Centre for Urban Greenery & Ecology

CUGE Standards

DESIGN GUIDES TO PROMOTE **BIODIVERSITY ON ROOF GARDENS**

CS E12:2017

Guidelines on Skyrise Greenery

Olive-backed sunbird (male)

CUGE CENTRE FOR URBAN GREENERY AND ECOLOGY

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DESIGN GUIDES TO PROMOTE **BIODIVERSITY ON ROOF GARDENS**

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The CUGE Standards Series comprises:

CS A Specifications on properties of planting media
CS B Landscape construction and management
CS C Urban ecology
CS D Landscape Design
CS E Skyrise greenery

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Design Guides to promote Biodiversity on Roof Gardens

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The CUGE Standards will be reviewed every three years. Concurrently, CUGE also gathers new information continually through on-going research.

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Design Guides to promote Biodiversity on Roof Gardens

SECTION 1 SCOPE

1.1 INTRODUCTION

1.1.1 This design guide book, a publication under the CUGE Standards Series, sets out to illustrate basic evidence-based design-principles and associated design recommendations for the planning, design, construction and operation of rooftop and vertical greenery, with focus on these elevated vegetated surfaces for biodiversity enhancement.

1.1.2 In regard to ecological design-principles for promoting roof garden biodiversity (herein focusing on, but not limited to, bird and butterfly species), this publication shall be taken as reference by way of the examples and illustrative suggestions provided.

1.1.3 This publication shall not, in any way, replace, substitute or supersede, whether in whole or in part, any existing and/or prevailing relevant statutory rules and regulations, and applicable codes of practice [although this reference should be verified for relevance and particular importance deserving of being highlighted] and standards and other technical references.

1.2 OBJECTIVE

1.2.1 Roof gardens are multi-functional spaces enjoyed for a variety of reasons. Besides being communal spaces for human enjoyment, and offering visual relief amidst the built environment, roof gardens have ecological potential as sites attractive to biodiversity. The design principles in this guide are intended to facilitate the decision-making process in the planning, design, construction and operation of roof gardens, specifically with the end intent for these elevated vegetated spaces to act as functional habitats for biodiversity.

1.2.2 The design of skyrise greenery and the planting of rooftop plants, trees and palms shall comply with the relevant codes of practice and standards of the relevant authorities (such as CP82:1999).

1.2.3 Engage and consult suitably qualified and experienced professionals to ensure the skyrise greenery design and implementation are well-considered, executed and safe for human users and maintenance. Design for Safety, being paramount, must be addressed upfront during the early planning and design phase of any project, and sustained throughout the lifespan of the project.

1.3 DEFINITIONS

1.3.1 Green roofs

Extensive green roofs are generally not designed for active recreational use. They are developed mainly for aesthetic and ecological benefits. Generally, they are low in installation cost, lightweight (90-150 kg/m^2), with shallow mineral substrates and minimal maintenance required. Inspection should be performed, at the minimum, once or twice a year. Plants selected are usually of low maintenance and are self-generative. Extensive systems are common in European countries, especially Germany and increasingly being installed in North America cities as well. Generally, they can also be placed on pitched roofs of up to an inclination of 30 degrees.

1.3.1.1 Ecological potential of green roofs

The lightweight green roof, in the Singapore context, is often applied on publicly-inaccessible roofs of existing buildings, as a horizontal aesthetic surface. The ecological appeal of the lightweight green roof lies in this isolation from the general public and building-users.

This lack of human physical contact (except during quarterly maintenance, subject to design) translates into low human disturbance **-** an attractive environment-trait to biodiversity.

Research on green roofs in other urban contexts have documented and shown that a variety of fauna species use the roofs' vegetation as food and nesting resources. (*Maclvor & Lundholm 2011, Dunnett 2015)*

1.3.2 Roof gardens

Intensive green roofs, or roof gardens, are designed to be accessible. These are often used for recreation and other social activities. Hence these are associated with added weight, higher capital cost, more intensive planting and higher maintenance requirements. The plant selection ranges from ornamental lawn, shrubs, and bushes to trees and palms. Regular maintenance such as mowing, fertilising, watering and weeding is required.

1.3.2.1 Ecological potential of roof gardens

Roof gardens are common features on new buildings in Singapore. These spaces are often designed with deep planters (with soil depth ranging from 1.0m to 1.5m or more) to support small rooftop trees and palms (ideally no more than 8m in grown/maintained height). These plants not only provide the much needed shade in the tropical climate but also lush canopies with resources (nectar, fruits, seeds, shelter, nesting materials, etc.) attractive to biodiversity.

1.3.3 Vertical greenery (Green wall)

Vegetated walls are built mainly for aesthetic and ecological benefits. The level of maintenance often depends on the design and safe accessibility of these vegetated vertical surfaces. These surfaces are generally more exposed to the drying effects of wind, especially with stronger winds at increased altitude. Growing plants in such harsh environment does require more care and frequent inspection of the plants and systems. The plant selection ranges from ornamental ground-covers, shrubs, to climbing vines and cascading plants. These are usually designed for visual appreciation. Regular maintenance such as fertilising, irrigation and judicious pruning (if the vegetated surfaces are safely accessible) are required on a regular basis. There are various methods of planting on vertical surfaces, with cost getting competitive and more affordable in recent years.

1.3.3.1 Ecological potential of green walls

Unlike most safely accessible roof garden spaces, predominantly designed to foster and activate human activities, vertical greenery by virtue of its verticality is comparatively isolated from human reach and often relegated as mere visual aesthetic surfaces. Depending on the design of the vertical greenery, the associated low human disturbance is an attractive environment-trait to biodiversity.

Research on walls with vegetation in other urban contexts has documented and shown that a variety of bird species use the green walls for foraging, shelter and breeding. (*Birds and the urban environment: the value of green walls; Caroline Chiquet, John W. Dover, Paul Mitchell, 2012*)

1.3.4 Rooftop greenery

Is the collective term for green roof (for both flat and pitched types) and roof garden (including ledge greening).

1.3.5 Skyrise greenery

Is the collective term for greenery at-height, including rooftop greenery and vertical greenery.

1.3.6 Flora

Is the collective term herein referring to both managed (intentionally planted) and non-managed (spontaneous) vegetation.

1.3.7 Fauna

Is the collective term herein focusing on, but not limited to, birds and butterflies. In urban ecology, birds and butterflies are charismatic taxonomy groups often used as 'flagship-taxa' in biodiversity inventories and as indicators of changes in the diversity of other taxonomic groups.

1.3.8 Ecological design

Ecological design has been defined as "any form of design that minimises environmentally destructive impacts by integrating itself with living processes," and as "effective adaption to and integration with nature's processes" (*Van der Ryn and Cowan, 1996*). This is a broad term. Application of which is with the aim to connect piecemeal efforts in green architecture, sustainable agriculture, ecological engineering, ecological restoration and other fields.

1.4 NATURE CONSERVATION MASTER PLAN (NCMP) & SINGAPORE INDEX ON CITIES' BIODIVERSITY

1.4.1 This design guide should complement and form part of an overall national/regional/local ecological network strategy, not limited to, the design of buildings, infrastructures, facilities, public spaces, etc. - With biodiversity conservation and enhancement within the city in mind. In the Singapore context, the (1) Nature Conservation Master Plan and the (2) Singapore Index on Cities' Biodiversity are in place to be suitably referenced.

1.4.2 The **Nature Conservation Master Plan** comprises of four thrusts as follow:

THRUST 01 Conservation of Key Habitats	**THRUST 02** Habitat Enhancement, Restoration, and Species Recovery	**THRUST 03** Applied Research in Conservation Biology and Planning	**THRUST 04** Community Stewardship and Outreach in Nature
• Safeguard and strengthen core areas • Secure and enhance buffer areas • Enhance and manage additional nodes of greenery throughout the nation • Develop ecological connections • Integrate nature with the broader urban landscape	• Habitat enhancement and restoration in core areas, buffers, other greenery nodes and ecological connections • Species recovery	• Comprehensive surveys and long term monitoring of ecosystems and species • Ecological research • Application of up-to-date tools, including GIS, numerical modelling, DNA technology, databases • Science-based policy formulation and management planning • Applied research on the management of human-wildlife interactions	• Incorporate of biodiversity into all levels of the education system • Citizen Science • Building of the Biodiversity Atlas • Greening of Schools for Biodiversity

For more information, please access the following website:
https://www.nparks.gov.sg/news/2015/6/nature-conservation-masterplan-consolidates-singapores-biodiversity-conservation-efforts

Within the ecological network, ecological roof gardens value-add as viable ecological stepping stones which can potentially:

(1) Enhance nodes of greenery on urban structures throughout the nation;
(2) Partake in the collective making of ecological connections;
(3) Facilitate in integrating naturalistic landscape into the broader urban landscape;
(4) Contribute towards urban ecology applied research and;
(5) Foster citizen science.

These are synergistic with the four thrusts outlined in the NCMP.

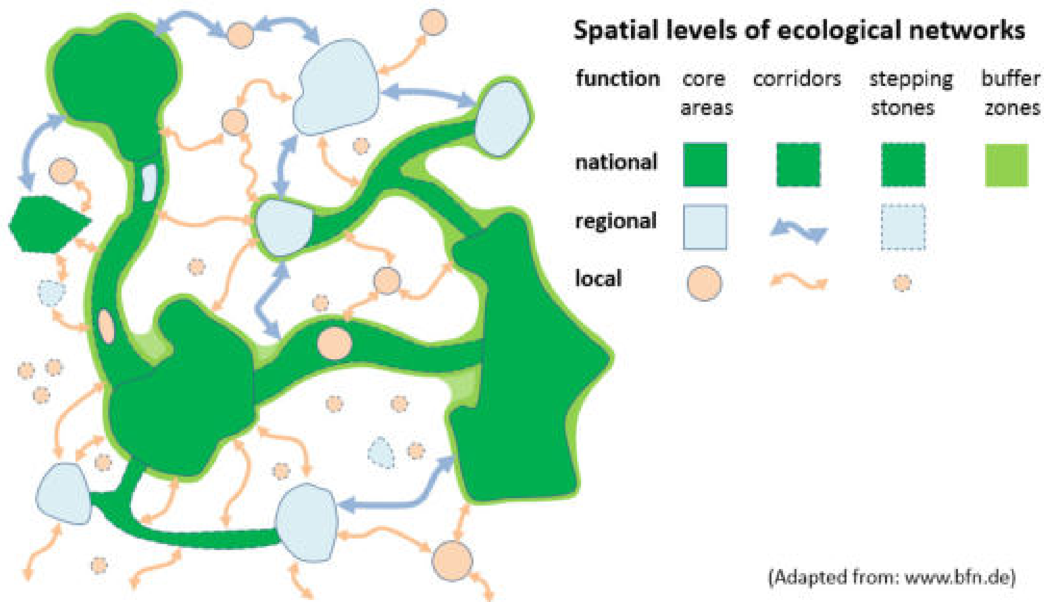
1.4.3 The **Singapore Index on Cities' Biodiversity** serves as a self-assessment tool for cities to benchmark and monitor the progress of their biodiversity conservation efforts against their own individual baselines. The following outlines the indictors for the city's self-assessment.

