Re-Imagining Nature in Dense, High Rise Urban Environment: the Present and Future of Green Building Infrastructure in Singapore

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Re-Imagining Nature in Dense, High Rise Urban Environment: the Present and Future of Green Building Infrastructure\(^1\) in Singapore

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\(^1\) *Building Green Infrastructure (BGI): Green infrastructure incorporated to become part of a building, including vertical greenery on building’s interior and exterior facade, rooftop gardens, indoor gardens, shaded or partially shaded pocket gardens and courtyards. The term Building Greenery is also used in this paper interchangeably.
Abstract:
From the futuristic Jewel at Changi Airport, the healing gardens at Khoo Teck Puat Hospital in Yishun to School of the Arts at Orchard Road, greenery has sprouted in buildings vertically and horizontally in Singapore, painting a growing green canopy for the dense, high rise city. This paper combines both analyses from first-hand site visits and case studies from external scholar studies to examine the performance of existing Green Building Infrastructures (BGIs) within Singapore’s unique urban context. The study reveals that the success of BGIs is highly dependent on the programming (i.e. thermal comfort design, accessibility, amenity facilities etc.), as well as the function and users of the existing building. Designs and planning that take those factors into consideration while being in line with the city’s general development goals, such as storm water management and pervasive greenery, are likely to bring out the most benefits in BGIs. To demonstrate, this paper also proposed several policy and planning recommendations that included several sets of rudimentary yet relevant parameters. Future research is encouraged to explore more complex combinations of considerations, their incorporation in design and policy making process, as well as a scientific and systematic method to evaluate BGI performance that includes both objective environmental impacts and subjective user experience that might be achieved through smart city developments.
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Introduction

Just days before I took off to Singapore for a research project in May, 2019, a video clip went viral on Facebook: a Maglev train glides through an indoor tropical garden with tiers of tall trees and lush plants; behind the elevated train track, an artificial waterfall pours down from the center of a toroid-shaped glass roof, highlighted by dazzling light shows and music in the background. This is Singapore’s newly opened shopping mall at Changi airport, the Jewel. In contrast to the impassioned comments on Facebook, the locals seem much more nonchalant about this futuristic, green-utopian addition to their city. “It’s just a show for the tourists; Singaporeans are numb to cool-looking buildings and shopping malls now.” says my aunt when she took me to visit the mall after I arrived; she has lived in Singapore for the past 15 years. Even at the scale of the Jewel, a building with indoor vegetation is a familiar concept for most Singaporeans who are quick to adapt to their ever-changing city; even Though the city-wide high rise greening movement only began barely twenty years ago (Yok, 2012; “Singapore, Capital City for Vertical Green,” n.d.)

The Jewel Changi Airport:
Left: The Maglev Train and the Rain Vortex; Right: Entrance to the Central Atrium Bottom Image Source: Author’s Collection
The vision for Singapore to become a “Garden City” was introduced in 1967 by former Prime Minister Lee Kuan Yew when the city was first systematically planned after its independence. Since then, it has implemented green spaces at all scales and surfaces to achieve this goal (Singapore National Library Board, 2015). Vertical greening and rooftop greening was viewed as a natural solution to balance this vision with economic development, population growth. The program Landscaping For Urban Spaces And High-Rises, aka LUSH, was a particularly relevant policy in this movement: first introduced in 2009 and has been continuously expanding, it incentivizes building owners in identified strategic areas to install at least 40% of their development site area worth of green roofs and vertical green walls with up to 50% funding of installation costs (National Parks Board, 2019; Urban Redevelopment Authority, 2019). As of 2017, there were already up to 82 hectares of rooftop gardens and green walls in the city, with LUSH projects contributing at a 15% annual increase rate (Hean, 2017; Sen and Charles, 2017).

At the time, my research was mainly focused on urban resilience. Despite the immediate visual appeal and apparent prevalence of green building infrastructures in Singapore, I was hesitant to include them as indicators of ‘resilience’, or even ‘sustainability’ in the broader sense. Frequently included in urban planning policy and design strategy narratives as an intersection between sustainability and resilience, rooftop and building facade greening have just as many controversies as their advocacies.

On one hand, vegetated roofs and walls could theoretically provide numerous environmental benefits such as improving air quality, grey-water reuse, run-off retention, micro-climate adjustment etc., on the other hand, however, some of the most widely advertised environmental
benefits have not been effectuated in practice. Whether green rooftops are successful strategies for Urban Heat Island effect mitigation, for example, is highly debatable. The cooling effect for local microclimate--of which the range is yet to be defined--could not be simply multiplied to indicate its effect on city-scale UHI mitigation. In fact, some mesoscale simulations identified city-wide cooling effect to be rather negligible: 0.1-0.8 °C from retrofitting 50% of Toronto rooftops (Liu and Bass, 2005), and 0.4-1.1 °C for 100% roof greening in New York (Rosenzweig et al., 2006). Additionally, the high upfront cost to retrofit a green roof and the level of maintenance required is often one of the biggest barriers for most property owners, which begs the question whether it is a worthwhile investment. Even on a city level, is green roof/wall retrofitting the best allocation of capital?

During my site visits in Singapore, I had the opportunity to interview Dr. Winston Chow, a Geography Professor at National University of Singapore. His research focuses on urban heat islands, urban vulnerability to climate change, and sustainable urban climatology in tropical and subtropical cities. He is an expert on heatwaves, droughts, and flash floods and one of the lead authors for the IPCC AR6, the 6th Assessment Synthesis Report by Intergovernmental Panel on Climate Change of United Nations. According to him, Building Green Infrastructure, mainly green roofs, is not a reliable strategy to mitigate city scale Urban Heat Island Effect or to improve urban resilience. In his past research, determining the cooling effect of a green roof by measuring the surrounding ground level air temperature and gradually increase the radius. The results showed a negligible difference. However, we both agreed that Singapore is going to continue the trend of pervasive urban greenery on buildings along with other sustainable efforts.
From a city planning point of view, ‘Sustainability’ and ‘Resilience’ are undoubtedly the priority in our time. Discussing an urban issue without realizing the backdrop of climate change and its unavoidable impact on any city would be ignoring “the elephant in the room”. The only way cities could stand a chance in the long term are to operate as if the increasingly irregular weather patterns--frequent flooding, prolonged heat waves, unstable weather and much more--is going to be the new normality. Any project in the built urban environment should therefore aim for the best practice to both mitigate the acute shocks and adapt to the chronic issues brought by climate change.

However, the solution for a problem as complex and large as climate change does not lie in a single measure. Despite the environmental benefits and mitigating effect they could provide, even assuming all achieved in practice, it is still a much bigger issue than building green infrastructure’s functional capacity to address. Of course, the resource and capital invested or those about to be invested could be used in other immediate measures supporting resilience and sustainability such as building marshlands and elevating buildings; this, however, does not deny the possibility and plausibility that green building infrastructures could be part of the bigger, systematic solution. It is precisely the purpose of this paper to discuss such possibility and plausibility, and more importantly, the ways to achieve them in the most beneficial and impactful way.
Methods

Previous scholarly research on this topic often takes a comprehensive approach: first analyzing the overall benefits and mechanisms of green roofs and vertical green space when generally applied, then referencing a few examples in different cities. However, such an approach can fall short when being applied to specific cases of green roofs and walls. As previously mentioned, the multi-functionality and overwhelming benefits of green spaces make it seem like a ‘no-regret’ deal to convert the existing grey concrete building surfaces to a green counterpart; Unfortunately, however, some benefits that are universal in theory might not be realized in practicality due to highly variable factors for each building site such as climate, implementation practices, maintenance systems… etc. Under the same logic, studies focusing on one or a few green roofs and green facades are bound to their specific condition as well. Outcomes of one case study cannot be inferred by the ones of another.

While acknowledging the necessity of understanding the general pros and cons of green roof/facade retrofit as well as the case-by-case nature of the topic, I would like to combine both the general pros and cons of green infrastructure in buildings, as well as case studies derived from my personal experience of visiting the sites, interviews with passing-by and cases from previous studies in the specific context of Singapore. This will then inform some recommendations for future city-scale building green infrastructure development in Singapore.

The paper will start with introducing how green roofs and green facades operate in Singapore, since they are the most common and most studied building green infrastructure. After establishing the Singaporean context covering its urban history, water systems and policies
relevant to BGIs, I will examine several case studies with evidence from both personal experience and other scholarly research in the same geological areas or similar context, without assuming all of the general characteristics to be applicable for any individual case. I hope to answer the following question: how and why green replacement policies came to be in Singapore? This is essential in understanding the nuanced implications of a seemingly straightforward urban greening strategy, which should later dictate the unique methods and priorities the city should adopt. I will later elaborate on such methods and priorities in Chapter 2 and 3.

Considering that a set of high rise greenery policies is already in place in Singapore, and is likely to be implemented on more buildings in the next few years, it might be less relevant to prove the environmental benefits of BGIs, partially because the integrity of scientific experiments in combination with the scale and volatility of urban climates do not grant many plausible methods of measuring such functions. Instead, I would like to dedicate the majority of Chapter 2 to examine some existing perception studies revealing the effectiveness of current building green infrastructures from users’ point of view.

This will then inform the policy and planning recommendations in Chapter 3 on how to maximize the benefits of building green infrastructures on city-level. In fact, since the effectiveness of BGIs is highly dependent on their specific implementation, I argue that green replacement policies standing alone does not guarantee the realization of GI services. However, conscientious city-level planning of BGI as well as a sound implementation of sustainable support systems will bring about most of the theoretical benefits. This includes: allocating
different types of BGI to different types of buildings depend on their performance and the characteristics of the existing building; enhancing accessibility both in the nature of such space but also the design processes, space making and way-finding; including auxiliary systems such as greywater irrigation systems, cisterns and solar panels in the design; prioritizing the areas with the most need with the most needed types and locations of rooftop green space. I will also discuss, in the context of new building technologies, big data and ‘smart city’, where and how could building greenery fit in.
Chapter 1. Green Roofs and Facades in Singapore

1.1 Context Analysis: the Singapore Condition
In 2009, the Urban Redevelopment Authority and the National Parks Board set a target of achieving 50 ha of high rise greenery by 2050, and an estimated $\frac{3}{5}$ of the goal was already achieved by 2012 (“Singapore: The First City in Nature?,” 2017); the target was later increased to 200 ha by 2030. To the date of writing in 2019, 100 ha is already implemented through 202 projects, representing an increment of 10 ha/year since 2012. At this rate, the city is well on track to achieve its target in another 11 years. This is counting only projects within the Skyrise Greenery program.

