pink to pale lavender flowers	—	Best growth occurs in cool and dry summer climates. Prune creeping thyme ground cover in the spring to maintain a compact appearance and again after the small white flowers are spent if additional shaping is preferred.	Edible leaves and stems. Mature seeds are used for flavoring sauces, meats, sausages, stews, chutneys, pies and cakes.
29	***Thymus***	**Creeping Thyme**	Deer, drought, shade, dry soil, rocky soil, salt	Susceptible to root rot in soil that is too moist	3-5	Fast	Evergreen; bloom time May to July, light purple, white, orange, red, yellow flowers; evergreen with lightly haired foliage	Butterflies, bees		Edible with a flavor and aroma akin to mint when crushed or steeped for teas or tinctures

Table 5.3 (cont.): Planting list of prototype 2-Herbs

Plant number	Species name	English name	Climate tolerance	Pest promotion or other problems	Overall size/in	Growth rate	Seasonal changing	Increase biodiversity	Maintenance	Special value
30	***Chamaemelum nobile***	**Chamomile**	Shade, drought	Can spread aggressively	3-6	Fast	Evergreen; Bloom time June to September; White rays with yellow centers flowers	—	—	Finely-dissected, fern-like foliage emits a fruity scent when bruised. Flower heads may be dried to make chamomile tea and medicine
31	***Viola sororia***	**Common Blue Viola**	Shade, clay soil, wet soil, deer, black walnut	Watch for slugs, snails, aphids, glasshouse red spider mite, violet gall midge, powdery mildews and pansy leaf spot	6-10	Medium	Deciduous; Bloom time April to Aug; blue-violet flowers with white throats; heart-shaped leaves	Butterflies and bees.	—	Leaves can be used in salads or cooked as greens. The flowers can be made into candies, cupcakes, frozen in ice cubes and jellies
32	***Heuchera* 'Melting Fire'**	**Coral Bells Melting Fire**	Deer, shade	—	10-18	Medium	Deciduous. Bloom from June to July, white flowers, purple foliage retained in winter	Butterflies, hummingbirds	Remove stems of faded flowers to encourage additional bloom.	—

The goal is for people to experience various types of VG since living wall system and green façade are both suitable for suitable 2. Given that plants for green façade might be invasive in some cases and lots of those are better grown by their own, I designed green façades at the end of this wall, the most east and west part. For both parts, they are kind of separated from the middle part. The west part goes back a little bit and shorter than others which provides good isolation for climbing plants. The east part is made up of two perpendicular walls which gives an abundant space for plants, and they can turn around to make a 3D effect when growing vigorously. Climbers I selected are evergreen plants in Chicago area then there will be vigorous green façades all around a year. They have different blooming seasons, summer (west) and fall (east), so they could have more variations during a year. There would be regular pruning needed for climbers to keep them away from the door and windows.

Figure 5.17: The most east part wall and it turns around. Image source: Google Streetmap

For the middle living wall system, plants are planted based on the 1'x 1' modular system. I divided this part of wall into 3 units using drainage pipes as divisions. The main concepts are that: 1) higher plants locate in the boundaries connecting green façades so they would not be covered by climbers' foliage easily; 2) higher plants are near the rainwater drainage pipes so they could be covered by beautiful plants easily to form an integrated living wall visually; 3) colorful and short plants are near the margins of doors and windows where they are more likely to be eye-catching. Also, those areas are easy for people to tough, in other words, to water, prune and harvest; 4) Plants without various seasonal changing are designed at the bottom where there is an existing planting pool with several plants. The bottom seems that can't avoid being blocked by former plants. It would not be too regretful if the covered plants are more like a green background. Plants selected have various blooming time from March to October, making an all-year-round landscape. For each unit, plant height is basically in a trend of increasing from middle to margin.