Indicators of the Singapore Index on Cities' Biodiversity	
Native Biodiversity in the City	
01	Proportion of Natural Areas in the City
02	Connectivity Measures
03	Native Biodiversity in Built-up Areas (Bird Species)
04	Change in Number of Vascular Plant Species
05	Change in Number of Bird Species
06	Change in Number of Butterfly Species
07	Change in Number of Species (any other taxonomic group selected by the city)
08	Change in Number of Species (any other taxonomic group selected by the city)
09	Proportion of Protected Natural Areas
10	Proportion of Invasive Alien Species
Ecosystem Services	
01	Regulation of Quantity of Water
02	Climate Regulation: Carbon Storage and Cooling Effect of Vegetation
03	Recreation and Education: Area of Parks with Natural Areas
04	Recreation and Education: Number of Formal Education Visits per Child Below 16 Years to Parks with Natural Areas per Year
Governance and Management of Biodiversity	
01	Budget Allocated to Biodiversity
02	Number of Biodiversity Projects Implemented by the City Annually
03	Existence of Local Biodiversity Strategy and Action Plan
04	Institutional Capacity: Number of Biodiversity-related Functions
05	Institutional Capacity: Number of City or Local Government Agencies Involved in Inter-agency Cooperation Pertaining to Biodiversity Matters
06	Participation and Partnership: Existence of Formal or Informal Public Consultation Process
07	Participation and Partnership: Number of Agencies/ Private Companies/ NGOs/ Academic Institutions/ International Organisations with which the City is Partnering in Biodiversity Activities, Projects and Programmes
08	Education and Awareness: Is Biodiversity or Nature Awareness Included in the School Curriculum
09	Education and Awareness: Number of Outreach or Public Awareness Events Held in the City per Year

For more information, please access the following website: https://www.nparks.gov.sg/biodiversity/urban-biodiversity/the-singapore-index-on-cities-biodiversity

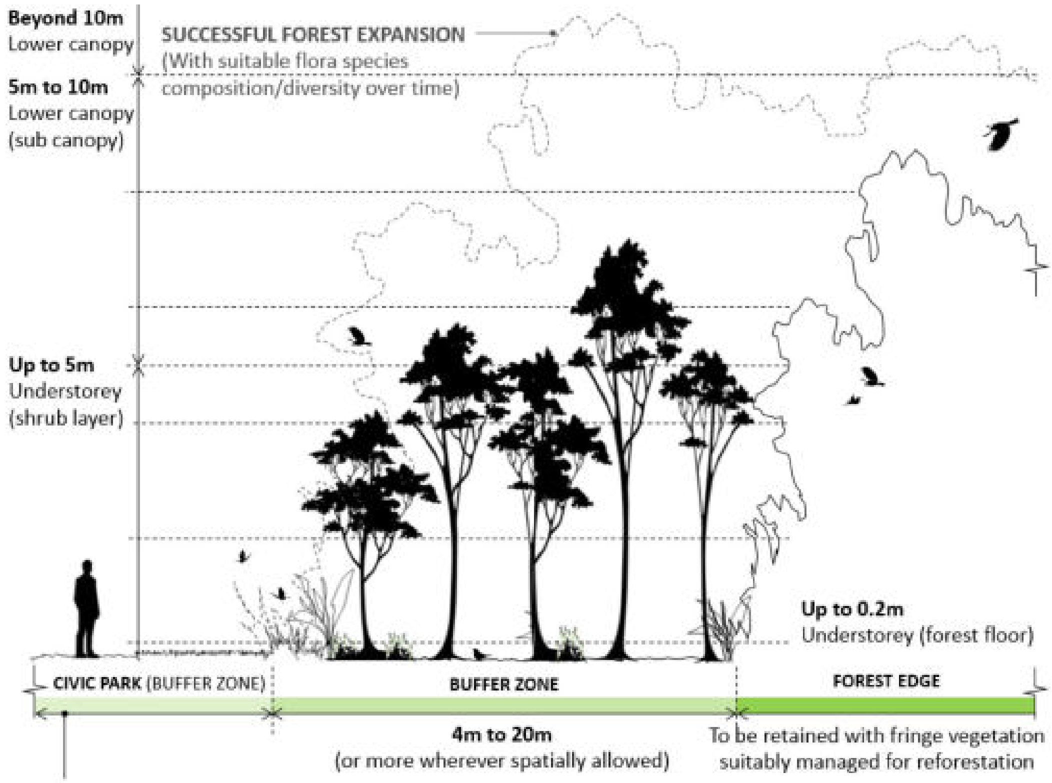
1.5 THE CONCEPT OF ESTABLISHING AN ECOLOGICAL NETWORK

Ecological networks consist of (1) Core areas, (2) Ecological buffer zones, (3) Ecological corridors and (4) Ecological stepping stones.
(*Source: http://www.sicirec.org/definitions/corridors*)



Spatial levels of Ecological Networks		
Levels	**Description**	**Function/Intention**
Core areas	• Original/Remaining habitats and natural areas. • Core areas are largest in area and (ideally) circular.	• Core areas are self-sufficient in containing all resources required for species populations to persist indefinitely in the absence of external disturbances. • Nature reserves • Habitat of original and/or remaining flora and fauna species. • Should be free of human exploitation, but monitored and managed sustainably.
Buffer zones	• Surround the core areas and corridors, to protect from possible disruptive external influences. • Buffer zones can help to make the shape of the protected area more circular.	• Buffer areas are areas adjoining core areas which provide supplementary foraging habitat for wildlife, but do not necessarily contain the structural resources favored for reproduction. • A certain measure of human exploitation is possible in the buffer zone. (Such as the use of the outer fringe of the buffer zone as part of a civic park space, urban farms, etc.). • The exploitation must not be detrimental to the conservation of core areas and corridors.

Corridors	• Create a permanent connection between the core areas. • Corridors are linear in shape and usually smaller in area than core areas.	• Corridors and stepping stones are areas which facilitate wildlife movement between core areas, enhancing landscape-scale genetic diversity and buffering the overall regional population from collapsing when main core areas are disturbed or removed. • To maintain/recover a certain degree of cohesion in otherwise fragmented ecosystems. • Through connecting fragmented habitats, the viability of fauna and flora species is improved by: ➢ Enlarging habitats, for example to improve the search for food; ➢ Dispersal of young animals; ➢ Movements of pollinators and dispersers; ➢ Re-use of "empty/emptied" habitats. • The presence and borders of suitable habitats are constantly in flux due to anthropogenic influences and pressure (i.e. urban expansion, climate change, etc.). Several factors affect remnant habitats and fauna species mobility. Corridors allow faunas to respond to local changes in their habitat by providing them an opportunity to move to another area of suitable habitat should the need arise. • Minimal and controlled human exploitation. Any such efforts (i.e. nature bike trails, forest trails, park connectors, etc.) must be sensitively planned and designed accordingly.
Stepping stones	• Small tracts of habitat between core areas. • Similar in area or smaller than corridors and (ideally) circular.	• Stepping stones are technically an alternative to corridors. Instead of acquiring large areas of land to create a corridor, conservationists instead target an area between core areas and enhance the habitat (e.g. reforestation) to make it amenable to various fauna. • This technique was originally meant to benefit mobile groups like insects and birds the most, but studies in South America have shown that even large mammals use them to move between fragmented core areas. In Singapore, the network of streams and canals have served as ecological stepping stones for smooth-coated otters (*Lutrogale perspicillata*). (www.nparks.gov.sg)



Forest edge civic park, with contiguous soil volume, has the spatial flexibility to serve community needs as well as biodiversity conservation needs/projections (ex: forest area expansion, native species reintroduction, educational outreach, etc.)

<u>Interface between the ecological core-area/corridor and the buffer zone</u>

The above is a sectional illustration of the interface between a buffer zone (in this case exploited as a civic park space) and an ecological core-area/corridor. Reforestation is highly encouraged along this interface, as a planning strategy, to mitigate external influences to the otherwise sensitive forest fringe/edge. Over time, reforestation and its vegetation maturation will facilitate the expansion of habitats and associated resources for biodiversity. Such efforts will contribute towards future-proofing dwindling nature spaces, and expand core areas. In city, it is possible to condense the section laterally to suit available space.

1.5.1 Strengthening the interconnectedness of habitats

1.5.1.1 The concept of countering the fragmentation of habitats and nature reserves rest on the establishment of ecological interconnecting corridors. This concept – on strengthening the interconnectedness of habitats - has been in existence for over 30 years and research is still underway worldwide in developing the best method/protocol of including ecological corridors in the landscape on various scales (i.e. local, regional, national, cross-national, etc.).

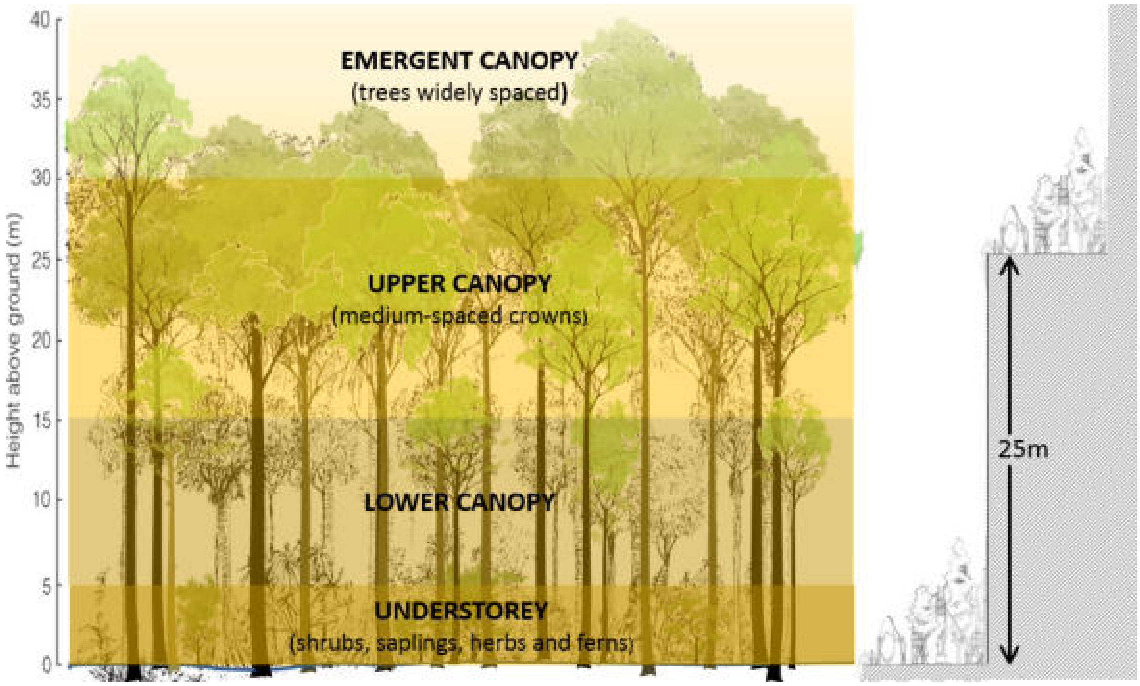
1.5.2 The role of Skyrise Greenery in the Ecological Network

1.5.2.1 Fragmentation of habitats is a major threat to many forest flora and fauna species. Habitat-specialist species, dependent on specific food resource, are vulnerable to habitat fragmentation. Terrestrial species, dependent on vast habitats, are also vulnerable to habitat fragmentation. Small-scale habitats (existing and/or constructed) are unlikely to provide for and support a viable population for such sensitive species.

1.5.2.2 Skyrise Greenery, by virtue of their vegetation isolation (both horizontally and vertically) on a development site (often spatially fragmented from neighboring greenery patches by roads), is at best serving as highly localised, small-scale, ecological stepping stones (in the lowest order of the ecological spatial levels). Birds and butterflies, being compact and capable of flight, are the most commonly observable fauna in such small-scale isolated habitats.

1.5.2.3 Nonetheless, development sites in proximity to ecological buffer zones are prime locations to exercise ecological design-principles, both to the upfront design and the downstream judicious maintenance of the development's skyrise greenery, if any, with the potential to enlarge existing habitats and resources, to the benefit of the overall ecological network.

1.5.3 Ecological Limitations of Skyrise Greenery



1.5.3.1 The scale and vegetation complexity of skyrise greenery can never be comparable with a true forest. The tallest rooftop tree is usually (and advisably) no more than 8m grown/maintained height for crown accessibility/maintainability reasons. Dimensionally, this is a far cry from the lower canopy of a tropical forest which is between at least 15m to 20m height.