The prevalence of rooftop, facade and indoor greenery/landscape is directly correlated to Singapore’s unique urban context. It is a conscious decision made by the Singapore government to balance the need for development and green space. In this section, I will discuss the macro-scale factors including urban history, socio-political status, government structure, climate etc. that dictated the state of existing building green infrastructure as well as the government’s current vision for its future development. Understanding the mechanisms of how the current state of Singapore’s BGI came to be is essential for the policy recommendations later to ensure the feasibility and whether they will be in accordance with the current condition.

1.11 Urban History
The concept of sustainability, well before it became a buzzword, has guided the city’s master planning strategies to make sure livability and sustainability are not compromised for economic development and urbanization. Among which, the Newtown Precinct Development by Housing
Development Board (HDB) and Urban Redevelopment Authority (URA) in the 1970s played a key role in shaping Singapore’s urban scape today (He, 2016). The authoritative, highly mobilized and trusted government took over the designing of both the public and private space for its citizens.

To reconcile the need for housing and economic development, millions were migrated from traditional villages (kampongs) cramped in central areas into newly built compact, blocky high-rise HDB buildings in the suburbs. This opened up space for new development in the Central Business District. While it was a harsh and sudden change in lifestyle for many, the sense of communal living and shared space was partially preserved through the use of smaller ‘estates’ layout, each with about 1200–2800 dwelling units sharing a common green garden (He, 2016). Many precincts share a typical layout: building blocks forming the enclosing space, playgrounds and pocket gardens in the center, with a driveway leading to a multi-level car park. Open space in a precinct is often raised above ground level to two to four stories of the car parks. The enclosure created a barrier for non-residents to pass through the space, as well as a sense of seclusion and privacy for the resident community from the outside streets (He, 2016).

Moreover, the government used public housing and precinct planning as an opportunity to shuffle the racial and ethnicity distribution in the city so different ethnic groups could integrate in the same living space. The intention was to break the existing segregation resulted from early day British planning where ethnic groups are allocated in different sections of the city to reflect different socio-economic statuses, and to prevent potential religious unrest brought by the formation of ethnic enclaves (He, 2016).
As the result of the reformation of residential and public space patterns since the 70s, a highly organized and government-maintained grid of citywide green space is clearly seen today. On ground, the urban greenery system breaks down into three levels: at state level, large continuous and most precious land area is dedicated to national parks such as the Botanic Gardens and commercial botanical garden, Gardens by the Bay to attract both residents and tourists; regionally, big public parks of 50-150 ha in size such as the West Coast Park, East Coast Park and Bishan-Ang Mo Kio Park are shared by visitors and residents of several neighborhoods; in the newtown developments, a hierarchy of small town parks (usually 1-1.5 ha in size, to serve one precinct of about 5000 to 6000 housing units), precinct gardens (0.2 ha, serving 1000 to 2000 housing units) and “green connectors” along drainage reserves are created (Ng, 2012; He, 2016). When the reformation first started, there was only 0.39 ha of open space per 1000 population in the city (Yuen, 1995); by 2001, that number was increased to 0.6 ha per 1000 population and targeted to be 0.75 in the 21st century (Urban Redevelopment Authority, 2001). In Singapore’s Population White Paper 2013, it was reported that open spaces allocated to parks and gardens covered 3% of the total land area, which equals to 0.8 ha of parkland per 1000 population. The 2030 goal is for at least 85% of all households to live within 400 meters of a park by 2030 (He, 2016).

Meanwhile, with their limited land resources, vertical development becomes the natural design choice for real estate and greenery alike. In the city center, the tallest commercial buildings rise to more than 60 stories. In the residential areas, 90% of the 3.4 million resident population lives in high-rise apartments: 84% in publicly built housing and 6% in private apartments and condominiums. URA’s long term 2001 Concept Plan in states that more are expected to live on
higher floors as the population is projected to grow to 5.5 million in 40–50 years’ time. The private and public housing sectors have respectively announced plans to build to 40 and 50 stories to accommodate the growing housing needs (He, 2016).

Behind the physical growth of the city was the economic boom since the 1980s. Along with the skyscrapers, there was an increasing interiorization as well as privatization of public space: parks and open spaces are replaced by the large air-conditioned atrium spaces in hotels and shopping centers, as well as ‘paid’ public spaces like curbside cafes and street front stores. Meanwhile, with the growth of public transport infrastructure, a proliferation of transit spaces took over what could have been amenity spaces where people simply pass through instead of dwelling, such as mass rapid-transit stations, station platforms, bus interchanges, and pick-up or drop-off points for vehicles (He, 2016). The urbanization and densification in Singapore has inevitably limited both the space and the opportunity for people to interact with nature in their routines, piling up the need for more greenery within the built environment.

The ‘Clean and Green’ image was also a boost for the thriving tourism industry in Singapore since the 80s, which contributes a large portion of the economy. In the three decades of the ‘Garden City’ campaign in Singapore, its emphasis had shifted somewhat from its original concerns—intentionally or not. The success of greening the city was such that by the 1990s, not only did the cleaned and widened avenues lined with tall tropical trees, the buildings covered with greenery inside and out and the green connectors at corners of building blocks created an aesthetic living environment, but also boosted the national image and was used as key strategies to attract foreign investment (He, 2016).
1.12 Policy and Industry
As the city becomes denser and higher, the URA and NParks (National Parks) adopted the concept of ‘pervasive greenery,’ to utilize any space possible to incorporate greenery into the built environment, including vertical building facades and rooftops (He, 2016). The previously mentioned Landscape for Urban High Rises (LUSH) and the Skyrise Greenery Incentive Scheme are just two of a suite of policy and initiatives that encouraged or mandated BGIs, the rest includes: Landscape Replacement Policy for Strategic Areas, Outdoor Refreshment Area and Landscaped Roof Tops, GFA Exemption for Communal Sky Terraces, Landscaped Deck, GFA Exemption for Communal Planter Boxes etc. Some of the buildings in Singapore that adopted vertical greeneries range from hotels to college buildings, such as “Shangri-La Hotel, the Botany Centre in Singapore Botanic Garden, Singapore Polytechnic Graduates Guild, Singapore Management University, carpark in Republic Polytechnic, Novena Suites and Naumi Hotel” (Wong, Tan, Tan, Sia, & Wong, 2010).

Today, there is a mature industry and an increasing market to support the implementation of rooftop and facade greenery. Skyrise Greenery listed 19 local contractors who are part of the program and are experienced in constructing all types of BGIs along with lists of plants to implement for rooftops and green walls respectively to make the process easier for building owners (“Contractors,” n.d.). The policy incentives have also bred a generation of architects in Singapore experimenting with different design possibilities for marrying greenery with bricks and concrete for the past decade, and have also gained much experience doing so. WOHA, for example, is a Singapore based architecture firm that has developed a unique approach in sustainable design in the tropical context. WOHA is one of the first firms around the globe that started vertical greening and putting sky terraces on skyscrapers. They have continuously
innovated what they emphasized as “social and ecological design”, winning over 60 awards for since 1994. Some of their most renowned projects include: Oasia (high rise hotel in downtown with exterior whole-facade vertical greenery), Parkroyal on Pickering (high rise hotel in downtown with sky terraces), School of the Arts (see case study in 2.1), as well as transit hubs and residential buildings across Southeast Asia (“WOHA - Singapore, Singapore—Architects -,” n.d.).

With available resources that complete the chain from policy incentive, design to construction, perhaps the only barrier is cost. Cost for implementing green walls are as high as S$1,000 to S$1,500 per m², S$150 to $400 for new extensive green roofs and $100 to $150 for retrofitting extensive green roofs (Eco-Business, n.d.). If the building is enrolled in the Skyrise Greenery program, limit for reimbursements for construction is $200 per m² for rooftop greenery and $500 for vertical greenery, excluding indoor vegetation or maintenance cost. Still, even half of the original cost is high for a lot of building owners, let alone the maintenance cost afterwards (see Chapter 1.3 Cost for reference). Local contractors stated that a regular extensive rooftop garden with a rainwater retention system would cost from S$20,000 to S$180,000 depending on the size: A typical commercial green roof costs between S$20,000 and S$30,000, holding 6,800 liters of water; An HDB carpark roof costs $120,000 to $180,000 and can hold 40,800 litres of water (Cheam, 2012).
Fig. 1. The heat map shows that existing buildings with green roofs and green walls are most concentrated in Central Business District. Data Source: Skyrise Greenery by National Parks Board, Singapore. Software: ArcGIS Online.

This is the reason why most green roofs and living walls are built by the owners of glamorous shopping malls, hotel buildings or office buildings with high level of capital and the buildings are used for commercial purposes, with the exception of several retrofitted green roofs on multi-storey car parks and some new public housing estates built by the Housing Development Board (Li & Norford, 2016). However, studies have demonstrated that vegetated features in buildings can increase the property value by 20% (Wood, 2014); interviews with residents of public housing show proof that the attractive images of public spaces within housing were valued as these contribute to increasing the market value of flats and served as visual and symbolic space markers, even if they are not used as social spaces (He, 2016). The added value from building greenery could incentivize private residential building owners despite the higher upfront cost. In fact, most residential buildings that have adopted some form of building green infrastructure are
higher-end, more luxurious apartment buildings that sell for much higher than average properties, e.g Orchard Residences and Newtown Suites.

It is still uncertain whether NParks will receive more funding for the Skyrise Greenery Incentive Scheme after the set expiration date in March 2020. So far, the incentive scheme has undoubtedly the most positive impact to rooftop and building facade greening in private buildings, and losing it would very likely lead to a slowdown in green rooftop coverage.

However, looking at the current target to reach the target greenery coverage to 200 ha by 2030 and the URA’s ‘Gardens in the Sky’ vision, it is highly likely that the program will continue in some form and more budget will be allocated.

1.13 Water System
Any form of greenery incorporation in buildings requires an irrigation system. The most cost-effective and common practice is to irrigate the vegetation with harvested rainwater from built-in retention tanks. In Singapore, this could be especially effective due to the high precipitation rate in the tropical climate. However, this seemingly straight-forward strategy goes through a more nuanced process in the city’s unique water system. Singapore has a mature island-wide rainwater retention system as part of the four National Taps (sources of water). With about 8,000 km of drains, rivers and canals throughout two-thirds of the island land area, rainwater and used water are collected through two separate systems. This makes Singapore one of the few countries in the world to harvest storm water on a large-scale, which makes up for 45% of the total domestic water supply along with high-grade reclaimed water known as NEWater and Desalinated Water (PUB, n.d.).
Prior to 2004, it was illegal for private building owners to collect rainwater, let alone building retention tanks. Fresh water is a precious resource on a small island like Singapore due to limited land area available to collect and store water. It is viewed as a national property owned and managed by the Public Utility Board (PUB) acting in the best interests of the nation. PUB eventually relaxed this policy. Now rooftop garden and storm water retention tanks in buildings have even become one of the key strategies to mitigate peak run-offs during flood season and lessen the pressure on the city’s drainage system.