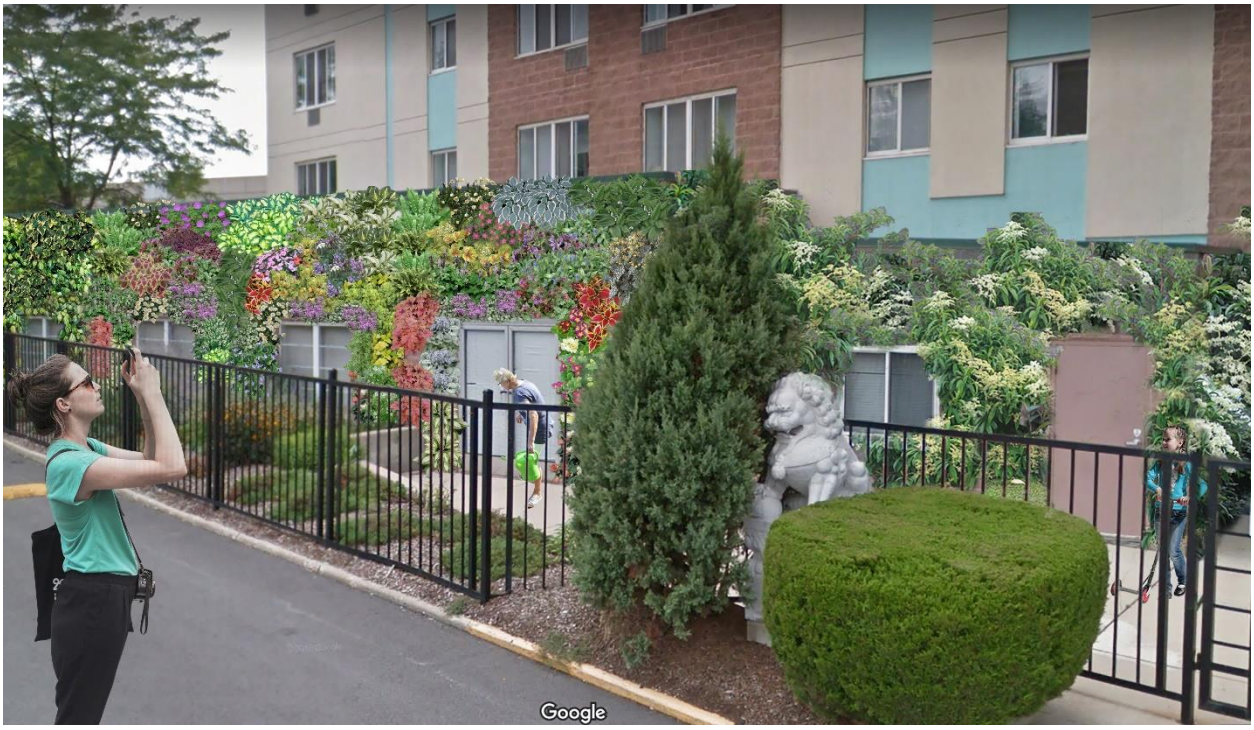

Figure 5.18: Perspective of the proposed vertical greening in blooming season

Prototype 3: Transportation, Station, Marginal Area

Proposal: Green Façade, Low Maintenance, No Damage to Surface Integration by Plants, No Sturdy Structural Support, Vigorous Foliage, Pollution Tolerance

Figure 5.19: The VG-proposed wall under a viaduct (left), a bus station of cta (right)

For margin areas of a city such as the buffer zone between downtown and rural areas, the space underneath viaducts which is called “urban black space”, and transportation stations, prototype 3 is the most suitable application. Common characters of these places are less pedestrian pass, little notice and relatively heavy urban pollution. An easy-maintaining VG is extremely important for this situation which can be achieved by a green façade instead of living wall system. Climbing plants commonly need low maintenance especially when mature, which basically contains pruning occasionally to control growth or extra watering during extremely hot weather. Another fundamental requirement for plants is no damage to the surface integration since almost all surfaces for prototype 3 belong to transportation infrastructure, such as pillars for highway or canopies for stations. We need that infrastructure to be long-lasting as much as possible. As a result, plants climbing by aerial rootlets should be avoided in this case because they can penetrate gaps and even the tiniest cracks, widening them and allow extra moisture to enter into the wall assembly. Freeze-thaw cycles can then increase the size of the openings and even dislodge masonry units. A solution for that can be adding structural support such as wire network to avoid direct touch between those plants and surface, but that would increase the construction budget and possible replacement of the support in the future, which is probably not preferred by sponsors to invest in those easy-ignoring place. For plants that don’t need sturdy structural supports, it’s still suitable to select them particularly when they have outstanding characters in other aspects. After all, non-sturdy supports are not very expensive and beautiful plants instead would make that worthy. A cascading groundcover is also a strategic way to avoid