1.5.3.2 A forest possesses both structural complexity and species diversity. Structural complexity is the physical variety of vegetation/canopy heights and layers. Species diversity is the biological diversity of plant species ranging from understory shrubs to sub-canopy, canopy, emergent canopy, lianas, lichens and epiphytes, etc. Given the spatial limitations, roof gardens are comparatively highly simplified systems with lower structural complexity and species diversity.

1.5.3.3 In principle, the taller the canopy continuity (the tallest being the emergent trees, 'giants' of a tropical rainforest), the more spatial opportunities (beneath the tallest canopy zone) there are for niches/layers of canopy microclimates to develop over time. While this is prevalent within a natural rainforest, recreating this three-dimensional spatial condition on a roof garden is not possible.

1.5.3.4 Often, roof gardens have limited surface area, limiting the overall rooftop tree/palm heights. Roof structures are also limited in load-bearing capacity. Large tall rooftop trees, even when located on adequately sized roof garden area, will need huge volumes of rooting media (soil and/or alternatives) to sustain growth. The resulting system weight will be enormous, and technically very challenging and costly to construct.

1.5.3.5 It is hence recommended that policymakers **do not allow** rooftop greenery to be considered equivalent to ground-level habitat. Nonetheless, rooftop greenery, as elevated ecological stepping stones, has its distinctive roles in the larger scheme of the ecological networks.

1.6 PERFORMANCE REQUIREMENT

1.6.1 Skyrise Greenery is contrived for human usage and benefits. The planning, design, construction, operation and maintenance of skyrise greenery (while fulfilling other relevant and/or intended functions) shall in no circumstance compromise on safety of users, workers and all personnel in the vicinity.

1.6.2 Design, construction and the maintenance of the skyrise greenery must comply with the Workplace Safety and Health Act and all other relevant regulations.

1.7 DESIGNERS' EFFORTS TOWARD ECOLOGICAL DESIGN

1.7.1 Select suitable flora species for the right locations. Consider the amount of daylight the application location/surface will receive daily.

1.7.2 Design, construct and connect the otherwise isolated greenery patches to form a continuous network of greenery, waterways and associated resources, as a mean to enlarge potential habitats and connectivity.

1.7.3 A well-executed ecological design that is also experientially engaging to human visitors will serve to reinforce the overall concept. This will help to promote the (1) exploration, (2) improvement and (3) performance verification of its systems and designs.

1.7.4 Ecological design is a powerful educational outreach tool to foster deeper public appreciation, understanding and strengthen public support for biodiversity and its conservation. Roof gardens' spatial proximity to human users has potentials for such educational outreach - especially true and complementary in the context of academic institution buildings and developments.

1.7.5 Observe and learn from existing natural systems (such as the water cycle, etc.) to help with the design and planning of regenerative landscapes and habitats.

1.7.6 Systems in nature and their associated forces and movements are often visible and tangible to the human naked eye and senses. Aesthetically, architects, landscape architects and associated designers should strive to learn and explore on the effective expression of these elements as a mean to deepen the human users' overall experience and connection with such concept and lifestyle.

SECTION 2 EVIDENCE-BASED DESIGN PRINCIPLES FOR ROOFTOP GREENERY

2.1 ROOF GARDEN ECOLOGICAL SURVEY (2014 TO 2015) SINGAPORE

2.1.1 A recent ecological survey on roof gardens, from mid 2014 to end 2015, jointly conducted in Singapore by the National Parks Board and the National University of Singapore, Department of Biological Science, sets out to:

- Gather empirical evidence to understand if the many roof gardens across Singapore, in their variety of forms, functions and site-parameters, do attract birds and butterflies;
- Identify the species and quantify the abundances of birds and butterflies species visiting these roof gardens;
- Identify roof garden site characteristics and parameters that attract birds and butterflies.

2.1.2 The results of the above mentioned survey have been published in a scientific journal.

- The scientific paper is entitled: "*Building biodiversity: drivers of bird and butterfly diversity on tropical urban roof gardens*".
- Available on the following web-link: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1905/full.

2.1.3 This publication expands on and contextualises the findings from the study for the landscape/building/urban design communities. These take the form of evidence-based Design Principles and associated Design Recommendations.

2.1.4 The **Design Principles** (and associated **Design Recommendations**) are developed based on the collective:

- Evidence-based salient points gathered from the afore-mentioned roof garden ecological survey;
- Salient points gathered from other relevant local and overseas studies and related literature;
- Current horticulture, arboriculture and landscape practices and existing ecological design principles;

2.1.5 We strongly recommend the application of said Design Principles to both **existing and new developments** for they will benefit both the human users and the larger environment.

2.1.6 This publication focuses mainly on the architecture-scale.

2.2 EIGHT DESIGN PRINCIPLES

2.2.1 **From the study**, the identified **Eight Design Principles** are as follow:

ROOFTOP GREENERY (AS ECOLOGICAL STEPPING STONES)							
DESIGN PRINCIPLES		**SECTION**	**RELATED TO**				**DESIGN SUGGESTION**
			UD	A	LA	M	
1	Height of roof garden	3.1		*	*		4.1
2	Planted area of roof garden	3.2		*	*		-
3	Exposure of roof garden	3.3		*	*		4.2 to 4.4
4	Complexity of Vegetation on roof garden	3.4			*		4.13 to 4.15
5	Judicious Maintenance of roof garden	3.5			*	*	4.16
6	Human presence on roof garden	3.6		*		*	4.5, 4.6
7	Noise Level on roof garden	3.7	*	*		*	4.7 to 4.9
8	Water Presence on roof garden	3.8			*		4.10 to 4.12

LEGEND:

Urban Design – (UD); Architecture – (A);
Landscape Architecture – (LA); Management – (M)

(shaded)	Evidence-based – Statistically strong
(unshaded)	Associative – Statistically not definitive, but with observable impacts

Note: rows 1–5 are shaded (Evidence-based); rows 6–8 are unshaded (Associative).

2.2.2 During the planning and design phase, the top five design principles should be considered holistically to maximise the potential of enhancing garden biodiversity. Each of the design principles, when applied in isolation, enhances the roof garden biodiversity potential only to a very limited extent.

2.2.3 Section 3 elaborates on each of the above identified Design Principles.

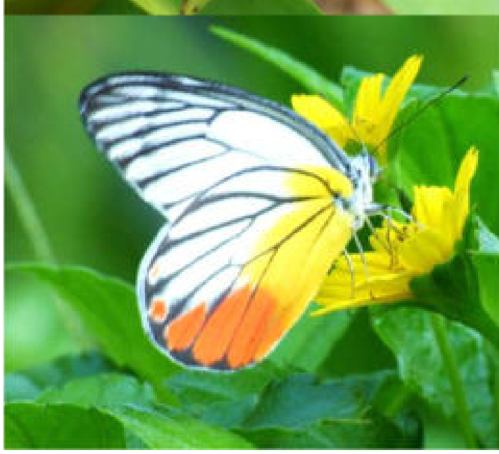
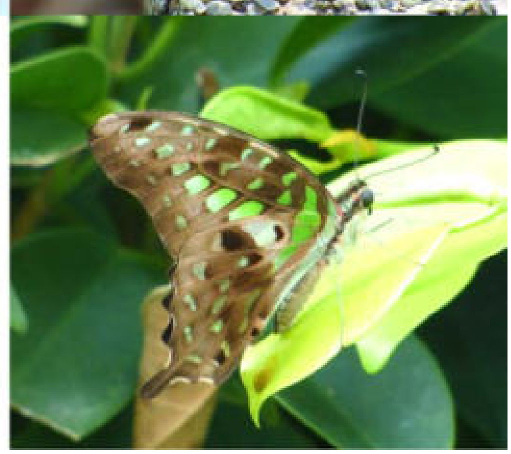
2.2.4 Section 4 elaborates on the associated Design Recommendations.









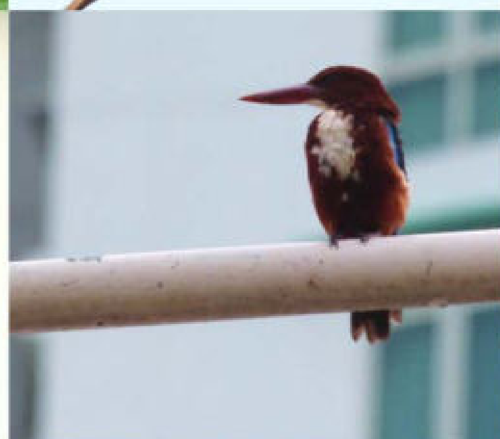
Some of the butterfly species spotted on roof gardens

A) Plain tiger
B) Cycad blue
C) Blue glassy tiger
D) Blue pansy
E) Common rose
F) Lemon emigrant
G) Lime butterfly
H) Tawny coster
I) Short banded sailor
J) Painted jezebel
K) Tailed jay

A	B	C
D	E	F
G	H	I
J		K





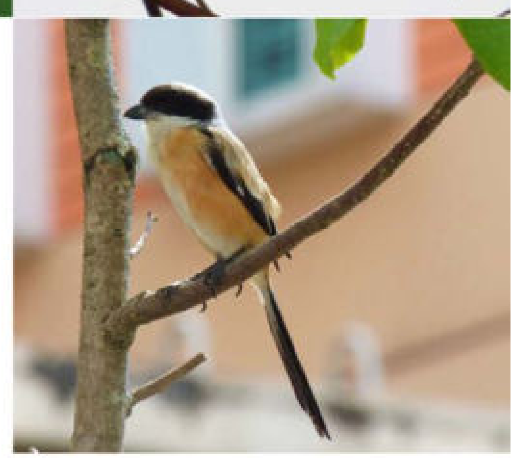





Some of the bird species spotted on roof gardens

A) Common flameback woodpecker
B) Scarlet-backed flowerpecker
C) Pink-necked green pigeon
D) Sunda pygmy woodpecker
E) White-throated kingfisher
F) Oriental magpie-robin
G) Blue-tailed bee eater
H) Olive-backed sunbird
I) Yellow-vented bulbul
J) Oriental white eye
K) Long-tailed shrike

A	B	C
D	E	F
G	H	I
J		K



SECTION 3 DESIGN PRINCIPLES

Biodiversity* attracting rooftop greenery design principles:
*The term "biodiversity" herein refers to bird and butterfly species in general. In the various sections of this publication, depending on the sections' specific contexts, this term may also suggest other relevant fauna and flora species.