In their recent publication *Managing Stormwater for Our Future*, the PUB has identified increasing challenges on the city’s drainage and retention system. First, Singapore has experienced heavier and higher frequency of intense rainfall events for the last three decades and the rainfall pattern has become less predictable with climate change. Record shows that the frequency of rainfall events with precipitation over 70 mm/h has increased at the rate of 1.5 days per decade from 1980 to 2012, and the maximum hourly rainfall has also increased from an
average of 96 mm to 117 mm in 2012. Additionally, the expansion of urbanized areas has led to greater peak flows to canals from streets, which also made expanding drainage system more difficult since they are often built close to critical infrastructure. In response, the PUB developed a holistic approach to enhance flood protection from source to receptor, which is where green rooftops and other forms of building greenery comes in.

As part of the source solution, implementing on-site retention to reduce peak run-off in developed areas by 25 to 35 percent has become a new requirement for all new developments or redevelopments by PUB’s Code of Practice since January, 2012. This is because rooftop gardens are an easy and efficient solution for slowing down peak load and the rainwater could be collected through a gravity-based system, which would later be pumped back for irrigation. Water captured with the vegetation layer would also go through evaporation and evapotranspiration, allowing even less rainwater load to enter the drainage system (PUB, n.d.).

In 2001, The Urban Redevelopment Agency developed a vision of ‘dynamic, distinctive and delightful’ city with a network of park connectors and opportunities for greenery to occur beyond ground level (Urban Redevelopment Authority, 2001). The main strategies of urban greening include having more parks and gardens including ‘gardens in the sky’ (Yuen & Nyuk Hien, 2005). Along with the target 200 ha of vertical greenery set by Skyrise Greenery Incentive Scheme, the governments’ vision has led me to believe that Singapore will continue to expand BGIs in/on more buildings. Overall, Singapore creates a perfect stage for all forms of building greenery both as a necessity as well as an experiment of a version of future sustainable cities. The condition Singapore is facing now is not unlike what other cities will face in the future:
cities will have to build denser and higher, leaving less ground space for greenery; the effects of climate change will also likely to change the climate pattern and lead to more flooding and drought events where city-wide single-building retention system becomes necessary.

1.2 Hypothesized Benefits of Building Green Infrastructure
Singapore is not alone in the building greening movement. Before Singapore started implementing green roofs and walls in the late 1990s and the early 2000s, cities in Europe had been leading the green roof movement for decades. Germany, for example, has a green roof area of 13.5 million m² nationwide by 2001, which makes up 14% of total roof area in Germany (Herman, 2003; Mann, 2002a). Since the 1960s, much interest and research had gone into the ecological benefits of green roofs, resulting in a high demand for the newly coined “extensive” roof greening; federal, state and municipal policies are also in place to encourage green roof construction (Ngan 20014). Berlin implemented a subsidy program from 1983–1997 which reimbursed private building owners approximately 50% of construction costs. Approximately 63,500 m² of green roofs was built in that period (Kohler and Keeley, 2005). Similarly, in Basel, Switzerland, 70% of its green roof target has been met (Wilkinson & Dixon, 2016). In another dense, high rise Asian city, Tokyo, private buildings larger than 1000 m² and public buildings larger than 250 m² are required to have 20% of the rooftop greened. As of January 1, 2005, there already is 54.5 ha of green rooftops in the city (“C40,” n.d.). Toronto, Canada, also approved a building policy that requires new constructed city-owned buildings to have a green roof coverage of 50–75% of the building footprint and to replace existing flat roofs with green roofs where it is feasible and practical (Carter & Fowler, 2008).
Green facades has also become a key strategy in enlarging green space in urban areas providing similar benefits to those of green roofs. Simpler in construction, the main elements of green walls include only plants, planting media, structures that attach plants to the facade and irrigation system. Although living walls may provide fewer opportunities for direct interaction compared to accessible green roofs, some benefits are unique to vertical facades due to their visibility and proximity to building users. The aesthetic value of green walls, interior air filtration and oxygenating, indoor noise attenuation… etc. can be enjoyed at a higher rate by users who spend the majority of their time inside the building. They are also more inclusive since anyone enter the building share the benefits instead of only those who have access to the rooftop, and accessibility is not limited by time of the day or weather conditions (Wood et al. 2014). The maintenance load that would come from foot traffic and weather erosion for rooftops does not apply for indoor green walls, either. However, vertical greenery does have the versatility to be implemented both on building exterior and interior, which means facades with vegetation can absorb noise that come from both inside and outside. This is especially useful if the building is located near busy streets, highways and airports (Ngan 2004).

Green infrastructure is often considered to be one of the major resolutions for pressing urban issues such as Urban Heat Island(UHI) effect, storm water run-offs, air pollution, etc. (Wilkinson & Dixon, 2016). Some widely accepted benefits of green infrastructure are categorized by the UK National Ecosystems Assessment (Dixon and Tim, 2016):

a. Supporting services--services that benefit the local ecosystem such as soil, photosynthesis that benefits organisms living within.

b. Provisioning services--providing products such as food and fiber.
c. Regulating services--regulating micro-climate and air quality.

d. Cultural services--providing recreational, health and wellbeing benefits for visitors, as well as adding to the aesthetic values and sense of place.

In theory, we could expect a sufficient green rooftop/facade to provide most, if not all of those services to some extent just like its ground level counterparts. Among them, b. Provisioning services are the easiest to quantify. Dependent on the specific rooftops and facades and the vegetation selection, different goods can be produced--easily grown vegetables such as lettuce and tomatoes are most commonly seen. However, such services are only applicable to a small portion of green rooftops that are programmed to production. d. Cultural services are sometimes in consonance with provisioning service. For example, a community rooftop garden that grows vegetables provides opportunities for farming and various other activities, which promotes social interaction and builds connection among those who visit. Other accessible green rooftops provide similar benefits as green spaces on ground level. Although the impact of cultural services is less tangible or quantifiable, it could be deduced from observation or represented by number of visitors.

A. Supporting services and c. Regulating services, however, involve much more complicated processes and are therefore more difficult to measure. As mentioned in the introduction, the Urban Heat Island (UHI) mitigation effect of rooftop greening is still scientifically debatable. Although on a micro level, plants and other forms of vegetation cover provides definite cooling effect through evapotranspiration and shading that a concrete traditional rooftop is not able to achieve, variations in other direct or indirect contributing factors to UHI frequently negate the
local effect of a green roof or facade: building material properties, anthropogenic heat emissions such as traffic and HVAC units, hydrological changes such as heat transmitted to streams via storm water runoff, and urban canyon (i.e. the street space defined by buildings on either side) geometry which determines outgoing radiative heat flux due to 'heat trapping' (Sharma et al., 2016).

The highly complex and diverse nature of urban building structures and neighborhood compositions, in combination with the inevitable temporality of collected air temperature data, also limits the existing research on green roofs to a small scale (individual buildings) and therefore could not be extrapolated to understand their impact on city level UHI effects. For example, the level of solar radiation, absorption and reflection occur in proportion to the level of building density; therefore, if a green rooftop or a green wall is situated in an urban canyon that is narrow or if the building is tall, the cooling effect in ambient temperature becomes weak to almost negligible (Ng et al, 2012). Widely cited mesoscale (tens of kilometers) simulations identified city-wide cooling of 0.1-0.8 °C from retrofitting 50% of Toronto rooftops (Liu and Bass, 2005), and 0.4 - 1.1 °C for 100% roof greening in New York (Rosenzweig et al., 2006b).

Micro-scale cooling is also one of the most prominent assumed benefits of green facades\(^2\). Unlike rooftop greenery, the cooling of green walls is more relevant to sensory temperature and provides sensible thermal comfort as they enclose the space where most human activities take place. Multiple studies have shown that the cooling effect on external wall surface temperature

\(^2\) Green Facades, aka. living walls, green walls or vertical greenery, defined as a system in which plants grow on a vertical surface such as a building facade in a controlled fashion and with regular maintenance.
ranges from 1.2 degrees (Netherlands) to as much as 16 degrees (China). According to a study carried out by Di and Wang on climbing ivies, the maximum temperature reduction is observed to be 16 °C compared to the front of the green facade (H. F. Di, 1999; Besir & Cuce, 2018).

Cooling effects on green walls also occur through water evaporation taking place in plants and substrate. During the process, the air layer over the plant is humidified and cooled--680 kWh energy is consumed for each cubic meter of water evaporation. The mechanism is described as passive air conditioning.

However, the process gets more complicated when wind is taken into consideration. Plants’ rate of evapotranspiration increases as wind speed increases, which supposedly enhances green walls’ cooling effect. However, foliage on exterior walls can reduce the wind speed coming into the building which is ideal in cold climates, but detrimental in tropical climates. According to Perini et al., the wind speed within the foliage decreases nearly 0.43 m/s in comparison to spaces that are 10 cm distance from bare wall and the wind speed inside vegetation could get to 0 (Perini, Ottelé, Fraaij, Haas, & Raiteri, 2011). A computer simulation study done by McPherson et al. shows the effects of wind speed and solar radiation on building energy performance in different climate zones of the US: For cold climates, heating costs are reduced by 8% but annual cooling costs for warm climates rise about 11% (McPherson, Herrington, & Heisler, 1988; Besir & Cuce, 2018). Whether this is the concern for Singapore is yet to be researched: although higher wind speed in warm and humid weather contribute positively to thermal comfort, the actual wind reducing effect where the yearly average wind speed is as low as 4.4 m/s is unclear (Wood 2014).
Some environmental benefits provided by vegetated roofs are less ambiguous, including storm water attenuation and biodiversity conservation (find the study on Singapore’s endangered species in urban green space). At the peak of a rainfall event or floods, vegetation and substrate layers on a green roof could retain a portion of the flow, part of which evaporates and evapotranspirates and thereby reduce storm water volumes; the rest would eventually flow through and enter the sewerage system, but is delayed in its release. Overall, green roofs lessen the load on sewerage infrastructure and saves maintenance and repairing costs. Within the process, green roofs also absorb and filter pollutants from storm water. The excess water which drains from a green roof can be infiltrated on-site when paired with source controls such as infiltration swales and retention tanks which could be later recycled as greywater for irrigation for the roof itself, car-washing or flushing etc. depend on the building needs (Ngan 2004).