surface damage, which can be achieved by planting plants in hanging baskets along the viaduct. Moreover, a vigorous foliage is favored in this situation to cover the bare concrete wall quickly and entirely, using green to beautify those unpleasing corners. A good tolerance to urban pollution such as transportation dust is a key point to make sure that plants can grow well without maintenance. Not only tolerance, plants that can absorb dust and purify the air are largely preferred in prototype 3. We should keep in mind that it's better to plant only one plant species in a continuous wall then there would be less invasive issue and the landscape would be neater and more orderly. I used the wall underneath a viaduct in the southwest part of Chinatown as an example. It is about 9-foot height, 1 foot wide soil belt at the base between the viaduct and the road asphalt, which is a perfect place to plant climbers.

Table 5.4: Suitable plants for similar cases as prototype 3 and their performances in "maintenance", "growth rate", "good coverage", "climbing way" and "climate tolerance"

Suitable plants for similar cases as prototype 3

Species name	English name	Maintenance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Climate tolerance
Aristolochia macrophylla	**Dutchman's Pipe**	Cut back in late winter to control growth. Pruned back hard (to approximately 8-12" from the ground) to strong leaf buds in late winter to early spring	20-30	Slow	5	Twining stem	Black Walnut, shade
Clematis tangutica	**Golden Clematis**	Water weekly, or more often in extreme heat or containers.	12-15	Medium	5	Twining leaf axles	Deer, Black Walnut, shade
Clematis viticella	**Etoile Violette Clematis**	Weekly watering or more often in extreme heat; prune every spring	10-15	Fast	5	Twining stems	Deer
Clematis 'Alba Luxurians'	**Clematis viticella 'Alba Luxurians'**	Prune in late winter to early spring as needed	8-12	Fast	5	Twining leaf-stalks	Full sun
Schizophragma hydrangeoides	**False Hydrangea Vine or Japanese hydrangea vine**	—	30-40	Fast but slow to establish	5	Stem-borne adhesive rootlets	Heavy shade, drought
Parthenocissus quinquefolia	**Virginia Creeper**	—	60-90	Fast	5	Sucker pads	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Black Walnut
Parthenocissus tricuspidata	**Boston Ivy**	—	60-90	Fast	5	Sucker pads	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut
Parthenocissus dalzielii	**—**	—	10-15	Medium	5	Sucker pad	Deer, Drought, Heavy Shade, Erosion, Clay Soil, Dry Soil, Shallow-Rocky Soil, Black Walnut

Table 5.4 (cont.): Suitable plants for similar cases as prototype 3 and their performances in "structural support", "seasonal changing", "increase biodiversity", "pest promotion and other issues" and "special value"