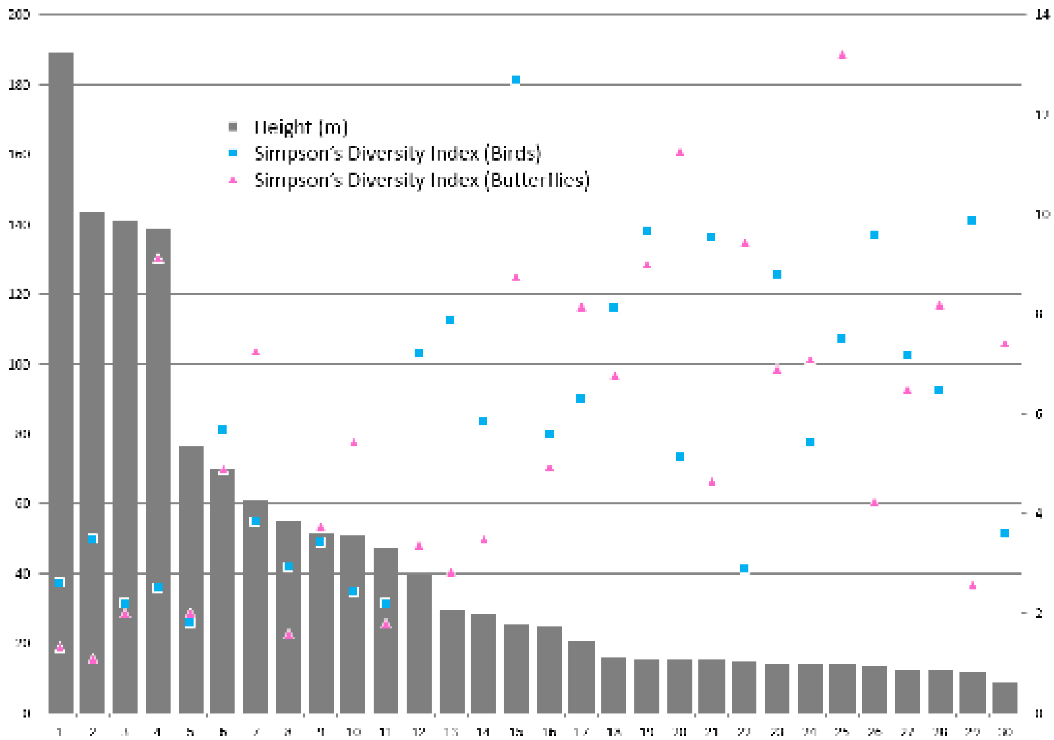
No.	Design Principles	Summary (Qualities/Descriptions)
1	**Height** of roof gardens	• In architecture design/massing, the suggested height of roof gardens (from its immediate ground finished level), with the intention to attract biodiversity, should ideally be <u>no more than 50m height</u>. ➢ Comparatively, roof gardens at lower height attract a broad suite of bird and butterfly species. ➢ Roof gardens at <u>no more than 20m height</u> are statistically <u>significant in attracting both bird and butterfly species</u>. ➢ Roof gardens <u>between 20m and 40m height</u> are statistically <u>significant in attracting bird species and to a lesser extent butterfly species</u>. • Beyond 50m roof garden height, the attractiveness of roof gardens to biodiversity appears to taper off. It is possible that this could be due to the higher energy demand for flight in the context of windier conditions at higher altitudes.
2	**Planted/herb area** of roof gardens	• Total planted area matters more than the total garden area (the total roof garden footprint). • In design, wherever the roof garden total area allows, have a <u>horizontal planted area with an ideal target of more than 1300m^2</u>. (*Please refer to Section 3.2 for the survey data.*) Nonetheless, small roof gardens do have a role to play as well and should be pursued to contribute to the total green area. • In design, wherever feasible, <u>create habitat/resource heterogeneity</u>, through a diverse selection of biodiversity-attracting plant species. • In design, <u>optimise the planting surface area/space</u> and their inter-connectivity to improve resource niches for biodiversity. Ideally, the rooting media should be contiguous to foster extensive root networks and microbial complexity.

3	**Exposure** of roof gardens	• Roof gardens open to the sky (exposed) are more attractive to biodiversity than sky terraces (sheltered roof gardens). • Roof gardens (exposed) attract statistically higher numbers of birds and butterflies. • Roof gardens (sheltered), in the form of sky terraces, attract statistically/distinctly lower numbers of birds and butterflies. • Hence in design, sky terraces should be optimised for human-focused functions, with open roof gardens potentially optimised as ecological stepping stones.
4	**Complexity** of vegetation on roof gardens	• It was statistically evident that as tree diversity and epiphyte species richness increase, bird diversity also increases. • Vegetation structure complexity greatly influences invertebrate species richness and abundance (*Smith et al., 2006*). • It is recommended to have <u>more species of epiphytes</u> in the roof garden, to enhance bird diversity. • In design, wherever feasible, plant a variety of tree species and allow epiphytes to grow (avoid removing the epiphytes) to enhance bird diversity. Epiphytes can also be selectively attached to host plants. • In design, it is recommended to plant <u>more species of bird nectar/fruit plants</u>, to attract significant diversity of bird species. Increasing application area will also increase opportunities for more flora species to be incorporated, based on species-area-relationship. • In design, it is recommended to plant <u>a variety of shrub species</u>, to enhance habitat quality for birds. • In design, it is recommended to plant <u>more species of butterfly nectar plants</u>, to attract significant diversity of butterfly. • In design, it is recommended to plant <u>some butterfly host plant species</u>, to enhance habitat quality for butterflies. • In landscape management, naturalised area on a roof-garden/green-roof, such as a “wildflowers” zone can be catered for.

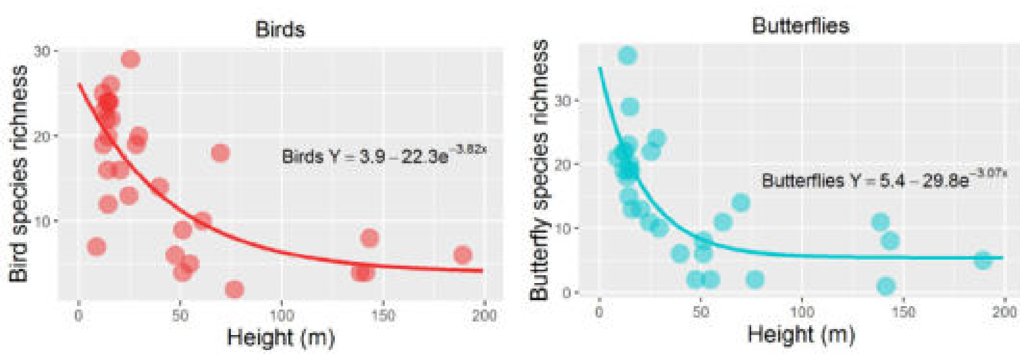
		• In design, wherever feasible, allow for contiguous rooting opportunities. Over time, this fosters a diverse extensive root zone community of micro-organisms and associated microbial activities beneficial to the roof garden biodiversity.
5	**Judicious** maintenance of roof gardens	• It was documented that both managed butterfly nectar plant species and non-managed (spontaneous) species (such as nectaring/flowering weeds – herein referred to as "wildflowers") are equally frequented (and hence equally important) to butterflies. • In landscape management, wherever feasible, allow for specific zone to naturalise. Maintenance in such zone, if at all, should be infrequent and light. • Reduce use of pesticides. Wherever feasible, avoid its use entirely. Pesticides are poisonous.
6	**Human presence** on roof gardens	• There is no apparent observed effect/impact of human presence on the observed biodiversity on a roof garden. • In design, consider planning/designing the biodiversity-focused zone (protected zone) away from the human-focused zone (non-protected zone), to control anthropogenic disturbance. • Such control, via spatial planning, facilitates downstream management of maintenance differences between the two functionally different zones.
7	**Noise Level** on roof gardens	• Morning anthropogenic noise level has a negative correlation with species richness. (There are several scientific studies highlighting the negative impact of anthropogenic noise, such as traffic noise, on birds and butterflies.) • In design, at the urban planning level, wherever possible, develop urban plan to be less car-and-road-dependent, with more emphasis on creating a car-lite, pedestrian-friendly environment. Hypothetically, this reduces traffic noise and creates opportunities for more synergistic urban greenery which can be biodiversity enhancing. • In design, at the architecture level, building massing/surfaces and its volumetric articulation can be further explored by designers to "deflect/diffuse/absorb" traffic noise. Professional acoustic engineers should be consulted early for design/development should such acoustic strategies be considered important.

		Hypothetically, such strategies can collectively manage urban noise. • In design, wherever possible in the planning of spaces, design the 'noisier' human zone away from the 'quieter' biodiversity zone. Separate via physical-compartmentalization of the human zone and/or through spatial-zonation to distant the 'quieter' biodiversity zone from the 'noisier' human zone - The latter is however much less effective in noise containment/mitigation.
8	**Water Presence** on roof gardens	• The presence of water resource on a roof garden has been postulated to be biodiversity attracting. • The design of water edge was observed to impact the ways birds and butterflies interact with the water. • In design, swimming pool edges (and any other water bodies designed solely for human users, wherein hygiene and water quality is of paramount concern) should be raised with steep drop to the water surface to discourage birds from drinking and bathing along these edges. • In design, naturalised ponds (and the likes, designed to be biodiversity attractive) should have gradual gradient/transition to the water edge. This provides spatial opportunities and encourages birds and butterflies to approach, pause and interact with the water. Ponds may attract dragonflies. Fishes can also be introduced but only in managed gardens.

3.1 HEIGHT OF ROOF GARDENS



The above chart contains data from 30 roof garden sites, surveyed monthly in Singapore over a period of 18 months.
(The X-axis indicates the 30 roof garden sites, with the lowest roof garden site on the far right and the tallest roof garden site on the far left. The left Y-axis indicates the height of the roof garden sites in meters. The right Y-axis indicates the Simpson's Diversity Index.)

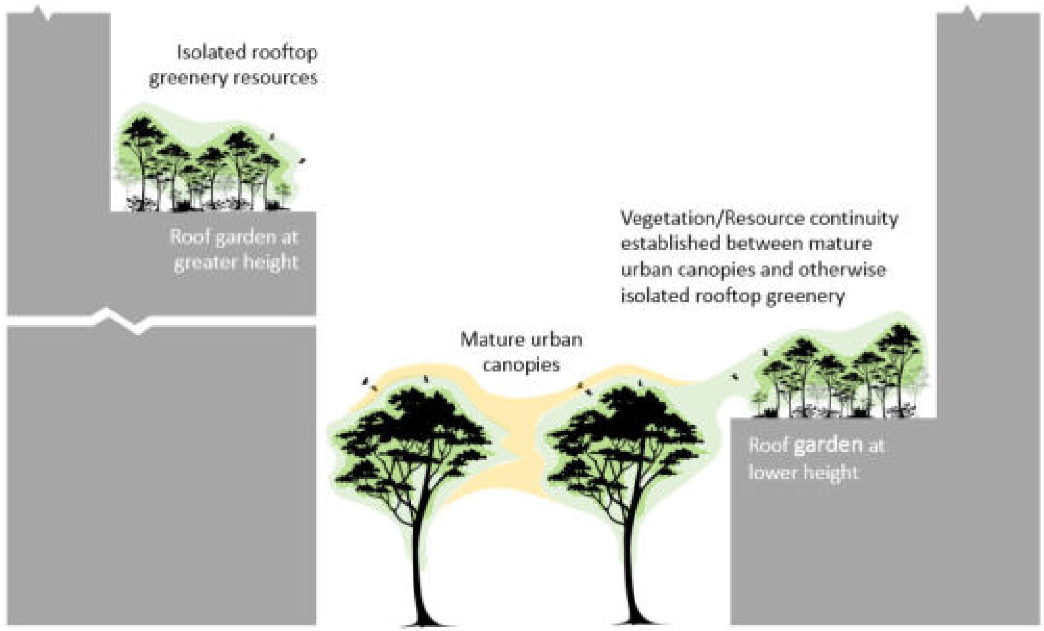


- Roof garden height is found to be a significant factor determining the overall attractiveness of a roof garden to birds and butterflies.

- Simpson's Diversity Index (a measure of species diversity and relative abundance) of both birds and butterflies decreased rapidly and non-linearly with increasing roof garden height. This implies that, in general, **roof gardens at lower height have comparatively higher biodiversity potential**.

- Often, roof gardens are **vertically-isolated** vegetation patches, separated from the surrounding ground-level urban vegetation.

- Collaborative efforts, between urban design and architecture design, should be made to connect these otherwise isolated elevated patches with the existing ground level greenery. This will facilitate/encourage vegetation and habitat continuity, and promote the associative biodiversity movement. Given time, this in turn will contribute toward establishing an ecological network across the city.



<u>Roof garden heights in relation to the ground level mature urban tree</u>

Conceptually, the above diagram demonstrates the spatial connectivity, by proximity, between the 'mature' ground-level urban trees and the adjacent roof garden 'young' vegetation. The intentional low height of the roof garden (roof garden finished level no more than 25m height from its immediate ground finished level) – a concerted architecture effort - made such spatial relation possible. Beyond, 25m height, roof garden becomes isolated. Beyond 50m height, roof garden becomes 'energetically more costly' for passing biodiversity to reach, hence less attractive as a resource node.