Green roofs could also work as urban wildlife habitats. A 3 ha green roof in Zurich is home to 10,000 orchids including some rare species, as well as 175 native wetland plant species (Brenneisen, 2003). Besides native/rare plant species as well as some small bird species, green roofs and living walls could also support invertebrates including moths, and earthworms and beetles, especially pollinators such as bees, butterflies (Ngan 2004). Pollinators play a vital role in all ecological systems. The alarming rate of pollinator habitat loss due to urban densification in recent years has become a pressing urban ecological issue. In theory, a green roof or green wall is a perfect solution to combine development and pollinator habitat preservation, which is proven true to some extent. A study in Chicago in 2014 revealed that 26 different bee species were found on 7 rooftops within the span of 2 years, among which 10 were not found on the same rooftops previously (Ksiazek, Tonietto, & Ascher, 2014). Another study in Zurich,
Switzerland investigated 40 sites and recorded over 4744 bees from 126 species within a period of 11 months (Braaker, Ghazoul, Obrist, & Moretti, 2014).

Meanwhile, the risk that comes with green roofs being habitats for certain animal species is that it may become an ‘ecological trap’ when habitats that cannot sustain reproducing populations (Donovan and Thompson 2001). Depends on the size and plant selections on the rooftop, species might first accept green roofs for nesting but fail to continuously breed later due to insufficient resources and space (Ksiazek, Tonietto, & Ascher, 2014). In general, there has been a lack of research done to record wildlife behavior on green roofs and even more so with living walls, especially for a period longer than a few months (Hofmann & Renner, 2018). Therefore, we could not yet confirm if green roofs or facades are sufficient long-term substitutions of wildlife habitats that would provide the same ecological service as ground level parks where there is generally more space and easier for species to migrate.

1.3 General Costs of Green Roofs and Facades
Building green roofs and facades is first an engineering and financial problem before it is a socio-political or environmental one. The common perception among practitioners is that green rooftops and walls automatically indicates higher construction and operation costs. This is not necessarily true. For example, there is an entire green roof installation service industry formed around green roof construction in Germany since the 1960s, which reduces the cost of construction significantly. When the first generation of green roofs showed signs of damage in the 1970s, new techniques and materials were developed to improve the design and engineering. According to the 2002 Green Roof Yearbook (BGL, 2002), over 200 landscape contractors in
Germany that install green roofs as well as over 200 suppliers of green roof materials and products (Ngan 2004).

However, the same economy of scale is not enjoyed in most other countries, even with Singapore’s evolving green building industry mentioned above. Despite improved manufacturing and installation methods over time, high upfront costs still limit the popularity of green roofs. Generally among practitioners there is a lack of understanding about direct, tangible and long-term economic benefits. Previous studies argue that due to the cooling effect and shading from plants would reduce energy cost for air conditioning and the protection of vegetation from weathering, green roofs would eventually prove to be less expensive than traditional exposed roof in the long term. Heat transmitted through a barren roof would be more than a rooftop with plantings due to the additional layers of drainage, substrates and vegetation that act as insulation. The California-based study by Simpson and Macpherson shows that tree shades have the potential to reduce annual energy use for cooling 10–50% (200–600 kWh) and peak electrical use up to 23% (0.7 kW); the results of another US-based estimate also suggest that strategic planting of lawns and other landscape plants could reduce total air conditioning energy requirements by 25%; another 2013 study pointed out that an individual green roof can reduce roof surface temperature by 15–45 °C, near-surface air temperature by 2–5 °C and building energy consumption by up to 80% (Peng and Jim, 2013).

However, would the long-term energy savings really off-set the high upfront construction and maintenance costs? If so, how long is the return on investment period? In a simulation study done by Wong et al., researchers from School of Design and Environment at National University
of Singapore, Singapore National Parks Board and Singapore Botanic Garden tested the life cycle costs of green roofs in tropical climate, Singapore in particular. They first identified several types of green roofs. Accessible roof gardens, aka. intensive green roofs, are often developed on residential buildings and are used as parks or building amenities with areas of paving and seating. The additional planter boxes and topsoil layer required for an intensive green roof lead to a heavier dead load ($30 \text{kN/m}^2 \approx 3060 \text{kg/m}^2$) on the building structure. Inaccessible roof gardens, aka. extensive green roofs, are not designed for public use and are mainly adopted for aesthetic and ecological benefits. Comparing to intensive green roofs, costs are lower, minimal maintenance is required and inspection is performed only one to two times per year for extensive green roofs. Additionally, their relatively low weight demand due to thinner substrate layers (50–150 kg/m$^2$) and simpler construction make them suitable for large roofs and existing structures (Wong, Tay, Wong, Ong, & Sia, 2003).

After comparing both types of green roofs with a simple exposed flat roof and a conventional built-up roof with multiple layers of insulation and reflective and waterproofing coating, the result shows that the initial construction cost for extensive green roof system with 100% turfing is $40.61/m$^2$ more expensive than the conventional flat roof, while an intensive roof garden with 80% shrubs and an intensive roof garden with 50% trees are $126.98/m^2$ and $129.68/m^2$ more expensive than the conventional flat roof, respectively. However, when compared to a common built-up roof with concrete topping, an extensive inaccessible green roof is $41.74 lower in initial cost, while green roofs with shrubs and trees are $47.33 and $65.56 higher, respectively (Wong, Tay, Wong, Ong, & Sia, 2003).
When taking the service life longevity and energy costs into consideration, an extensive green roof has a life cycle cost of $579,121, which is $53,827 less than an exposed flat roof and $91,477 less than a conventional built-up roof. Intensive green roofs with shrubs with annual energy savings up to 5000 kWh compared to that of a built-up roof, show a lower life cycle cost than conventional built-up roof--although the payback doesn’t occur until the 35th year within its 40-year longevity (Wong, Tay, Wong, Ong, & Sia, 2003).

As previously mentioned, the National Parks Board and Urban Redevelopment Authority launched Skyrise Greenery Incentive Scheme (SGIS) in Singapore, which funds up to 50% of the construction costs of rooftop or vertical greenery and could significantly offset the initial cost. However, this only applies to existing buildings and the reimbursement is capped at $200/m² for rooftop implementation and $500/m² for vertical implementation. Funding also does not extend to hardscape elements such as pebbles, trellises, benches, decking, etc. on rooftops, or indoor vertical greenery (“Skyrise Greenery,” n.d.).

Based on previous studies, we could conclude that most accessible intensive green roofs carry a higher life cycle cost than conventional or extensive alternatives, at least with current technology. Realistically, if green roofing doesn’t provide incentive through lower long term costs, most of its other potential benefits such as storm-water retention, improving air quality and social services are mostly concerned by the cities/ more relevant to planners and city officials. Therefore, perhaps policies that monetarily compensate or encourage green roofing and green walls at city-level are the most effective, if not the only method to realize such practice.
Within this rationale, the cost-benefit analysis would involve a drastically different set of considerations for city officials and planners. For example, if building green infrastructure is viewed as an alternative to ground-level green space; the costs are then not compared to conventional roofs, but to costs purchasing land parcels and constructing parks. However, as Carter and Fowler pointed out, a major caveat is that city-level green roofing policies require jurisdictions to have adequate funding sources, which may vary based on annual budgets. In several jurisdictions in Germany, green roof subsidy programs were eventually terminated after a number of years because of budget constraints (Carter & Fowler, 2008; Ngan 2004). This is the concern of Singapore’s SGIS as well since the incentive scheme is effective from 1 April 2015 and will expire on 31 March 2030 or when the incentive scheme funds are fully disbursed, whichever earlier. Participation in the scheme will be on a first-come, first-served basis, subject to availability of funds.

Considering that such policies already exist in Singapore, this paper is less concerned with the quantitative analysis showcasing the cost-effectiveness of green roofs and green walls as urban green infrastructures to encourage such policies. While recognizing the importance of sufficient budget, it is also beyond the scope of this paper to discuss how to generate consistent funding to sustain greenery policies. Rather, the following chapters will consider the factors that contribute to realizing the benefits in existing cases of building green infrastructure, and propose some policy and design recommendations to maximize those benefits.
Chapter 2. Case Studies

I had the opportunity to visit several buildings with assorted types of green rooftops and green walls in Singapore from May to June, 2019, ranging from tall office buildings, commercial shopping malls, rooftops of public apartment buildings retrofitted rooftop farms to green walls in school buildings. In this chapter, I have selected multiple building types in combination with different forms of greenery incorporation, aiming to include a variety of existing designs and their performance. I will apply some urban studies methods such as traffic mapping, observational study and interviews in order to understand the real-life usage of various building green infrastructure. I aim to uncover an individual’s motive and experience visiting buildings with greenery, and combine the surface-level impressions with any perceptible implication of the technical. While acknowledging the complexity of human perception and there are many ambiguities in how one ‘feels about’ a space that cannot be captured within several qualitative parameters, the term ‘perception’ is used here in the general sense of how things are ‘seen’ and ‘knew’ which reflects users’ motives, preferences and attitude towards a space.
Solaris is a 79 meter, 3,065 m$^2$, 15-storey office building in Fusionopolis, a Research & Development hub within the business park One North in Queenstown. Built in 2001, Solaris achieved 108% greenery replacement, representing more than 8000 m$^2$ and over 95% of which is above ground level, with its revolutionary eco-design and landscaping strategies. The building consists of two towers connected by a central atrium, with each floor wrapped with a sky terrace with trees and vegetation. The central atrium and the inside walks of the sky terraces are designed for passive ventilation and is not air-conditioned or artificially lit during the day, which contributes to the total energy saving of 36%. In addition, Solaris also incorporated a gravity-based rainwater harvesting/recycling system with storage tanks both on rooftop and below ground, climate responsive facade which adjusts angles depends on sunlight reception, extensive shading louvers and pocket indoor gardens which also benefit the health and well-being of office workers in the building. (“SOLARIS, Fusionopolis (Phase 2B), One North Singapore,” n.d.).
The exterior of the building is covered with a green ramp of 1.5 kilometer linear that continuously extends from the ground level to the upper levels of the building, connecting the basement with a cascading sequence of terraces and rooftop gardens at higher levels. The densely planted trees and plants along the ramp on each floor shades and cools the building facade. On ground level, the main entrances connect the atrium with One-North Park across the street to introduce cross-ventilation and create a corridor to green public space. The below ground level car parks are also partially exposed for the same purpose.

The day of my visit as a typical summer day in Singapore with a high humidity of 90% and a temperature around 30 °C. Despite the multiple passive cooling strategies installed in the Solaris building, the heat was not tamed and the center atrium still felt like a greenhouse, if not just as warm as outside the building; cross-ventilation was futile due to the lack of natural breeze. Not surprisingly, during the several hours I spend in and around the building, no one stayed in the atrium for over 5 minutes. Most people are office workers passing by or taking a phone call, who either left the building or quickly went back to the heavily conditioned office space.
According to several workers I managed to interview in the space, that was the norm of the central atrium where usage is low and mostly as a transit space rather than a dwelling space, mainly because of the lack of air-conditioning and the heat and humidity became unbearable, even though part of the design intention is for it to be an event-hosting space. However, they did express appreciation for the extensive greenery throughout the building interior and exterior, which creates an one-of-a-kind, refreshing working experience, which they enjoyed showing friends and families when they come to visit. The ramp and the roof gardens do get used for work breaks on cooler days. The solar shaft appears to be one of the most successful features, keeping the building lit even on an overcast day when I visited. The trees and plants at the terraces, pocket gardens and the exterior ramps are also very well-maintained, which proved the rainwater irrigation system that supports all vegetation to be successful.