Suitable plants for similar cases as prototype 3

Species name	English name	Structural support	Seasonal changing	Increase biodiversity	Pest promotion or any other problems	Special value
Aristolochia macrophylla	**Dutchman's Pipe**	Wall, or sun porches, verandas, pillars, posts, trellises, arbors, fences	Deciduous; bloom time May to June; Yellow, green, purple flower	—	—	—
Clematis tangutica	**Golden Clematis**	Wall, trellis, fence, arbor, porch, lamppost or other stationary structure	Deciduous; Bloom from July to Sep; Bell-shaped, bright yellow flower	Butterflies and hummingbirds	Watch for Clematis wilt, spider mites	—
Clematis viticella	**Etoile Violette Clematis**	Arbor, fence, or trellis, or allow to climb through shrubbery	Deciduous; Bloom from July to Sep; violet-purple flowers	Butterflies, hummingbirds	—	—
Clematis 'Alba Luxurians'	**Clematis viticella 'Alba Luxurians'**	Structure support for climbing. No structure support serve as cascading groundcover	Deciduous; bloom time July to Sep; white flower	—	Wilt, powdery mildew, rust, fungal spots, and stem cankers are common.	—
Schizophragma hydrangeoides	**False Hydrangea Vine or Japanese hydrangea vine**	Walls, arbors or trees	Deciduous; bloom time June to July; white, pink flower; the dark green leaves have a noticeable silvery overlay; Reddish-brown stems in winter	—	—	—
Parthenocissus quinquefolia	**Virginia Creeper**	—	Deciduous; Bloom from May to Aug; red leaves in autumn; white-green flower	Birds	Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems.	—
Parthenocissus tricuspidata	**Boston Ivy**	—	Deciduous; Bloom from June to July; red-purple leaves in autumn; yellow-green flower	Birds	Susceptible to a number of insect pests including beetles, scale and leaf hoppers. Berries are toxic; Mildews, leaf spots, canker and wilt are occasional problems.	—
Parthenocissus dalzielii	**—**	—	Deciduous; bloom time April-June; white-blue flower	Birds	Also susceptible to a number of insect pests including beetles, scale and leaf hoppers.	—

Table 5.4 (cont.): Suitable plants for similar cases as prototype 3 and their performances in "maintenance", "growth rate", "good coverage", "climbing way" and "climate tolerance"

Species name	English name	Maintenance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Climate tolerance
Parthenocissus henryana	**Silver vein creeper**	—	20-30	Fast	4	Sucker pad	Deer, clay soil
Passiflora incarnata	**Wild passion flower**	Prune to control it growing	6-8	Fast	4	Root suckers and tendrills	Drought
Bignonia capreolata "Tangerine Beauty"	**Cross-vine**	Prune after flowering if needed.	20-30	Fast	5	Branched tendrils with adhesive disks	Heavy Shade
Hedera helix	**English ivy**	—	20-80	Fast	5	Stems with adventitious roots	Urban dust, Drought, Heavy Shade
Ipomoea palmata	**Mile-a-minute Vine**	—	8-10	Fast	5	Twining stem	Urban dust, Drought, Heavy Shade
Ipomoea purpurea	**Morning Glory**	—	6-10	Fast	5	Twining stems	Full sun, deer, urban pollution
Lonicera heckrottii	**Flame Honeysuckle**	Needs good air circulation	10-15	Fast	5	Twining vine	Deer, Urban pollution, Black Walnut,
Lonicera sempervirens	**Trumpet Honeysuckle**	Prune right after flowering	10-20	Fast	5	Twining vine	Deer, Clay Soil, Black Walnut

Table 5.4 (cont.): Suitable plants for similar cases as prototype 3 and their performances in "structural support", "seasonal changing", "increase biodiversity", "pest promotion and other issues" and "special value"