3.1.1 Roof Garden below 50m (from the site's immediate ground finished level)

3.1.1.1 Roof gardens at lower heights attract a broader suite of bird and butterfly species guilds.

3.1.1.2 Depending on the urban tree species in the tropics, in general, a mature urban tree can range from 15m to 30m in grown/maintained crown height, or more.

3.1.1.3 If the roof garden is with intent as an ecological stepping stone, the design and the height of the roof garden must be customised to the site's existing mature trees/palms conditions (such as the canopy shape, spread, etc.) and their height, so as to facilitate vegetation continuity, by proximity, between the existing mature tree/palm crowns at ground level, and the young rooftop vegetation.

3.1.1.4 Prior to design, site survey will be necessary to ascertain the height and conditions of the existing mature trees/palms. When necessary, certified professional arborist(s) should be consulted. The collated trees/palms information should be included in the design-tender-brief of the development. This is to ensure that the ecological design intention, if any, get carried through the development's design process and construction.

3.1.1.5 In architecture design process, there are numerous site forces, restrictions, limitations, concerns and other over-riding factors influencing the surface distribution, height and shape of a development's volume(s). Ensure that the building massing and roof garden design are aligned with such site issues.

3.1.1.6 Broadly, in design, it is recommended that roof gardens below 50m (from the immediate ground finished level) be designed with focus on creating ecology-centric spaces (i.e. biotic water bodies, more vegetation complexity, etc.), with more soft-scape provisions and spaces.

3.1.1.7 Below 50m height, roof gardens possess comparatively higher biodiversity potential. Broadly, roof gardens:

- **At no more than 20m height** are statistically significant in attracting both bird and butterfly species **;**
- **Between 20m to 40m height** are statistically significant in attracting bird species and to a lesser extent butterfly species**;**

3.1.1.8 Please refer to Section 4 for a design recommendation based on this design principle:

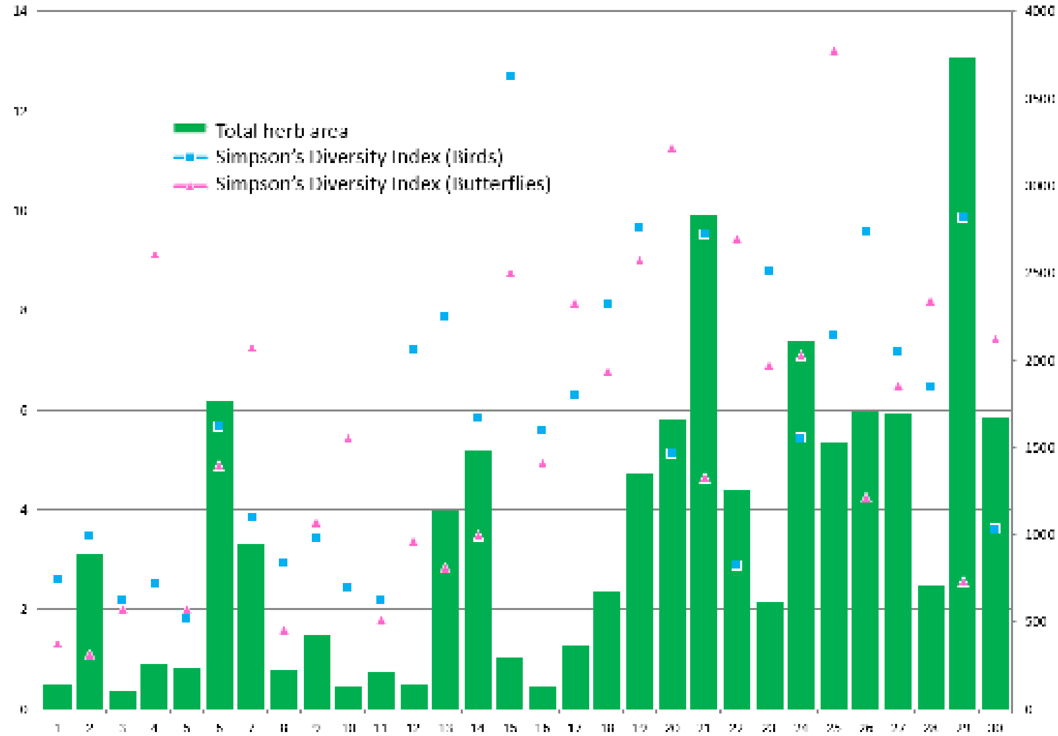
DESIGN-SUGGESTIONS	
Ecological potentials of roof gardens at various height zones	Section 4.1

3.1.2 Roof Garden above 50m (from the site's immediate ground finished level)

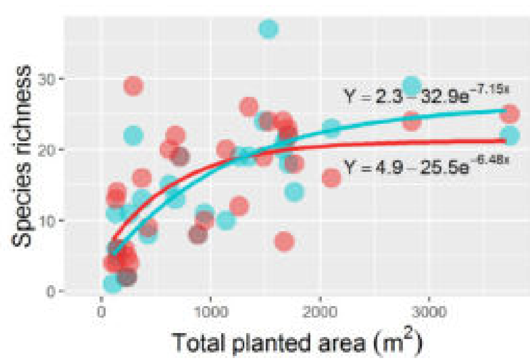
3.1.2.1 With increase altitude, beyond 50m height, roof gardens become highly isolated from the site's immediate ground level mature vegetation. Vegetation continuity is challenging to establish vertically. Roof gardens beyond 50m height hence possess comparatively lower biodiversity potential.

3.1.2.2 In design, it is recommended that roof gardens beyond 50m (from the immediate ground finished level) be designed to focus on creating human-centric spaces (i.e. playground, etc.).

3.2 PLANTED / HERB AREA OF ROOF GARDENS



The above chart contains data from 30 roof garden sites. The general trend depicts that (1) lower roof gardens have more total planted/herb area (2) correlating with higher Simpson's Diversity Index of both birds and butterflies.
(The X-axis indicates the 30 roof garden sites, with the lowest roof garden site on the far right and the tallest roof garden site on the far left. The left Y-axis indicates the Simpson's Diversity Index. The right Y-axis indicates the total herb area in meter square.)
Generally, the higher a building goes, the smaller the floor surface area with lower likelihood of landscaped areas. Ancillary provisions such as the mechanical and electrical services and building maintenance units, etc., will also compete for floor surface area.



Approximate area threshold for species richness are 1100 m^2 for birds and 1300 m^2 for butterflies.

3.2.1 Total horizontal planted/herb area, on a single roof garden level, was identified to be a significant factor impacting the roof garden attractiveness to passing biodiversity, in the following ways:

- The **total horizontal planted/herb area (area with vegetation) matters more than the total roof garden area**.

- Wherever the roof garden area allows, a **planted/herb area of at least 1300m^2** is recommended, on a single landscaped level. While this is an ideal target, it does not preclude smaller roof garden which still have value even if not large.

- The data indicate increasing returns on wildlife benefit up to **1100 m^2 for birds** and **1300 m^2 for butterflies** - validating the notion that roof gardens should be regarded as habitat islands.

- In typical high-density urban developments, the above are approximations of managed greenery for biodiversity enhancements.

- Wherever allowed in landscape design, **create habitat/resource heterogeneity**, through a diverse selection of biodiversity-attracting plant species, especially nectaring and fruiting species, preferably in locations with lower human disturbance. Please refer to:

SECTIONS	
Complexity of vegetation on roof gardens	Section 3.4
Plant species lists	Section 5
DESIGN-SUGGESTIONS	
Recessed rooftop trees and palms	Section 4.13
Network of vegetated refuges and passageways on a roof garden	Section 4.14

3.2.2 INTENSIVE ROOF GARDEN

- On intensive roof garden, the **total planted/herb area**, by definition, is the total achieved non-tree vegetated area, namely horizontal roof surface covered by (1) lawn cover, (2) shrub cover, (3) climbers, (4) epiphytes.

- In landscape design, the ideal target for total horizontal **planted/herb area should aim at the areas described in clause 3.2.1**.

- With concerted ecological design efforts, no roof garden is too small to contribute towards urban biodiversity enhancement. Every patch of vegetation in the urban environment has potentials to contribute ecologically.

3.2.3 EXTENSIVE GREEN ROOF

- On extensive green roof, the **total planted/herb area**, by definition, is the total horizontal roof surface covered by (1) lawn cover, and (2) shrub covers.

- In landscape design, the ideal target for total horizontal **planted/herb area should aim at the areas described in clause 3.2.1**.

- There are anecdotal observations of mid-storey birds and butterfly species foraging amongst both the managed and non-managed (spontaneous) vegetation of roof gardens. Birds were spotted feeding on the seeds of wild-grasses and butterflies feeding on nectars of flowering weeds! With concerted design and management efforts, designated locations on the roof gardens can be allotted intentionally to naturalise, with infrequent judicious maintenance, whenever deemed necessary by the building-management.

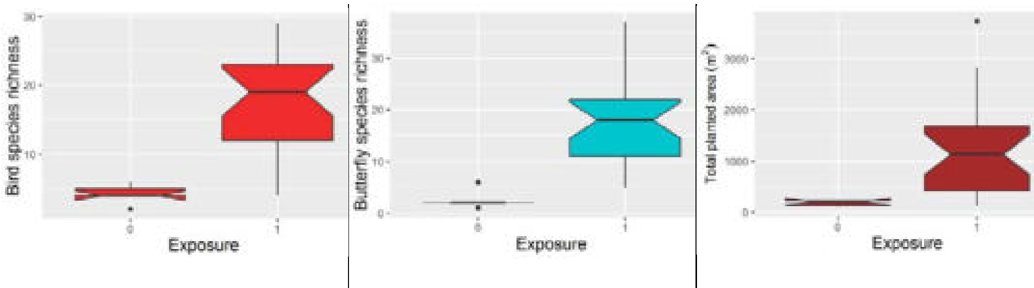
- Extensive green roof when designed and/or allowed to naturalise can become effective resource nodes for passing biodiversity. Please refer to:

DESIGN-SUGGESTIONS	
Naturalised extensive green roof	Section 4.15

3.2.4 To create habitat/resource heterogeneity on a roof garden, the landscape design should have a combination of the following vegetation types:

VEGETATION TYPES	**ATTRACTED FAUNA SPECIES**	**PLEASE REFER TO:**
Large lawn area and low growing ground cover area	In general, attracts under-storey dwelling bird and butterfly species	• Section 5, *Plant Species Lists*
Large shrub area	In general, attracts mid-storey dwelling bird and butterfly species	• Section 5, *Plant Species Lists*
Spontaneous vegetation (i.e. weeds, nectaring weeds, seeding grasses, etc.)	Attract under-storey dwelling bird and butterfly species	• Section 5, *Plant Species Lists* • Section 3.5, *Judicious maintenance of roof gardens*
Rooftop tree/palm	Attract canopy dwelling bird and butterfly species	• Section 5, *Plant Species Lists* • Section 3.4, *Complexity of vegetation on roof gardens* • Section 4.13, *Recessed rooftop trees and palms*

3.3 EXPOSURE OF ROOF GARDENS



Non-exposed sites supported much lower planted areas than exposed sites. The associated fauna species richness is lower.

3.3.1 Exposed roof gardens (roof gardens open to the sky) are identified to have higher combined Simpson's Diversity Index compared to non-exposed roof garden sites (sheltered sky terraces). In short, **exposed roof gardens are more attractive** to birds and butterflies.

3.3.2 Sheltered sky terraces attract statistically far lower numbers and species of birds and butterflies. Birds in flight observed at the fringes of such developments rarely enter such sheltered sky terraces. However, there have been anecdotal accounts of some birds, such as the Olive-backed sunbird (*Cinnyris jugularis*), nesting in balconies and roof eaves.

3.3.3 This is hypothesised to be attributed to the spatial-constraints in such confined spaces, wherein there are few or no escape routes for the birds.