In a 2014 facade analysis done by Anthony Wood, the solar shading in Solaris using the climate-responsive facade system, vertical greenery and extensive shading louvers effectively countered the heat retention of the double-glazed perimeter facade. The combination of those effects helped the building achieved a low external thermal transfer value of 39 W/m² (Wood, Bahrami, & Safarik, 2014).

Still, Solaris is considered one of the most ground breaking projects in the green rooftop and vertical greenery field, designed by architect TR Hamzah and the pioneer in ‘Urban Greening’, Dr Ken Yeang. The designers weaved the landscaping elements into the fabric of the architecture, instead of defining a clear boundary between utility space and landscape space like
most others. The architects paid attention to the building’s visual appeal for users inside the building as well as visitors from outside. For example, the planter boxes for trees on the green ramp is designed to be as shallow as 800 millimeter to reduce the ‘bulkiness’ visual effect. To compensate, plant species are carefully selected so the root system would spread horizontally, rather than those rely on deep soil; fertilizers and soil amendments are also provided through the irrigation system to maintain soil nutrients and sufficient water, which comes from the rain harvest storage of 700 m³. The financial resources and ambition makes it an impressive attempt for marrying landscape and architecture, but not a replicable or effective model for future buildings and certainly not for retrofitting existing ones.

2.2 School of the Arts, Singapore (2010)

Located at the heart of downtown Singapore on the historic commercial street Orchard Road, School of the Arts was designed by WHOA architects and completed in 2010. The structure is comprised of three main wings connected with sky bridges and pocket gardens. The unenclosed
ground-level design is effective for both sustainability and social purposes: unlike Solaris, the semi-open structure creates both uninterrupted air passageways for passive ventilation through the main building mass; a strong visual connection is also established with the public realm outside, framing views for both building users and pedestrians. The exterior facades of the three wings on the north and south sides along the main air corridors are covered in modules of simple mesh panels with green vines expanding from precast concrete planters, adding up to a coverage of 6,446 m², about 26% of the total surface area. Whereas the east and west side facades are aided with angled vertical fins to increase shading (Wood, 2014). All trees from the original site are preserved from the original site, including the one that breaks out from the set of stairs at the entrance; a matrix of pocket gardens are also located in the breezeways in the building and each wing is topped with a rooftop garden with a 400 m running track. Gardens are equipped with benches and other outdoor furniture to encourage usage.

The design considers the best practice for both establishing and sustaining the greenery. Not using the suggested plant species provided by Skyrise greenery, the landscape consultants conducted simulation experiments with 8 different species of creepers and chose the tropical species Thumbergia Grandiflora for its ideal rate of growth and even coverage. The irrigation system utilizes rainwater harvesting and automated irrigation pipes under each planter. However, frequent maintenance and inspection are still required to ensure healthy plant growth. The planters for vines growing to the exterior facade are thus located in the building corridors for accessibility.
Unlike the office building Solaris is, SOTA’s programming requires extra attention to balance security, openness to the public, and access to nature since the building is mainly used by high school students and is located in the city center. The incorporation of vertical greenery and gardens is no more environmental-driven than design-driven: the soft addition of plants and vines provides a sense of security and seclusion from the busy urban scene outside to an otherwise exposed mass structure. Users would find themselves constantly in the blurred peripheral of the interior and exterior, enjoying the interaction of the sunlight and greenery, the street bustle and activities in the indoors. The result is a design that resolves the downside of its context by embracing the advantages of it.

During my visit to SOTA on a rainy summer’s day, the wind directing design did enhance comfortable breeze despite low air movement and high humidity levels at the lower levels. The
uneven sets of staircases and the generous use of wood panels with draping vines on surrounding walls at the entrance invite visitors to sit and dwell instead of merely passing, turning a transit space into also an amenity space. The pocket gardens are accepted and used as part of the regular indoor space during class breaks, contrasting the distinction of the vegetated ramp and indoor office spaces at Solaris. May the rooftop and pocket garden trees lack in shading, and the cooling effect of the vines uncertain as they are, the fulfillment thematic purpose, seamless integration, and high multi-functional usage have already proved the design to be successful.

2.3 Marina Barrage, Singapore (2008)

Marina Barrage is a $2 million dam project built across the 350 meter wide Marina Channel in 2008, creating the 15th reservoir of Singapore and the first in the inner city. It serves a three-fold purpose: forming a 10,000 ha water catchment area and providing 10% of the city’s water needs, largely increased Singapore’s water resilience and lessened the pressure on water importation or desalination; part of a comprehensive flood control scheme that protects low-lying areas in the...
city from inundation by releasing excess flow to the sea during heavy rainfall; providing water related recreation opportunities because of steady waves unaffected by tides, as well as education and outreach through the sustainability gallery which is also located at Marina Barrage (“Marina Barrage--Green Roofs.com,” n.d.).

The rooftop park is a large continuous lawn, around the size of four football fields, that extends from the ramp on the ground level in the central courtyard of the building complex, spiraling up to the second and third level; the park creates a large open space for public recreational use such as kite flying and picnicking, or could be booked for private events. Singapore’s largest solar panel collection of 405 panels is located at the southwest tip of the park, producing 76,000 kWh electricity per annum, enough for around 50% of electricity needed onsite or for 180 average households’ daily use.
The irrigation system is equipped with sensors to detect rainfall, which would deactivate the sprinklers to minimize water waste. Apart from necessary cementing and water-proofing, the construction material, VersiCell, covering 14,000 m² of the green roof park is 100% recycled from plastic. Instead of the traditional heavy gravel course to facilitate drainage, the VersiCell modules are lightweight, which reduces loads on the main building structure, and could capture and drain water rapidly during heavy rainfalls. According to the Public Utility Board’s official website, the rooftop lawn reduces maximum surface temperature of the building by 3 °C.

Since its official opening in 2009, Marina Barrage has become an iconic destination for both locals and tourists. The sustainability gallery offers tours throughout the day to advocate for Singapore’s sustainability and resilience efforts and to demonstrate the benefits of the reservoir and the barrage. On the day of my tour, a group of researchers were also visiting from Malaysia and Indonesia, taking notes and asking the technical details of the dam. Meanwhile, groups of elementary and middle school students kept swamping into the central courtyard on their bikes and in their bright green biking shirts for a break near the fountain.

Although as usual, the weather has constrained most visitors to the shadows or the air-conditioned indoors and the lawn rarely gets used in days like this, the green rooftop is the defining character of the Barrage. It is thematically fitting, if not necessary, as an architectural statement for Singapore Government’s dedication to realizing the “City in a Garden” vision in the age of climate change. Standing on the rooftop—which is almost mandatory if you visit Marina Barrage, an uninterrupted panoramic view of Marina Bay and the iconic skyline of
Marina Bay Sands, and the newly added Gardens by the Bay, the Cloud Forest Conservatory unfolds. This is the latest version of the postcard for this 54 years old city.

2.4 The Jewel Changi Airport, Singapore (2019)

![Left: Rain Vortex Acrylic Funnel; Right: Terraces at Shiseido Forest Valley](Image Source: Author’s Collection)

Even among all the dazzling shopping malls and hotels throughout the city with trendy indoor vegetation, green roofs and living walls, the Jewel at Changi airport is unmistakably and quite literally, the crown jewel of the city’s increasingly green canopy. The Shiseido Valley in the central atrium is one of the largest indoor gardens in Asia, spanning vertically across five stories and representing approximately 22,000 m² of greenery area. Over 3,000 tropical trees and 60,000 shrubs of 120 species were brought in from around the world to construct this breath-taking indoor forest. Visitors could easily access the atrium garden from all levels and all directions in the mall due to the central location and its scale. From any store space, they will first enter smaller pocket gardens and the lush tropical simulation would reveal itself in front as they follow the sound of the waterfall. Depends on the level, visitors might find themselves either on the
ground level central atrium or on one of the stepped terraces with trees and cascading small water falls overlooking the center pond. The terraces are connected with a ramp stretching from below ground level to the canopy park on the fifth floor, so visitors are free to ascend or descend in a rainforest-esque walk without interruption. The Vortex, besides being the world's tallest indoor waterfall, also collects rainwater for irrigating the plants.

Bottom Left: Canopy Park; Bottom Right: Indoor Pocket Garden on Second Floor
Image Source: Author’s Collection

This approach might be comparable only to Solaris, the previously mentioned project that also exhaustively integrated trees and plants on a continuous ramp throughout the building’s vertical facades. However, instead of planting trees and vegetation on an exterior ramp, the Jewel kept it all within the central space of the building to create a protected concentrated space for visitors to enjoy. Such design is less effective for potential noise and Urban Heat Island attenuation, but ensured that the indoor landscape is the centerpiece of the building experience and centralized the micro-cooling effect from the vegetation. Every other element, including the Vortex, the sound of water and music, the round shape of the building and the pocket gardens on the
peripherals of the atrium, are all carefully orchestrated to lead visitors to the center and building up to the big moment of revelation.

As mentioned at the beginning, from the glamorous central business district malls ION Orchard and Bugis Junction to small neighborhood malls, it has become a popular practice for shopping malls to incorporate some type of landscaping elements into the building as a marketing and customer retention strategy. Environmental incentives aside, in a highly competitive market where retail space per capita is as high as 11.6 ft², business owners in Singapore are understandably eager to incorporate any eye-catching novelty that appeals to customers and others are swift to catch up (“Singapore malls take lead in bumping up food space to counter online hit,” 2017). Joye et al. introduced the concept of Biophilic Store Design, namely adding greenery in retail spaces as a strategy to alleviate stress and attention fatigue resulted from the overwhelming sensory information in store environments, which would hypothetically attract more customers, boost their rate of return and in general, provide a more pleasant retail experience. It was later confirmed by Wolf’s study, revealing more positive customer feedback and higher price acceptance towards biophilic stores and shopping malls compared to the traditional ones. Some customers claimed that they are willing to travel further to shopping malls that are integrated with trees and vegetation (Joye, Willems, Brengman, & Wolf, 2010).

The incentive for the Jewel, however, is a little more than just attracting customers and the scale is not just to rise higher than its competitors. Changi Airport is the biggest port of entry in Singapore and handles over 6.1 million passengers every year. Therefore, the experience in the Changi is the first and last impression of the city for the majority of the visitors, and the only
impression for those who transit. The 1.3 billion dollar project started out just to expand the capacity of Terminal 1 as well as its open-air carpark. This led to a strategic conception of augmenting Changi Airport’s as a global air hub and a destination in itself.