Species name	English name	Structural support	Seasonal changing	Increase biodiversity	Pest promotion or any other problems	Special value
Parthenocissus henryana	**Silver vein creeper**	—	Deciduous; bloom time April-June; green flower; leaves with silver veins and turn to burgundy in autumn	Birds	Keep an eye out for glasshouse red spider mite and vine weevil	—
Passiflora incarnata	**Wild passion flower**	Trellises, arbors, walls or fences.	Deciduous; Bloom from July to Sep; White with purple crown flower; yellow berry fruit when mature	Butterflies, bees, birds	Roots can spread aggressively. Root rot can occur in wet, poorly-drained soils, particularly in winter.	Plant can be used as an herbal medicine. Roots can be made tea. Fruits are edible.
Bignonia capreolata "Tangerine Beauty"	**Cross-vine**	Fences, arbors, walls, pillars, large trellises and other structures	Deciduous; Bloom from May to June; tangerine color flowers, reddish-purple foliage in fall	Hummingbirds	—	—
Hedera helix	**English ivy**	Fences, trellises or walls	Evergreen. Bloom time Sep to Oct; Greenish white flowers followed by blue-black berries	Birds	Aphids, mealybugs, caterpillars, loopers and scale may appear. Watch for leaf spots, canker, bacterial leaf spot, stem rot and powdery mildew.	—
Ipomoea palmata	**Mile-a-minute Vine**	Fences, trellises, arbors and arches	Evergreen. Bloom time seasonal ; lavender flowers with a darker purple centre	Butterflies and hummingbirds	—	Can be used as medicine
Ipomoea purpurea	**Morning Glory**	Trellis, fence or arbor	Deciduous; Bloom from June to Oct; purple with white throat flower;	Butterflies and hummingbirds	—	—
Lonicera heckrottii	**Flame Honeysuckle**	Trellises or espaliers; fences	Deciduous; Bloom from June to August; rose pink with yellow interior flowers	Hummingbirds, Butterflies	Powdery mildew and leaf spots may occur.	—
Lonicera sempervirens	**Trumpet Honeysuckle**	Trellises, arbors and fences	Deciduous; bloom time May to June; Scarlet/orange with yellow inside flower; red berries in late summer to early fall	Birds, Hummingbirds, Butterflies	Watch for aphids	—

Table 5.4 (cont.): Suitable plants for similar cases as prototype 3 and their performances in “maintenance”, “growth rate”, “good coverage”, “climbing way” and “climate tolerance”

Species name	English name	Maintenance	Overall size/ft	Growth rate	Coverage (1-5)	Climbing type	Climate tolerance
Celastrus scandens	**American bittersweet**	Prune in late winter to early spring; Mature vines require little pruning other than removal of dead or excess growth.	15-20	Fast	5	Twining woody vine	Full sun; deer, drought
Humulus lupulus	**Common hop**	Stems may be pruned to the ground in autumn after a hard frost.	15-20	Fast	5	Stiff downward facing hairs that provide stability and allow them to climb	Drought
Vitis coignetiae	**Crimson Glory Vine**	Restrictive pruning in winter and realise the extent of growth when first planting.	30-60	Fast	4	Woody stem with tendrils and wrap themselves around any firm support	Heat, cold and wind
Ampelopsis brevipedunculata	**Porcelain vine**	Trim stems as needed to maintain desired shape	15-20	Fast	4	Tendril climbing	—
Rhodochiton atrosanguineus	**Purple bell vine**	—	5-12	Fast	5	Twining stems	Cold
Pyracantha	**Firethorn**	Annually pruning	6-18	Fast	5	Climbing shrub	Drought; heavy pruning

Table 5.4 (cont.): Suitable plants for similar cases as prototype 3 and their performances in "structural support", "seasonal changing", "increase biodiversity", "pest promotion and other issues" and "special value"

Species name	English name	Structural support	Seasonal changing	Increase biodiversity	Pest promotion or any other problems	Special value
Celastrus scandens	**American bittersweet**	Fences, arbors, trellises, posts	Deciduous; bloom time May to June, greenish white-yellow flowers, orange-colored fruits in fall and winter	Birds, bees, butterflies	Euonymus scale and two-marked treehoppers may cause significant damage in some areas	—
Humulus lupulus	**Common hop**	Various support structures	Deciduous; Bloom from Sep to Oct; yellow-green flower	Butterflies	Skin contact may cause dermatitis.	Brewing for bittering beer
Vitis coignetiae	**Crimson Glory Vine**	Fence, trellis, wires, frameworks, and smaller branches of trees or shrubs	Deciduous; Bloom from July to Aug; heart-shaped leaves with gold, orange and red color in autumn; light green flower	—	Attract Japanese beetles but not serious	Medicinal plant; brewing for wines
Ampelopsis brevipedunculata	**Porcelain vine**	Trellises, arbors, walls or fences.	Deciduous; Bloom from July to Aug; greenish flower; light-blue berries in fall	Birds, mammals	Watch for Japanese beetles. Fruits are not edible.	—
Rhodochiton atrosanguineus	**Purple bell vine**	Fences, trellises, arbors and arches	Deciduous; bloom time May to Sep; red-purple flower	—	May be attacked by glasshouse whitefly and glasshouse red spider mite	—
Pyracantha	**Firethorn**	—	Evergreen in warm winter climates but semi-evergreen to deciduous in the St. Louis area; Bloom from March to April; white flower; bright orange-red berries in early autumn through winter	Blackbirds; wood pigeons	Caterpillars; Fireblight, Aphids; thorns may cause injures easily	—