3.3.4 Roof gardens can be broadly classified as:

Left image: Exposed (open) roof gardens. *This elevated greenery type is open to full sun throughout the day. Under abundant daylight, flowering/fruiting species can bloom and bear fruits to provide valuable food resources for birds and butterflies. Spatially, such open site offers clear resource visibility to passing aerial species, and multiple escape options in times of need.*

Right image: Non-exposed (sheltered) roof gardens. *This elevated greenery type is sheltered from direct sunlight. Depending on the site's orientation, limited hours of direct sunlight are received per day by the plants. Energetically, this is not conducive for triggering blooms and fruits. Sheltered rooftop trees and palms are also often spotted in less than ideal health conditions. The lack of head-room for growth of the tree/palm crowns is also a common problem amongst this typology, affecting both canopy form and foliage health. Without a reliable food resource base, coupled with the lack of resource visibility and spatial escape routes in such comparatively confined spaces, this typology is observed to attract few birds and butterflies throughout the entire duration of the survey.*

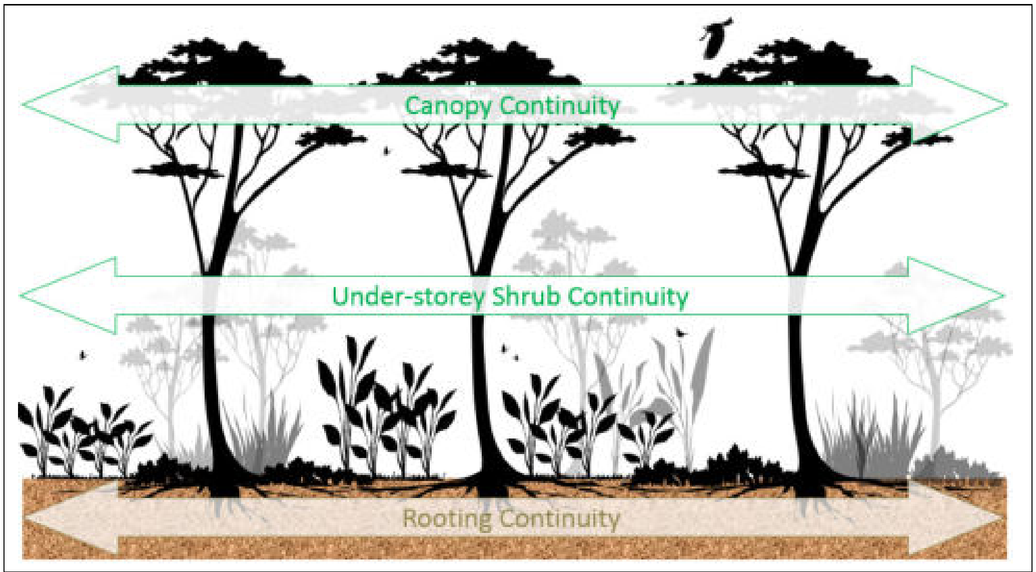
3.3.5 Please refer to Section 4 for Design-Suggestions on:

DESIGN-SUGGESTIONS	
Roof garden exposure types	Section 4.2
Height to depth ratio of non-exposed (sheltered) roof gardens	Section 4.3
Open perimeter percentage of non-exposed (sheltered) roof gardens	Section 4.4

3.4 COMPLEXITY OF VEGETATION ON ROOF GARDENS

- A habitat with vegetation complexity offers more ecological resources and spatial niches for wildlife to exploit. This attracts biodiversity.

- Complexity of vegetation comprises of (1) Structural complexity (2) Species diversity and (3) Vegetation continuity.



(1) Structural complexity can be enhanced through:
Increasing the "layers" of greenery
Growing (and/or allowing the spontaneous growth of) climbers and epiphytes
Growing a mix of turf, herbs, shrubs, long grasses

(2) Species diversity can be enhanced through:
Having **more species of epiphytes**
Planting **more species of bird nectar/fruit plants**
Planting **a variety of shrub species**
Planting **more species of butterfly nectar plants**
Planting **some butterfly host plants**
Planning and designing for **"Wildflowers" area**
Planning and designing for **contiguous rooting**
Wherever sustainably available, **use biodiversity-attractive native plant species**

(3) Vegetation continuity can be enhanced through:
Landscape design layout to foster growth of continuous tree canopy layer
Landscape design layout to foster continuous under-storey shrub layer
Landscape design layout to foster shared/contiguous planter space and rooting media

- As tree diversity and epiphyte species richness increase, bird diversity also increases.

- Tree diversity* and epiphyte species richness* are major predictors of bird diversity on roof gardens. As tree diversity and epiphyte species richness increase, bird diversity also increase. [*Species diversity consists of two components, namely, (1) species richness – a simple count of species; and (2) species evenness – quantifies how equal the abundances of the species are]

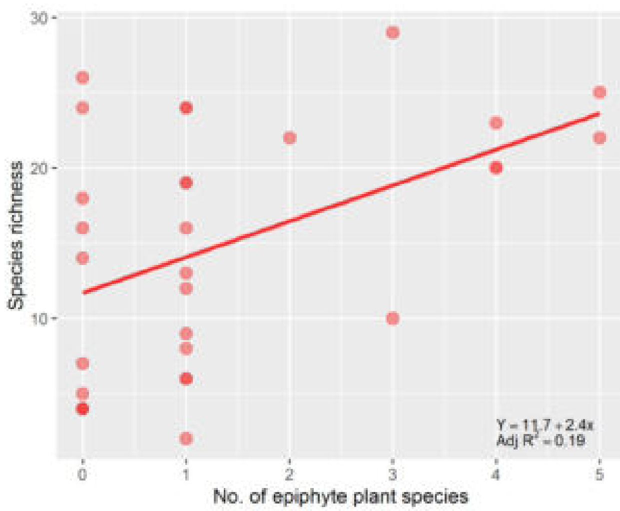
- Birds are attracted to the roof gardens, not just for food resources, but are also responding to the structural attributes of the trees and epiphytes. (*Garden et al., 2010*), such as perching in trees while grooming and vocalising.

- Using trees of different (1) species, (2) crown heights and (3) crown shapes enhances vegetation structural complexity, apart from providing diverse resources. Some birds simply fly through using the rooftop tree canopies and shrub stratum as sheltered flight paths.

- **More than garden area**, vegetation structural complexity greatly influences invertebrate species richness and abundance (*Smith et al., 2006*). It is therefore recommended that design and maintenance efforts for vegetation structural complexity be made even for small roof gardens, upfront during the project design phase.

3.4.1 PLANT SPECIES DIVERSITY ATTRACTS BIRDS AND BUTTERFLIES

3.4.1.1 From the study, it is recommended to have **<u>more species of epiphytes</u>** in the roof garden, to enhance bird diversity. Apart from providing food resources, epiphytes also enhance vegetation complexity by offering foraging substrates, refuge and nesting sites for birds (*Cruz-Angon & Greenberg, 2005; Cruz-Angon et al., 2009*)

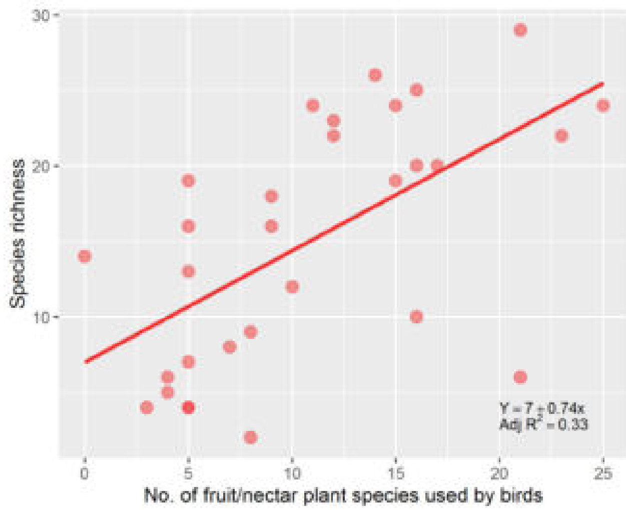


Scatterplot of Species Richness for birds at each site against epiphyte species recorded at each site. For birds, epiphyte species richness is important, with an approximate threshold of at least two species of epiphyte plants. (Evident based on the data from the 30 roof gardens sites.)

- In design, invest in (1) planting different tree species and (2) allow the epiphytes to grow (avoid removing the epiphytes) to enhance bird diversity. This can be planned from the onset of design phase by the architects/landscape-architects/designers/etc., conserved and enhanced by the subsequent building manager during operation.

The image on the right depicts some epiphyte species that have spontaneously established on a fish-tail palm (Caryota mitis). The identified epiphyte species are Asplenium nidus, Davallia denticulata and Pyrrosia piloselloides.

3.4.1.2 In design, allow planting of **more species of bird nectar/fruit plants**, to attract significant diversity of bird guilds.



For birds, bird fruit/nectar plant species richness is important, with an approximate threshold of at least eight species of nectar/fruit plants. (Evident based on the above data from the 30 roof gardens sites.)

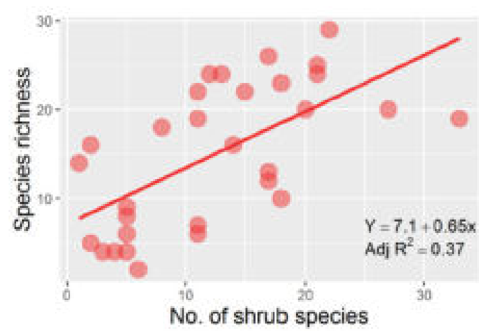
- Rich plant species diversity on the roof garden provides greater habitat/resource heterogeneity and availability for birds, attracting a greater diversity of bird guilds.

- Planting of bird nectar/fruit plant species is the most direct way to boost bird diversity on roof gardens. Bird nectar/fruit plant species richness attracts not just nectarivorous/frugivorous bird species but also carnivorous/insectivorous bird species, because nectar and fruit plants attract small animals and invertebrates which become the food resources to the birds.

3.4.1.3 In design, allow planting of **a variety of shrub species**, to enhance habitat quality for birds.

- Rich shrub diversity provides greater habitat/resource heterogeneity and availability for birds, attracting a greater diversity of bird diet guilds.

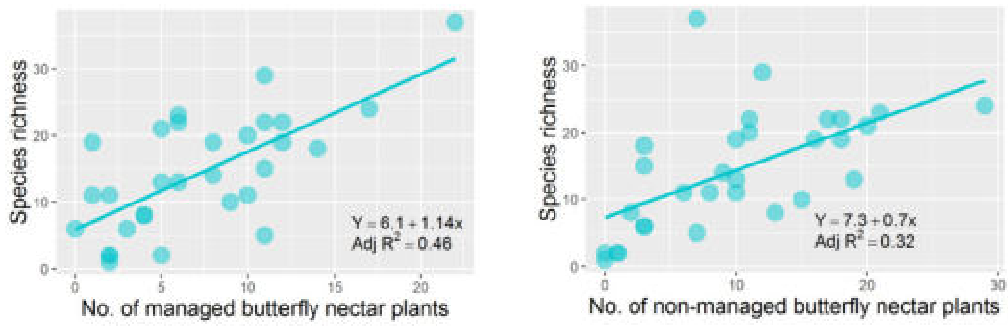
- Shrub species richness has a positive correlation with understorey bird species richness. This suggests that shrubs encourage visitation by understorey bird species.



For birds, shrub species richness are important, with an approximate threshold of at least 10 shrub species. (Evident based on the above data from the 30 roof gardens sites.)

- Mid-storey insectivorous bird species, such as the common tailorbird (*O. sutorius*) are also observed to forage amongst the low dense shrubs for insects.

3.4.1.4 In design, allow planting of **more species of butterfly nectar plants**, to attract significant diversity of butterfly.