The result is not only visually appealing, but also highly efficient in its mixed-use with gardens, attractions, retail, dining, lodging and seamless integration with airport operations. It has now completely changed the airport experience for many. The family in front of me in line checking in to their flight made sure they came 3 hours early to make their last stop at the Jewel before heading home. In Singapore’s PM Lee Hsien Loong’s speech, he described Changi Airport’s development reflecting the country's journey from third to first-world status (“Jewel an ‘instantly recognizable icon’ that has made Changi Airport more competitive,” n.d.). Not unlike the Marina Barrage, the Jewel—although privately owned—has become a recognizable landmark as part of Singapore’s new national image. Considering the new ‘City in a Garden’ slogan, an indoor tropical forest seems only appropriate.
Citiponics at Ang Mo Kio is an exception among the existing intensive green roofs in Singapore which are predominantly commercial buildings programmed for recreational purposes. On the rooftop of a multi-storey car park in a HDB (public housing) housing complex in Bishan, the company Citiponics Farm implemented Aqua-Organic Systems (AOS) to grow organic leafy greens using a network of pipe structure where water and nutrients is supplied constantly. This is the first carpark rooftop urban farm in Singapore. The company claims that the production on the 1,800 m² farm could be sufficient to provide for 1,600 people for a month. The first harvest is expected in just two months’ time after its opening in February, 2019 (Teh, 2019).

According to the company’s official website, this innovative urban farming practice trumps traditional soil farming in several ways: it only uses 1/10 of the amount of water that would be used in a traditional hydroponics system; no pesticides or fertilizers is needed since vegetables grown out of clay pebbles in the plastic pipes, not soil; produces zero waste in the production process and water is always recycled in the system; the system is mainly machine operated and relies on far less energy or human labor than traditional farms. Singapore’s Senior Minister of
State for Trade and Industry, Dr Koh Poh Koon, praised that the new carpark farm is "produced by (the) community, in the community, for the community". The farm employs local residents, including older residents from a nearby senior community home. The company is also looking into providing internship and volunteering opportunities for students in the future. The produce will be sold to a local low-price grocery store chain, Fairprice, and sold to the community at its store located in the neighborhood after it’s harvested. This will reduce carbon footprint used for transporting vegetables that will otherwise have to be imported from further farms or even overseas (Teh, 2019).

Thematically, the rooftop farm provides food, employment and learning opportunities for the local community. Structurally, the pipe network is a relatively low cost and low maintenance program due to its lightweight (each framework is less than 75 kg), loading less weight on the building structure comparing to intensive green roof or a soil-based rooftop farm. The material used for construction is claimed to last over 15 years in tropical climate and is “anti-mosquitoes”, which is especially relevant to Singapore’s conditions where mosquitoes can be a big concern in residential areas. An obvious caveat of this model is its exclusivity. Although situated on top of a carpark in a public housing complex, the rooftop farm is privately owned by Citiponics and is not designed for public recreational use; the rooftop is not open to visitors or even residents of the same housing complex. Incidentally, there has not been much promoting for the rooftop farm. On the day of my visit, it took me and a friend who lives in the area much walking around to even locate where the car park is since there was no signage for it. When we finally got there, the entrance was locked and a worker gestured us that the farm is closed for visitors.
Chapter 3. How to Maximize the Benefits of Building Green Infrastructure in Singapore?

There is no doubt that green rooftops and green walls will continue to be the future look of Singaporean cityscape. The case studies in Chapter 2 gave some examples of different types of buildings and different building greenery designs. In this Chapter, I will analyze some previous user perceptions studies showcasing the effectiveness of different methods of incorporation, and combine those external insights with my own experience mentioned in Chapter 2 to inform a set of master planning suggestions within Singapore's urban context.

3.1 User Perceptions
Building Green Infrastructures is the modern hybrid of the built environment and landscape features that have only been in existence from late 1990s to early 2000s in Singapore, to which the urban space and its occupants are still slowly adapting to (Yok, 2012; a+u, 2012). They operate in the “in-between” both visually and functionally. As discussed in the first Chapter, the replacement area ratio of landscape elements to building footprint does not represent true *replacement*; most building green infrastructure in its current state is not comparable to its ground level counterparts. Environmentally, the microclimate effects have varied in past studies depend on the building and the site climate; socially, they are not as accessible or noticeable as parks and open lawns where pedestrians could pass by and utilize without previous knowledge of the space. In most cases, the BGIs serve exclusively to the users of the existing building, which is a result of both their physiology and absence of publicity. They should by all means be treated and planned as a separate type of green space from the ground level ones.
Ultimately, the perception of the public about their surrounding space determines its success. Urban spaces are designed to serve people living and working in the city, and building greenery is no exception. Understanding how people interact with them is essential for designing more successful, functioning and popular building greenery in the future. To expand from my own experience described in Chapter 2 Case studies, I aim to uncover the effective and ineffective aspects of the current state of building greeneries using several studies regarding the usage of rooftop gardens and indoor or courtyard gardens in Singapore, Penang (Malaysia), Hong Kong and Tokyo. Among the three cities, Malaysia is geographical close to Singapore and thus have a similar climate as well as overlaps in demographics; Hong Kong is also an island city with a humid subtropical climate and dense, high-rise development; Tokyo is less similar to Singapore’s climate than the other two cities but resembles its urban physiology.

Such studies are still inevitably limited to the specific buildings, time, sample groups and different parameters they included; thus do not offer a coherent or parallel comparison. In general, there is also inherent difficulties in transforming qualitative information such as user satisfaction to quantitative data. Some parameters are, however, universal and intuitive such as thermal comfort, desire for interaction with greenery, need for space to be alone or family activities, which are included in all the perceptions studies below. Therefore, the analyses are mainly observation-driven and survey-based for a realistic sense of how green roofs and walls function in practicality and how most users experience them.

As explained in the first chapter, another limitation in such studies is the difficulty of accumulating qualitative data in a long period of time, not only because of the technical
complexity of obtaining data, but also due to the discrepancy among different agencies in the building process (the architect, building owner, building manager and the tenants, lack of inherent evaluation component) and the volatile nature of any environmental effects. Some microclimate data such as air temperature and wind velocity are collected, but are highly limited to the time of the day and period of recording when the measurements are taken (Xue, Gou, & Lau, 2016); In those cases, quantitative survey results describing thermal comfort can more realistically encapsulate the overall user experience in the long term.

3.11 Rooftop gardens on Residential Buildings
According to a survey conducted in a perception study in the neighborhood Choa Chu Kang New Town, a typical Singaporean public housing town with predominantly residential development (307 out of the 583 ha total area), there was a contrast of generally low usage and high level of awareness and willingness to use towards public rooftop gardens. Within a random stratified sample group of 333 residents living near (<5 min walk) and away (≥ 20 min walk) from the rooftop gardens, only around 58 people have visited the rooftop garden, among which 44 people are from households near the gardens. Over 90% of the group know of the rooftop garden and 84% responded that they would use rooftop gardens if they are provided in the neighborhood within a short walking distance. In contrast, the majority (73%-98%) of the group do use other public parks frequently (Yuen & Nyuk Hien, 2005).

Accessibility and visibility appear to be the reasons for the low utilization reported in the Choa Chu Kang case. Unlike ground level parks, access to roof gardens in the site is at present through staircases only, which demands a certain level of physical fitness and local knowledge of the
location of those staircases. This is reflected in respondents’ comments on why more roof
gardens should not be supported: they are not practical, ‘no one would go there’; while ‘Roof’
gardens is too hot for comfort’ (Singapore located 1°N of the equator records day temperatures
of high 20–30 °C) and ‘nothing there fancies me’ were two major reasons in another study on
why residents in another public housing town did not visit the roof gardens (Tan 2003/2004;
Yuen & Nyuk Hien, 2005).

Another important residents’ feedback pointed out that the roof gardens should be made unique
and different from the other ground plane parks and gardens. Residents suggested that rooftop
gardens should include water features and special plants as possible points of distinction, which
will lead to community connectedness to the space. This reveals the challenge in current roof
gardens planning to recognize the different needs and aspirations of multiple users and interest
groups. About 80% of the respondents voted for more roof gardens while a minority (8–12%)
expressed concern over issues of maintenance, insects and safety.

Another resident perception study was done in Singapore in 2010, 5 years later to the first. By
then, rooftop gardens and other vertical greenery systems were already “widespread”. Both the
public and the professionals are gradually accepting them as a new building norm in an effort to
transform the city from “Garden City” to “City in a Garden”. Though the 2010 survey focused
less on residents’ motives to visit and personal experience but on the general understanding of
vertical greenery and green roofs as a city-wide building practice, it sampled again, a group of
residents from several New Towns including Choa Chu Kang, government agencies and
professional architects (Wong, Tan, Tan, Sia, & Wong, 2010).
The result was surprising in revealing that even with the rate of vertical greenery growth on Singaporean buildings in the 2000s, the awareness level was still low among residents. 333 out of the 400 residents said they have not heard of vertical greenery systems, and 340 did not know of any building that had incorporated such systems (Wong, Tan, Tan, Sia, & Wong, 2010). Similar to the previous study, over half of the residents expressed willingness to see more green facades in the buildings they live and work in, and over 64% agreed that extensive greenery facade implementation would enhance Singapore’s city image. Some discrepancies in terms of concerns for such systems between residents and professional architects reflect a lack of outreach and education on high rise greenery for the general public. For example, adding green facades to buildings will lead to influx of pests, mosquitoes and unwanted animals, which will affect the comfort of their daily life, is one of the residents major concerns. However, both architects and landscape architects in the survey pointed out that such problem could be easily eliminated through regular maintenance (Wong, Tan, Tan, Sia, & Wong, 2010).

3.12 Pocket Gardens and Rooftop Gardens in High rise Office Buildings
Perception study conducted by Xue et al. in fourteen high rise office buildings in Singapore and Hong Kong (seven buildings, and over 200 participants from in each city) also confirmed the desirability of greenery in a working environment, where “participants from the air-conditioned offices revealed significant higher concerns about health issues than those participants from the mixed-ventilated offices. The mixed-ventilation design performs as a bridge to connect the indoor environment and outdoor space, which enables people to have contact with nature. Additionally, the preferred building morphology of the workplace is the pattern of a building
complex instead of a single building. The complex form integrates the configuration of courtyards, podium gardens, green terrace, public plaza, and other types of open spaces with the building clusters, which contributes to better health perceptions” (Xue, Gou, & Lau, 2016).