Figure 5.20: Perspective of the proposed vertical greening. Using plant is Hedera helix.

Conclusion

Vertical greening as an efficient method to add interests, activate residents, purify urban environment and cover unpleasing surfaces, is getting increasingly popular at present. To apply suitable VG, we should take those things into consideration: 1) building's land use, 2) wall's direction, 3) major users, 4) location and the most important 5) expectations. For each prototype, some labels were given based on those considerations, which aims to identify the wall's attributes and think about the most important criteria for plant selection. The responsive proposals were suggested for each prototype from the type of VG and plant criteria. Plants should have good performance for all the criteria proposed. For VG in public space such as commercial center, public open space and education center, living wall system is a better choice since it can provide a more delicate landscape with a large amount of plant species. Then plants' seasonal changing and increasing biodiversity should be thought highly of. For residential area, living wall system and green façade are both favored. The primary consideration for proposed VG should be low pest promotion and other issues. High seasonal changing and special values will add more interests to VG. For marginal areas of a city or some "dark" areas underneath highways, VG should be as simple as possible but still with vigorous foliage. Besides, wall's direction should also be taken into consideration fundamentally, especially for north-facing walls which require plants with a good tolerance for heavy shade.

In the design phase, it's key to be aware of wall's size, which helps us decide how big a planting group should be—not too big then the wall would be boring but not too small or the VG would be unorganized and messy. When we draw the planting plan for living wall system, we should base on the modular grid system which is the actual way plants being planted. But for the final appearance, the grid sense would not be so obvious since plants are mature with vigorous foliage. Besides the suitable plant species, we should also consider the seasonal changing and plant height when design. Do not put so many plants with similar blooming time together or there may be a relatively "bare" time period of the VG. Various blooming time or overlapping blooming time can easily achieve a year-round landscape. For height, the basic strategy is that closer to human view or standing point, shorter plants should be; farther or more marginal, taller plants should be. Then there would not be some plants totally blocked by former plants. The whole VG would like a small hill and give people a 3D landscape. With suitable types of VG, plant selection and aesthetic design, the final landscape would be attractive, effective and sustainable.

References

[1] Augustyn, Patricia Bauer, & Brian Duignan. (2019). *Art Institute of Chicago | museum, Chicago, Illinois, United States*. Encyclopedia Britannica. https://www.britannica.com/topic/Art-Institute-of-Chicago

[2] Chan, C. T. W. (2018). Promoting Vertical Greening in High-rise Residential Buildings within Urban Areas. *Pacific International Journal*, *1*(2), 29–38.

[3] Coma, J., Pérez, G., Solé, C., Castell, A., & Cabeza, L. F. (2014). New Green Facades as Passive Systems for Energy Savings on Buildings. *Energy Procedia*, *57*, 1851–1859. https://doi.org/10.1016/j.egypro.2014.10.049

[4] George H., & Roeder, Jr. (2005). *Artists, Education and Culture of*. http://www.encyclopedia.chicagohistory.org/pages/83.html

[5] Gilfoyle, T. J. (2006, August 6). 'Millennium Park.' *The New York Times*. https://www.nytimes.com/2006/08/06/books/chapters/0806-1st-gilf.html

[6] Kinzer, S. (2004, July 13). LETTER FROM CHICAGO; A Prized Project, a Mayor and Persistent Criticism. *The New York Times*. https://www.nytimes.com/2004/07/13/us/letter-from-chicago-a-prized-project-a-mayor-and-persistent-criticism.html