For butterflies, species richness of both managed and non-managed plants (spontaneous vegetation; weeds; "wildflowers") is important. (Evident based on the above data from 30 roof gardens sites.)

- A roof garden with rich butterfly nectar plant diversity provides a wide range of flowers that attract and cater to different butterfly guilds.

- Flowers on plants of various habits (trees, shrubs, wildflowers, etc.) attract butterflies of different stratum guilds to forage (*Reid & Cullin, 2002*).

- Both deliberately planted butterfly nectar plant species and spontaneous species ("wildflowers") have been observed to be equally important for (equally frequented by) butterflies.

Left image: A Plain tiger butterfly attracted to a "wildflower", Tridax procumbens. Middle image: A Blue glassy tiger butterfly attracted to Bidens alba. Right image: A Common rose butterfly feeding from Asystasia gangetica.

- It is also possible to enhance butterfly species diversity by intentionally (1) planting larval food plants (*Krauss, 2005*) and/or (2) improving the habitat quality of the garden (*Thomas et al., 2001*). Please refer to *Section 5, Plant Species Lists*.

- Such sensitive corner of the roof garden should be with controlled access (such as a lockable garden gate) to minimise potential conflict between human-users and the butterfly larvae. Please refer to:

DESIGN-SUGGESTIONS	
Limiting human access into the protected zone (of a garden)	Section 4.6

3.4.1.5 During the landscape design phase, **"wildflower" area** can be intentionally designated by the architects/landscape-architects/designers/etc. During the operation phase, the building operator/manager can take over the enhancement and preservation of the "wildflower" area. Please refer to *Section3.5, Judicious Maintenance of Roof Gardens*.

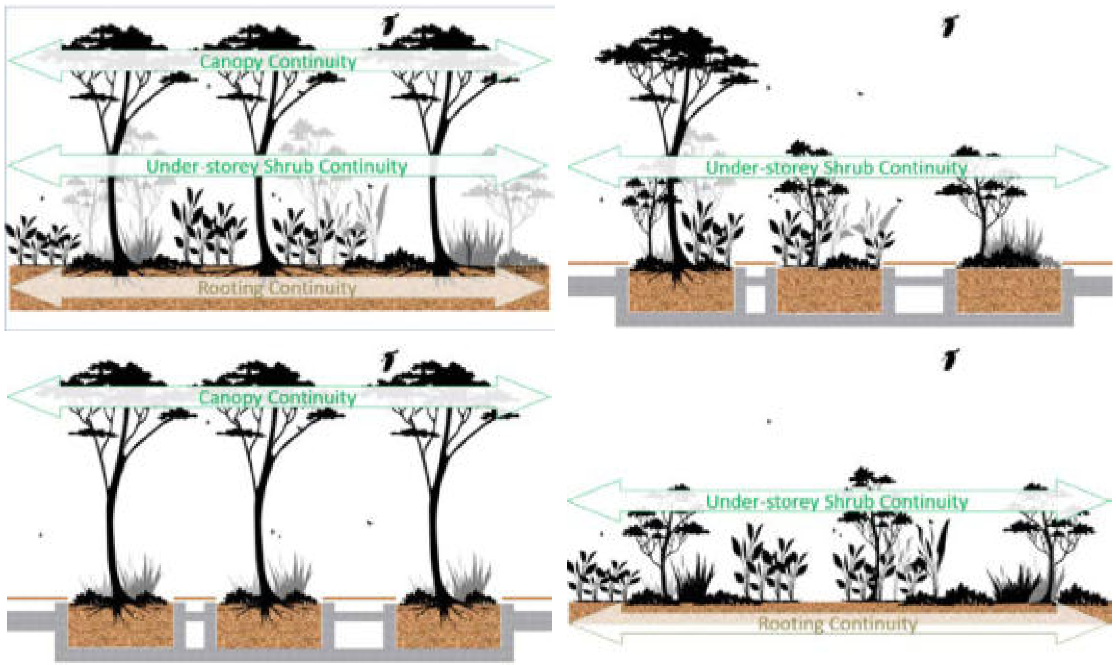
Right image: Extensive growth of a flowering weed species, Youngia japonica, which is attractive to butterflies. In the "wildflower" area of the garden, with controlled access, spontaneous vegetation can be tolerated and judiciously managed occasionally.

3.4.1.6 In the roof garden design, wherever feasible, plan the planter spaces to **allow contiguous rooting**. Over time, a contiguous rooting volume shared by diverse species will create a diverse community of substrate micro-organisms, invertebrates and associated microbial activities. These will become beneficial resources to roof garden biodiversity. Birds have been observed feeding on the seeds and invertebrates on rooftop lawns. Please also refer to:

DESIGN-SUGGESTIONS	
Network of vegetated refuges and passageways on a roof garden	Section 4.14

3.4.1.7 Where sustainably available, **use biodiversity-friendly native plant species**. Apart from being likelier food sources for native animals as they have coevolved (*Tan, 2006*), use of native plant species also supports plant species conservation. Currently on roof gardens, the proportion of introduced plant species (89%) overwhelms the native plant species (11%) – a common phenomenon due to the easy availability of exotic ornamental plant species in the market and the generally stronger tolerance of these exotic species to exposed dry site conditions (*Tan, 2006*). There are opportunities to improve the use and popularity of native plant species in the urban landscape. There are many native plants that have evolved to tolerate dry and exposed conditions, and more field trials are needed to bring these to the market. Please refer to *Section 5, Plant Species Lists*.

3.4.2 CREATE VEGETATION CONTINUITY ON THE ROOF GARDENS



- As illustrated above, Vegetation Continuity has three broad vegetation spatial zones, namely:
  - Vegetation Continuity of the tree canopy;
  - Vegetation Continuity of the under-storey foliage;
  - Vegetation Continuity of the rooting zone;

  On a roof garden context, all three spatial zones can be re-created. Wherever feasible, make spatial and structural provisions to allow Vegetation Continuity at all three spatial zones, mimetic of natural habitats. (For example, the top left of above illustrations.)

- In principle, within each spatial zone, create (1) Species Diversity and (2) Structural Complexity. This design principle is applicable to both intensive roof garden as well as extensive green roof.

  - **Species diversity** in the flora context, is achievable through selecting a diverse list of plant species. Please refer to *Section 5, Plant Species Lists*.

  - **Structural diversity** in the flora context, is achievable through selecting a range of foliage forms, heights and their compositions, by an experienced landscape architect.

- Regarding extensive green roofs, please refer to:

DESIGN-SUGGESTIONS	
Naturalised Extensive Green Roof	Section 4.15

- Regarding intensive roof gardens, for the planting of tall rooftop trees and palms (up to 8m in grown/maintained height), please refer to:

DESIGN-SUGGESTIONS	
Recessed Rooftop Trees and Palms	Section 4.13

- Vegetation Continuity of the rooting zone/media can be achieved through shared planter design, allowing multiple trees, palms, shrubs, groundcovers, dry areas, wet areas to occupy the same continuous planter. Please refer to:

DESIGN-SUGGESTIONS	
Network of vegetated refuges and passageways on a roof garden	Section 4.14

- Planters/Flower beds provide nectar, fruits, seeds and invertebrates as food resources for birds and butterflies. However, wide planter beds with dense planting are often unwittingly trampled on during periodic landscape maintenance, especially when repair or landscape works are required in the middle of such planter bed. Blooms and foliage can suffer mechanical damage unnecessarily, affecting these resources' availability to visiting birds and butterflies.

- Within broad planting areas, the maintenance paths can be narrow, discreet and curved to be less visible to all but the regular maintainers. This will help reduce trampling to conserve the food resources (the already established foliage, flowers, seeds, etc.) for the visiting biodiversity, while also avoiding compaction of substrate which can damage the sensitive fine roots and adversely affect the plants' health.

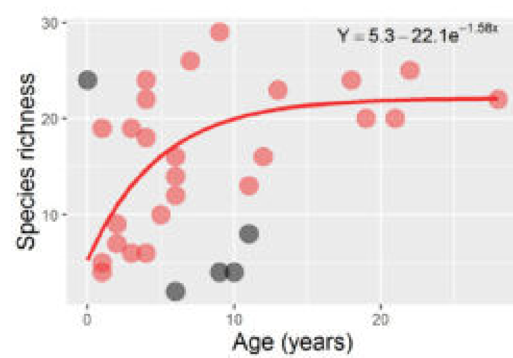
DESIGN-SUGGESTIONS	
Shrub/Flower bed widths	Section 4.16

3.5 JUDICIOUS MAINTENANCE OF ROOF GARDENS

Judicious maintenance is a broad term to describe maintenance work done with conscious, selective treatment(s) and removal of plant parts, targeting only the problematic areas (such as diseased plant parts, dried leaves, etc.), while retaining the well performing and unaffected parts, without excessive pruning, nor upsetting the already established ecology and systems of the site. Good judgement is imperative. In the same vein, naturalistic landscape design trends also question and shift current perceptions on landscape maintenance.

In the city, it is possible to condense the section laterally to suit available space.

3.5.1 SET ASIDE LOCATION TO NATURALISE - In landscape design, such as on a roof garden, set aside a designated area to naturalise. Design and landscape this area as the "biodiversity" corner of the roof garden. Periodically access this area for judicious maintenance and to check for stagnant water.



For birds, site age is important, with an approximate threshold of 6 years. (Evident based on the above data from 30 roof gardens sites.)

3.5.2 EXERCISE ACCESS CONTROL – To manage human presence in the naturalised area, have a lockable "gate-way" as access-control. This can be coupled with fencing, hedging, etc. as barriers, to keep human-users out, unless granted access by the facility manager. Changes in level and 'green-wall type' low barriers may also help inhibit access, and can be explored in the garden design.

Please refer to:

DESIGN-SUGGESTIONS	
Limiting human access into the protected zone.[1] (of a garden)	Section 4.6

3.5.3 CONDUCT REGULAR SITE INSPECTION – Conduct regular site inspection (no less than twice every week, with each visit no more than four days apart) to these sensitive area(s). Inspect and ensure there is no water ponding, drainage issue (due to drainage choked by fallen plant debris), etc.

- During inspection, any rooftop tree/palm health and/or safety issue should be highlighted to the building management for due action.
- If assessed to be not an immediate risk/threat (i.e. potential falling plant debris from roof edge, etc.), these highlights must be regularly re-visited, monitored and surfaced during the quarterly or half-yearly inspection.

3.5.4 CONDUCT PERIODIC (QUARTERLY) ROOFTOP TREE/PALM INSPECTION - Rooftop trees/palms should be periodically inspected (quarterly) for trees/palms stability, potential falling plant debris from height beyond the roof edge, etc.

- Rooftop trees/palms and tall vegetation (any plant more than 2m height) should be periodically assessed for their stability. The assessment includes, and is not limited to, the following:
  - Assess the rooting and overall stability of the tall plant;
  - Look for signs of wood decay on trunks and branches that may affect the rooftop tree/palm stability;
  - Look for signs of disease;
  - Look for signs of harmful insect infestation, etc.
- Wherever deemed a concern, certified arborists in Singapore can be engaged for inspection and consultation. The list of certified arborists in Singapore can be found in the following web link: http://www.cuge.com.sg/Listing-of-Certified-Arborists
- Wind speed increases with altitude. On a rooftop, wind load can be a loading/safety issue. Tall plants with large dense canopies (acting as 'sail area' that catches wind) are especially susceptible (and can possibly succumb) to the wind loads.
- Taller plants/trees/palms must be suitably set back from the roof edge by a horizontal distance no less than the maintained grown height of the plant. This is to lend spatial-control, such that should these tall plants be unexpectedly fallen by unforeseen natural forces, such as intense wind gusts, etc., the fallen whole plant and its parts land within the

[1] *The proposed design option demarcating the protected and non-protected zones should be well-integrated within the overall landscaping scheme and should not adversely impact the overall spatial quality, accessibility and communal usability of the garden area.*

confines of the roof garden space with no plant debris falling beyond the roof edge jeopardising public safety.