Xue et al. iterated that some greenery is better than no greenery at all, however, the existence of greenery doesn’t mean it is going to be effectively utilized, especially in a tropical climate like Singapore’s. A study in 2010 highlighted the difference in usage and perception towards different forms of building green infrastructure even within the same building. It also revealed that thermal comfort is the biggest determining factor for the amount of usage for the landscape gardens in tropical regions, given that users are aware of their existence. A survey was conducted among workers in a high rise office building in Malaysia about the three types of existing landscape gardens: Sky Court Garden (215 m² semi open garden on 10th floor with one wall with water cascades, a fish pond, open gym, tables and chairs, similar to the setting of the pocket gardens in SOTA), Balcony Garden (67 m² garden on the 13th floor enclosed by 3 walls with tables chairs), Rooftop Garden (380 m² open garden on the 21st floor with benches) (Taib, Abdullah, Syed Fadzil, & Yeok, 2010).

Among the three, the sky court garden displayed the lowest average air temperature (mean value=29.9°C comparing to 32.7°C and 43.2°C for Balcony and Rooftop), highest wind velocity (0.67 m/s comparing to 0.016 m/s and 0.58 m/s), and therefore the highest thermal comfort, which was reflected by the survey results: 88% of the respondents have visited the Sky Court garden while only 35% have visited the Balcony and the Rooftop Garden. For those who have not visited the sky court garden, 31% responded that they did not know that the garden existed,
and the same reason were given by 83% of those who have not visited the Balcony Garden. For those who are aware of the gardens, lack of accessibility (10%) was the biggest reason for not visiting. For the Rooftop Garden, however, 21% reported that the preference for staying indoors was the main reason other than accessibility due to the high sun exposure and temperature. They also extrapolated that the same limitation of accessibility (only accessible through a staircase) might have also led to the low usage in Yuen et al.’s 2005 study (Taib, Abdullah, Syed Fadzil, & Yeok, 2010).

In addition, the survey also shows that visitors of the Sky Court Garden were mainly attracted to the water cascade and pond (46%) over other features. The introduction of water elements not only enhances the ambiance, but also helps to further reduce the temperature (average 25 °C water surface temperature recorded). Even though the Rooftop Garden has the same composition of greenery and even higher in quantity and similar seating opportunities, thermal comfort have surpassed other factors in users’ decision to visit (Taib, Abdullah, Syed Fadzil, & Yeok, 2010).

3.13 Rooftop Gardens in Hospital Buildings
Many studies have been done in the past to prove the healing benefits and anti-depression effects of greenery. It is not surprising that gardens have been incorporated in hospitals to provide a therapeutic space for both patients and staff to relieve the mental stress from a hospital environment. An observation and survey based study conducted in a highly used public hospital in downtown Tokyo revealed the courtyard is most popular among inpatients and the general public (the courtyard is open to public during weekdays), which receives 200-400 visits every day during the study period (April to February), among which 30-90 are inpatients. However, most...
of the visits are just passing by and less than 5 people would spend over 20 minutes in the garden on any day (Ishii & Iwasaki, 2009).

Another study done in 2011 by Davis in a hospital rooftop therapy garden in Tennessee, U.S., also consisting of behavior observation and survey questions about the physical, emotional, spiritual, and social impacts of the garden on both patients and hospital staff. The garden is surrounded by other hospital buildings higher than the one the garden is located at, creating a feeling of a protected courtyard, barring one side overviewing the downtown street scene. Due to the rehabilitation nature of this hospital, the usage of the garden is more controlled and managed by the hospital. Many patients don’t usually have time to freely stroll around the garden due to a full day schedule of therapy sessions, but the garden would be used for events such as picnics or games and special rehabilitation facilities are provided for some sessions. Unlike the Tokyo study, however, when the garden do get used in patients’ own time, 15 out of the 28 observed users came to the garden for a prolonged time for activities ranging from smoking, playing basketball, relaxing to taking a therapy walk for 20-45 minutes (Davis, 2011).

The appreciation for the garden was confirmed by the survey results where the response from patients when asked whether the garden helped patients regain life skills such as mobility and self-confidence in a way different from indoor areas, was overwhelmingly positive, and 88% of staff members reported that the garden was unique in that it provided real-life situations, rather than simulated situations in indoor areas such as the gym or recreation room. The garden in this case provides more than just perception level benefits, but also creates an opportunity for patients who need to experience real-life situations while remaining within the supervision of the
hospital. Some common responses also include “to see changes[outside] while in the rehabilitation center”, “to get away from the hospital smells,” or simply “to see green” (Davis, 2011).

On the other hand, it appears that hospital staff do not have easy access or opportunity to use the garden as much as their patients due to lack of breaks during work. Nearly 70% of responding staff reported their use of the garden as being patient activity- or therapy-related, while less than 15% said that they go to the garden for any personal use. 20 out of the 25 staff in the survey responded that they did not typically choose the garden over an indoor break area; while the ones that did use the garden stated that it was relaxing and a chance to get away from the hospital. 15 responded that the garden was difficult to view from indoors, who could otherwise benefit from at least the view (Davis, 2011). Other than institutional changes that are needed to boost the usage of gardens among staff, incorporating greenery to indoors where even when doctors and nurses can enjoy some contact with greenery when passing in their work routines could be an effective solution.
Though no perception studies have been conducted in Singaporean hospital buildings, some of them have adopted indoor gardens, green facades and rooftop gardens as well. Khoo Teck Puat Hospital (KTPH), for example, is a general acute and care hospital as part of Yishun Community hospital. Opened in 2010, the public hospital consist of three main buildings with a central courtyard, 8 roof gardens, 5 levels of corridor planters and 81 balconies with planter boxes. The designers thoughtfully designed themes for the rooftop gardens for them to be educational and entertaining, including a wide variety of edible fruit trees, vegetables and herbs that are used by the hospital kitchen. On vertical level, there are terraced gardens at the podium roof deck levels with private pockets. To cater for thermal comfort for visitors, these gardens recycle cold air from the operating theatres at the lower levels; there are green walls with plants are watered in streams, which serves as a for filtering grey water intended for a bio-pond. Over 70% of the
The hospital is unmistakably operating in concert with the Singapore’s overall “City in a Garden” concept. In fact, Mr. Liak Teng Lit, the Chief Executive Officer of Alexandra Health Singapore who had a vital role in the planning and commissioning of the new general hospital directly pointed out that “KTPH was conceptualized as a ‘hospital in a garden, and a garden in a hospital’ (“Khoo Teck Puat Hospital (KTPH),” n.d.). The intention was to create a healing and engaging environment through gardens for patients, staff and the whole Yishun community.

Since its opening, KTPH has gained a high reputation and won numerous awards including the first place in the Skyrise Greenery Awards in 2010. Although KTPH is a particularly extensive and successful case, Singapore General Hospital, Ng Teng Fong General Hospital and Changi General Hospital have all enrolled in the Skyrise Greenery program and adopted some form of greenery as well, pursuing the same healing and therapeutic purposes; It is likely to become a more common trend in Singaporean hospitals in the future.

Overall, the perception studies mentioned above as well as the case studies in Chapter 2 have revealed some common factors that contribute to the success, or lack thereof, in building greening:

A. for studies conducted in Singapore or cities that are in a similar climate context, namely Malaysia and Hong Kong, thermal comfort turns out to be the determinant factor for usage. Singapore experiences a fully humid equatorial climate with a high average annual temperature of 27.5 °C and a low average wind speed of 4.4 m/s (Wood 2014), which means...
simple shading of a few trees is not sufficient most times, especially in locations like rooftops where there is extra sun exposure. It’s not hard to understand why when given the option, people tend to stay indoors with the comfort of air conditioning, e.g. Marina Barrage; they also prefer the courtyards and pocket gardens that are semi-shaded by the building walls to rooftop gardens, e.g. Office Building in the Malaysia study, School of the Arts, Solaris. This is confirmed by Lin, Tsai, Hwang, and Matzarakis’s investigation on the influence of outdoor shading effects towards the usage of public open space, which testified the area-averaged sky view factor as the indicator of solar radiation level could be negatively associated with the park utilization under the tropical and subtropical climate conditions (Lin, Tsai, Hwang & Matzarakis, 2012).

B. The usage of different building greenery is correlated to its programming as well as the building type. For buildings that have all day-time occupancy and high usage, such as school buildings(School of the Arts), office buildings(Solaris and study in Malaysia), shopping malls(the Jewel) and hospital buildings (Ishii & Iwasaki and Davis’ study), gardens and courtyards are also highly used as a break from the indoor environment, especially in those inherently high-stress environments where users don’t have the opportunity in their schedule to completely step outside to a park. For buildings that have lower usage and when users have easier access to ground level green space, such as residential buildings, rooftop gardens tend to be less visited than ground level gardens. This might be caused by space design, attractions, and the function as Yuen & Nyuk Hien pointed out, but more for thermal comfort, security and accessibility concerns. During my visit in Singapore, the locals started to use parks as gathering, recreational spaces and exercise grounds after dark when the air gets cooler. In this case, the ground parks are not replaceable by rooftop gardens also due to the spatial and functional limit.
C. Private, commercial building owners are incentivized to incorporate building greenery and less held back by the cost than buildings of other kinds. It has been the cases that greenery in forms of rooftop gardens and indoor vegetation add property values for apartment buildings and attract more potential customers for shopping malls, which make the incentive for profits exceed the concern for high cost and maintenance. For public buildings and other private buildings that are more reliant on recurring avenue, policy incentives or mandates such as Skyrise Greenery or LUSH would be the bigger driving factors.

D. In general, building green infrastructure should be made more accessible for all types of buildings in terms of way-finding, accessibility safety and most importantly, advertising to make their existence know to users.

### 3.2 Planning and Policy Recommendations for Future BGI Development

The general term ‘Building Green Infrastructure’ has been used in this paper to describe all types of landscape elements attached to buildings that have emerged, or are emerging in Singapore’s cityscape, including rooftop gardens, interior green facades, exterior green facades, pocket gardens that are semi-shaded by the building mass, and indoor gardens that are completely enclosed within the building. The Singapore government has put forth a vision of seamless greenery spanning the ‘dynamic, distinctive and delightful world class city’ and creating more ‘gardens in the sky’ and making them more accessible is inevitably going to be a key strategy to achieve this vision for reasons mentioned in previous chapters. (Urban Redevelopment Authority, 2001; Yuen & Nyuk Hien, 2005). However, there are many ways a city could look ‘green’ while not achieving the assumed benefits; the blueprint of future Singapore might be covered entirely with green canopies, but the process of getting there, or to do it smartly, requires careful planning.
As previously established, building green infrastructure should not be viewed as a higher level equivalent of ground level parks. Environmentally, its microclimate adjustment effects are still unconfirmed due to limitation of the scale (one rooftop or one wall is too small); socially, green infrastructure that’s attached to a building almost exclusively serves the building users, while ground level parks are open and accessible to all. This doesn’t mean that building green infrastructure is inferior to its ground-level counterparts; rather, they should just be treated and designed differently to fulfill their own unique purposes. The reasonable goal of building green infrastructure is not to substitute parks. They operate in nuanced ways and serves specific functions for specific groups of users. As exemplified in the studies above, this requires multiple design considerations. Informed by conclusions derived from the last section, I will use Geographic Information System, specifically ArcGIS Online and ArcMap, as tools to visually combine several sets of parameters and generate respective planning recommendations tailored to Singapore’s city context.