[7] Kubba, S. (2017). Water Efficiency and Sanitary Waste. In *Handbook of Green Building Design and Construction* (pp. 413–441). Elsevier. https://doi.org/10.1016/B978-0-12-810433-0.00008-3

[8] Laffey. (2009). *Chinatown: A "hidden jewel" worth seeking—Chicago Tribune*. https://www.chicagotribune.com/chi-chinatown-profile_chomes_062jun26-story.html

[9] Perini, K., & Roccotiello, E. (2018). Vertical Greening Systems for Pollutants Reduction. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 131–140). Elsevier. https://doi.org/10.1016/B978-0-12-812150-4.00012-4

[10] Rakhshandehroo, M., Mohd Yusof, M. J., & Deghati Najd, M. (2015). Green Façade (Vertical Greening): Benefits and Threats. *Applied Mechanics and Materials*, *747*, 12–15. https://doi.org/10.4028/www.scientific.net/AMM.747.12

[11] Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban Form and Extreme Heat Events: Are Sprawling Cities More Vulnerable to Climate Change Than Compact Cities? *Environmental Health Perspectives*, *118*(10), 1425–1428. https://doi.org/10.1289/ehp.0901879

[12] USGS. (2018). *Census profile: Chicago, IL--IN Urbanized Area*. Census Reporter. http://censusreporter.org/profiles/40000US16264-chicago-il-in-urbanized-area/

[13] Weinmaster, M. (2009). Are Green Walls as "Green" as They Look? An Introduction to the Various Technologies and Ecological Benefits of Green Walls. *Journal of Green Building*, *4*(4), 3–18. https://doi.org/10.3992/jgb.4.4.3

[14] Wong, N. H., Tan, A. Y. K., Tan, P. Y., Sia, A., & Wong, N. C. (2010). Perception Studies of Vertical Greenery Systems in Singapore. *Journal of Urban Planning and Development*, *136*(4), 330–338. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000034

[15] Zha, Y., Gao, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing*, *24*(3), 583–594. https://doi.org/10.1080/01431160304987

CHAPTER 6: CONCLUSION

A new VG classification was proposed in this research which first time included green roof and balcony garden. Suitable conditions considering from location, overall size, building type, design creativeness, plants characteristic, cost and maintenance for each type of VG have been summarized. I developed nine criteria for plant selection based on a literature review about people's concerns and expectations, and corresponding climbers and herbaceous plants were suggested for each criterion. For every plant, there were also evaluations about their performance on other criteria to help designers have a comprehensive plant knowledge. Downtown Chicago was a pilot site to think about how to use these theories in real VG project. Starting from finding the most suitable locations, I researched what benefits VG can bring then found areas that are not doing well in those aspects, which means issues in those areas could be solved by adding more VGs. After deciding the targeted VG locations, I proposed prototypes for highly commercial area, residential area and marginal area in downtown Chicago. Design strategy and planting list have been suggested which could be applied broadly in any similar conditions.

This research developed a comprehensive understanding about VG and highlighted possibilities for VG applications in compact cities through an integrated analysis and design. Although the idea of VG is still at the starting point and not accepted entirely around the world, as one type of smart landscape it still functions outstandingly to benefit urban ecology and qualify human life. Up to date, it may be one of the best strategies to solve greenspace insufficiency in compact cities. It could also be an attractive and indispensable landscape in all cities. One of tendencies of VG is that we can develop vertical farms in urban areas that lots of cities are already doing. In order to make VG more viable, the following research directions can be significant:

1) Improvement of VG's technique such as structural support, irrigation, module, planting substrate and construction
2) Methods that help to make VG cheaper
3) Strategic design process for VG projects
4) Comparisons between VG and traditional ground green space such as mental health, human interaction and sustainability
5) Propaganda of VG to make it more acceptance

6) Better relationships between VG and other green infrastructures to form a smart urban green system

I hope in the future either the theories or practices of vertical greening will be developed further, taking into consideration of the former research questions and better integration of existing green spaces to achieve a more livable urban environment.