With the considerations generated from previous sections as well as some open map resource from ArcGIS Online, I created a story map visualizing some preliminary examples of possible sets of planning scenarios. Original data was acquired from open map sources on ArcGIS online, by authors: GY_admin7 and AtlasPublisher. Link to Storymap on Specific Visualization of each Planning Recommendation:

https://arcg.is/0r9fSC
3.21 Balancing Flood Mitigation and Urban Food Production with Public Housing

At city level, food production and flood mitigation are two goals that have been proven to be achievable through implementation of rooftop gardens. As mentioned before, storm water retention is now required in all new developments and retrofitting sites to lessen the load at peak flow in a storm water event. Rain gardens are an ideal form to connect both water retention purposes as well as residents’ accessibility to green space. While acknowledging that rooftop garden not being a sufficient alternative to ground level parks, in the context of increasing densification, a lower, car-park level, well programed rain garden is the next best solution. The figure below shows some potential building sites for rooftop rain garden retrofit in the neighborhood Little India. The sites are selected at the intersection of flood prone zones (PUB, 2019) and HDB buildings that have low access (further than 0.2 miles) to ground level green spaces (Coombes, Jones, & Hillsdon, 2010).
Besides storm water control during heavy rainfalls, increasing food production is also one of the city’s priorities in future development. Currently, Singapore relies heavily on importation to feed most of its population due to limited agricultural land: 90% of its food supply is imported, and less than 1% of its land is dedicated to farming. The Agri-Food and Veterinary Authority in Singapore has been diversifying sources of food and optimizing of local production to enhance its food security. One of the most invested strategies is space saving farming technologies such as hydroponics, which has contributed to a 30% increase in local vegetable production over the past decade (Tortajada & Kumar, 2015). Companies like the previously mentioned Citiponics and Skyrise Greenery have been continuously experimenting and succeeded in vertical farming and hydroponic farming.
The success of Citiponic’s farm at the HDB car park in Bishan Ang Mo Kio sets a great precedent for future urban vertical farming practices as well as public-private-partnership business model. Considering the rooftops at residential buildings are rarely used due to reasons such as the hot weather, accessibility, program and special limit, and given the well planned precinct ground level green space, HDB buildings became the ideal sites for future vertical farming development. Especially since the low cost and lightweight of hydroponic farming, there would be no extra cost on retrofitting the roofs, which is presumably one of the biggest barriers for rooftop greening in public housing complex.

Shown in the story map(link above) is a city-wide map of potential HDB buildings that could be retrofitted into urban vertical farms. Below is a zoomed-in view of some potential sites in the neighborhood Bishan Ang Mo Kio. For this scenario, I also considered residents’ immediate access to food sources. Conventionally, any area further than 0.5 mile away from food sources is considered a ‘food desert’. However, in highly urbanized Singapore with a rich and extensive food culture, there are numerous convenient stores, grocery shops, restaurants, even hawker centers and street-side vendors providing sufficient food regardless of the proximity to supermarkets. However, this is to exemplify how other factors could be taken in consideration when strategizing the locations of vertical farms. It might be so that residents have easy access to food regardless of where the farms are, but the least that this map tells is that those are the buildings that are furthest among all public housings from a formal supermarket with stable supply of fresh produce.
At building level, factors such as user experience, well being, air quality and thermal comfort exceed climate adjustment as factors that determine the success of building greenery. The incorporation of indoor green infrastructure such as indoor gardens, pocket gardens and atrium courtyards have been received high usage and positive perception among users due to the thermal comfort provided by both the indoor environment as well as the natural greenery. In this scenario, school buildings and hospital buildings are prioritized as development sites for several reasons: the function of the building and user pattern ensures high usage of indoor spaces and potentially rooftop gardens (if multifunctional like track field on the rooftop of SOTA); the main building users, namely students and patients, could especially benefit from greenery due to their high stress regular environment, but are usually confined within the peripherals of the building.
space because the nature of their activities. This makes a stronger case for implementing indoor greenery, which is currently not reimbursed through the Skyrise Greenery Incentive Scheme.

3.22 Combining Indoor Greenery with High-usage Buildings

Although indoor greenery is not likely to provide and city-wide environmental benefits, even less so than exterior greenery, the city should consider extending the Skyrise Scheme to incentivize public buildings with high usage such as school buildings, community centers and hospitals where users could largely benefit from close contact with natural elements for the purpose of citizen well-being. The map below explores some potential hospital and school buildings for indoor green infrastructure, excluding the ones already implemented. Buildings within 0.2 miles to a flood prone zone are marked to prioritize rooftop rain garden implementation for storm water concerns.

Fig. 3 Potential Hospital and School Sites for Green Roofs or Indoor Greenery
Data Source & Software: Public Utility Board; ArcGIS Online
The examples above only illustrate a few possible sets of rudimentary considerations to plan for the smart growth of building green infrastructures. In realistic planning processes, if they were to take place, should involve a systematic evaluation and a much more comprehensive analysis, including various stakeholder Point of Views, financial and technological concerns. For example, other building types such as commercial buildings (shopping malls and hotels) should receive a different set of parameters to determine future site location and ways to incentivize. Currently, they incorporate rooftop gardens and facade greenery mainly as a marketing strategy, to attract and retain customers. It is effective because of the building’s existing usage, retailing, which implies overwhelming sensational information. The addition of landscaping elements are necessary to create a better experience. Ex. the Jewel. In those cases, additional funding support from the public sector might even be unnecessary and the amount should be allocated to public building greening instead.

Planning for single buildings would be an inevitably arduous process. However, the Singapore context has led me to believe such a possibility: the efficient and highly authoritative government, mature and highly skilled green building industry, a successful urban greening history and a population that highly trusts its administration… All the factors made up for an ideal test ground for some seemingly impossible urban innovations before, why not another?
Conclusion

When I was researching on Singapore’s urban spaces, I read about a unique feature in HDB housings, the void deck. It is a semi-open space created by the elevation of the building block to create some ground-level ventilation and to alleviate the otherwise oppressive density of the building masses. The void decks have played an important cultural role in structuring the spatial practices of the everyday life of residents despite its purely architectural intention (He, 2016). As the residents’ living space reduces from villages (kampongs) to closed-off apartments, shared open space that is usually used for big family get-togethers and cultural events that are common in Asian traditions also disappeared. The spacious and unused void decks on ground levels became the perfect substitution. Traditional events quickly adapted to the new environment. Located on the ground floor, anyone can easily locate and access the space, and shading from the building mass provided necessary thermal comfort.

The Malay would host large weddings where guests are invited to a feast on the void deck and later to visit the bridal and grooms’ home. The Chinese often uses the void deck for funerals which lasts three to seven days. During the time of the proceedings, friends and families come to offer their condolences, elaborate Taoist or Buddhist rituals are performed, and papier maché offerings are burned in the belief that they will be used by the dead in the afterlife. In those event settings, the deck would be filled with make-shift furniture, temporary tents, toilet units, sometimes even sound and lighting systems, which was also easy to set up due to the ground level location (He, 2016).
The original blank public ‘non-space’ transforms into a stage where only exclusive groups partake in the events, but anyone passing are invited, or enforced, to become an audience. Surprisingly, in modern high rise apartment buildings where hundreds dwell without knowing each other, the village/kampong community mentality somehow remained: neighbors demonstrated extraordinary tolerance despite the deprivation of a supposedly public space. In fact, the Town Council regulations eventually officialized the taking place of such activities, requiring a low charge and permit (He, 2016). When I first read about the void decks, I thought they were the perfect metaphor for Singapore’s unique and exciting cultural historical heritage; now I think their popularity, multi-functionality and cultural integration could be an inspiration for the future of Singapore’s urban development as well.

It is inspiring, and somewhat comforting, to discover the persistence of tradition and culture identity had seized a physical corner of the pervasive modernization in Singapore, especially when the future trend of urban spaces in Singapore is looking ever more technologically advanced. Pervasive building greenery is just one of the many steps to follow. Singapore is ranked as the top smartest city in the world according to the Global Smart City Performance Index 2017 by Juniper Research, and the city has all intention to keep its place (“Singapore best performing ‘smart city’ globally,” 2018).

In Urban Redevelopment Agency’s latest Master Plan issued in 2019, Punggol, a district at the northeast tip of the island is designated as Punggol Digital District (PDD) as the city’s first step in experimenting a “next generation, smart and integrated district”. It is designed to house the key growth industries of the digital economy like cybersecurity and digital technology, as well as
an inclusive and green lifestyle destination with uninterrupted greenery connection to the two parks in the region. To achieve the vision, PDD will integrate a suite of district wide technology such as an open digital platform that oversees the management and collects data of the various buildings within a single estate system; a centralized logistics hub where all goods can be dropped off and picked up to improve productivity and reduce traffic; a district cooling system that centralizes cooling needs; a pneumatic waste collection system with a district-wide underground vacuum-pipe network; a smart energy grid that will seamlessly allow clean energy to be part of daily use.

Today, there is a lack of universally accepted, systematic guidelines for measuring human perception of the landscape elements. This reflects the overlook of user experience in the building industry, where the process from design to operation is highly segmented. The architects usually rely on their professional knowledge to provide a good building experience within the budget, and the building owners and managers are only responsible for the practical operations and maintenance of the building after construction. The feedback from users is deemed less relevant not only because there is no one party that oversees the process or programmed to care, but also because construction is not a reiterative process where there is little opportunity for improvements once a building is constructed. However, technologies such as the open digital platform in PDD presents possibilities for instant user feedback and features in buildings could be adjusted accordingly.

Singapore’s urban development is at a key point where the past meets the future. There is one rule of thumb that will always dictate the success of urban spaces even in the most technological
advanced developments. As Rogers and Urban Task Force pointed out, ‘Public spaces work best when they establish a direct relationship between the space and the people who live and work around it’ (Rogers and Urban Task Force, 2005). The demand for green open space is a universal need, but it also ought to take a customized form when implemented in different cities. In Singapore, success of public space requires respecting its rich and integrated culture, its diverse demographic, its climate and other characteristics that’s unique to the city. Sometimes people interact with urban spaces in unpredictable ways despite the designers’ best intentions, such as the case in void decks. City planners should be inspired by the Town Council’s reaction: the designing and programing of public place should be a reiterative process where space adapt to users’ feedback, not the other way around. As the city continue to become greener and smarter, there are also emerging opportunities to include more of the city users’ voice in the process of design and building.
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