- Please refer to *CS E09:2012*, *CS E10:2014* and *CS E11:2014*, for more information on rooftop trees, palms and tall shrubs on roof gardens.

3.5.5 AVOID USE OF NOISY, FUME PRODUCING MECHANISED EQUIPMENT - Wherever possible, avoid the use of loud motorised equipment, as this creates noise-disturbance and fumes (if it runs on liquid fuel), which deter and poison biodiversity. For example, a topiary hedge in proximity to such sensitive area must not be pruned by powered hedge trimmer. Manual use of hedge-pruner is preferred. Alternatively, select quality powered equipment that are quieter and cleaner, and keep them well maintained.

3.5.6 KEEP SOME LAWN AREA UN-MOWED – Lawn areas need not be fully mowed. Fringe locations alongside the "biodiversity" area can be intentionally left unmowed (as illustrated in section 3.5) and allowed to naturalise with spontaneous vegetation. Wildflowers and wild grasses will return given time, contributing to the overall habitat resource in the form of nectar, small fruits, seeds and invertebrates.

- Where feasible, avoid over-weeding the lawn. In the study, many of the granivorous bird species observed on roof gardens were feeding on the naturalised lawn.

- The naturalised lawn supports granivorous bird species (such as Munia species) and the invertebrates which in turn attract insectivorous birds such as the oriental magpie-robin (*Copsychus saularis*).

3.5.7 WITHIN THE NATURALISED ZONE, RETAIN THE SPONTANEOUS VEGETATION (WILDFLOWERS AND WILD GRASSES) - Given time, flowering spontaneous vegetation ("wildflowers") will sprout on un-mowed/under-maintained lawn and shrub beds. Butterflies are observed and recorded to frequently visit these wildflower resources. Field trials are necessary to find out what works and what does not work and how best to maintain the proposed design.

In general, butterflies show little preference between native or exotic plants. (*Bergerot 2010*). For a list of wildflower species, please refer to *Section 5, Plant Species Lists*.

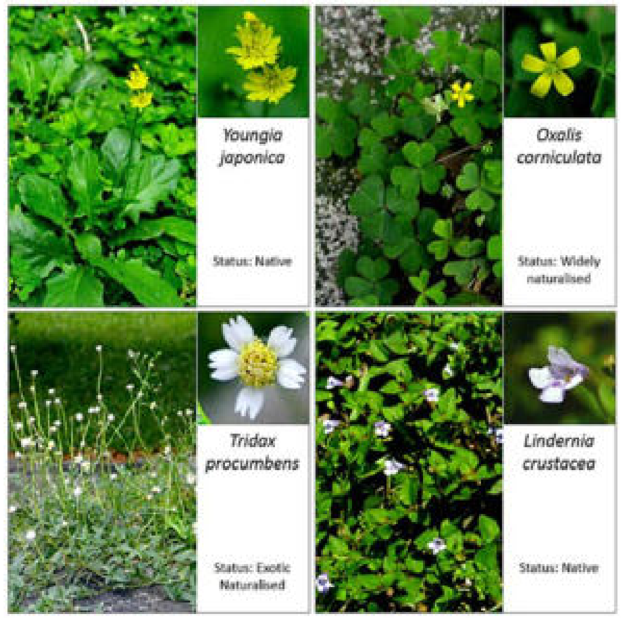
- On roof gardens, wildflowers contribute positively to the overall butterfly nectar plant species richness/diversity - an important predictor of butterfly guild richness – to sustain diverse butterfly guilds.

- While the wildflower species spotted in Singapore are mostly exotic, native butterflies use these flowers as nectar sources as long as the flowers possess the following characteristics:

  - sufficiently short corolla tube length;
  - white or bright colours;
  - diurnal flowering;
  - scented;
  - with sugar concentration (*Scott, 2014*).

- Wildflowers are spontaneous, flourish easily and require no fertilisers or maintenance, while providing an abundance of nectar for butterflies. This is an extremely cost-effective way of attracting butterflies onto roof gardens.

- Wildflowers are resilient and spread easily. Should building owners/operators desire more control over wildflowers and its spread, it is recommended that certain areas of the roof garden be designated for such spontaneous vegetation to establish and mature.



3.5.8 DO NOT USE PESTICIDES – From the study, it is observed that a large proportion (48%) of the bird species on roof gardens are carnivores and insectivores. However, animal prey cannot be considered a fixed food resource for the birds in the roof gardens because of the widespread practice of pesticide application on roof gardens.

- While enhancing animal prey availability is not the priority of a roof garden design, nonetheless, it is recommended that site managers/operators avoid using pesticides.

- Some commonly used pesticide varieties such as malathion, used to control mosquitoes, are toxic to birds and butterflies (*Devine & Furlong, 2006; Hoang et al., 2011*).

- There are several other passive means of managing mosquitos and other undesired invertebrates in a landscape. Please also refer to www.nea.gov.sg for guides on mosquito control.

- **THE CHEMICAL APPROACH -** Horticulturists and building managers should explore more non-poisonous pest control methods. For example:

    - **Mosquito dunks/pellets** when in standing water, releases larvicide and provides a biological mosquito control by destroying the mosquito larvae before it hatches into the adult mosquito. A special bacterium, *Bacillus thuringiensis israelensis* (Bti), is a strong biological pesticide consisting of microorganisms which produce toxins that kill mosquitoes at larvae stage. Bti is toxic also to specific insects such as butterflies, moths, flies and beetles. Bti is not harmful to humans, fish, amphibian, birds, cats, dogs and plants. Use this method upfront, during the regular inspection.

    - The chemical **pyrethrine** (used in scientific study involving canopy fogging) is not poisonous to other animals such as birds, because the used natural pyrethrine breaks down under UV-radiation within ten minutes. The application of pyrethrine via fogging requires windless conditions. Fogging using pyrethrine is usually practised after sunset. Use this chemical only as a last resort.

- **THE ECOLOGICAL APPROACH –** A diverse invertebrate community attracts insectivorous birds to feed, which in turn help to keep the invertebrate populations under control. There are many other instances in nature where insects and fungi exhibit forms of biological pest and disease control. Below are some examples.

  - **Beneficial insects** – Some common ones are ladybird beetles, praying mantis, ground beetles, dragonflies, etc. Spiders are also beneficial. (These creatures prey on aphids, whiteflies, mites, etc.)
  - **Soil fungi** - An interesting group of predators are soil fungi, which produce loops that contract when a nematode passes through.
  - ***Trichoderma*** - Several strains of the fungus *Trichoderma* have been developed as bio-control agents and are successfully being used commercially in place of fungicides.
  - **Pheromone traps** - In parks, pheromone traps have been used successfully. These traps rely on commercially produced pheromones. (In nature, beetles and weevils produce these pheromones to attract mates.) These traps work by reducing the insect population thereby reducing plant damage. (*P. Sanderson et al., 2010)*

- **ADVANTAGES OF USING LESS PESTICIDES AND CHEMICALS**
  - Reduce health risks to gardeners.
  - The garden becomes a safer place for children and pets to visit and play.
  - Less contamination to the landscape.
  - Garden soil stays healthier and more fertile, boosting healthier plants in the long run.
  - Improves insect species diversity (which in turn will attract insectivorous birds to the garden and help keep the insect populations under control in a natural way.).
  - More pollination by bees, butterflies and other pollinators.
  - The garden will become more ecologically balanced in the long run.

- **ORDER OF CONSIDERATIONS AND CONTROLS -** Gardeners should understand and keep in mind that garden pests and problems do come and go. Go by the following order of considerations and controls, and tailor the operation framework for your gardens.

<table>
<tr><th rowspan="2">1
Prevent</th><th>Question: How can I prevent the problems?</th></tr>
<tr><th>Solution: Keep the garden healthy</th></tr>
<tr><td colspan="2">• Plant varieties suited to your site. Some sites are sunny while others are shady. There is a great variety of plant species to choose from. Choose plant species suitable to the site’s daylight condition.
• Know the common insects and diseases prevalent in the area/garden and plant the resistant varieties.
• Encourage beneficial insects.
• Interplant vegetation species, to slow the spread of problems.
• Stake plants suitably to keep the foliage off the ground and dry.
• Irrigate regularly to reduce drought-stress to plants.
• Fertilise regularly and on-schedule to boost plant vigor.
• Apply mulch to reduce splashing of soil and pathogens onto the plants.
• Identify, remove and properly dispose of diseased or infested plants/plant-parts.</td></tr>
</table>

<table>
<tr><td>2
Monitor</td><td>Question: Is it a persisting problem or an isolated incident?
Solution: Understand the situation</td></tr>
<tr><td colspan="2">• Inspect/monitor plant regularly for any sign of garden pest and disease (ex: holes in plants, wilting, and discoloration). Check the underside of leaves.
• Before treatment, identify the real problem. Determine if the damage is caused by disease, an insect, nutrient deficiency, pet-rabbit damage, etc. (For example, spraying insecticide onto a bacterial wilt is futile. Diagnosis is important.)
• Is the problem spreading/persisting or is it temporary? Some problems are seasonal and non-permanent.</td></tr>
<tr><td>3
Analyse</td><td>Question: How much damage can I tolerate?
Solution: Avoid over-reacting</td></tr>
<tr><td colspan="2">• Is the insect making the leaves ugly, but not harming the plant health?
• Will the problem be gone before any real damage is done to the plant?
• Is the problem temporary and isolated that will clear when the weather changes or the insect moves on?
• How tolerant are you in seeing caterpillars feeding on the host plants for a few weeks in return for some butterflies? (Most host plants recover after a generation of caterpillars has fulfilled its cycle.)</td></tr>
<tr><td>4
Control</td><td>Question: How can I stop the problem before the damage spreads?
Solution: When the problem persists, try out the least toxic solution first</td></tr>
<tr><td colspan="2">• Trapping garden pests with lures, sticky bands, pheromone traps, etc. is useful for lowering pest populations and for monitoring the problem's severity.
• Pest removal by hand is easiest if started early.
➢ Remove the infected or infested plant/plant-parts before it spreads.
➢ Monitor for pest egg masses on the undersides of leaves. Squash or remove the eggs before they become a problem.
➢ Some pest insects are slow moving, especially while mating, and can be easily removed by hand.
➢ Borers can often be cut out of the affected plant part without killing the plant.
• Pesticides use may become necessary.
➢ There are numerous organic and botanical pesticides available.
➢ Start with the least toxic and most effective pesticides.</td></tr>
</table>

- Undesirable animals such as rats, mice and cockroaches are attracted to food garbage. An abundance of food garbage such as in the proximity of Food & Beverage outlets, especially where hygiene and good practices in waste management are not exercised, will attract such pests. Wherever, there is such a problem, the facility manager should engage experienced pest control services. In no circumstances should public health be compromised. Please also refer to www.nea.gov.sg for guides on pest control.

3.6 HUMAN PRESENCE ON ROOF GARDENS

3.6.1 Roof gardens are conceived and made for human usage, pleasure and comfort. Additionally, roof gardens, when planted with suitable nectaring/fruiting species, double up as habitats (with food, water, shelter, nesting materials, etc.) for birds and butterflies. With concerted efforts, roof gardens can be functional habitats which support urban biodiversity conservation.

3.6.2 On a roof garden, human crowds create disturbances, directly through (1) increased noise level and (2) disturbed vegetation.

- Hardy urban-adaptor faunas (i.e. the many commonly sighted bird and butterfly species in the city) can tolerate such disturbances.
- The more sensitive fauna species perceive such disturbances as survival threats and will avoid such environments, even if these areas contain visible food resources and shelter.
- In short, a roof garden with unmanaged excessive human disturbances will deter birds and butterflies.
- Broadly, human presence/visitation/disturbance on a roof garden can be grouped into three main types, namely:

Visitation Frequency		**Visitor type**	**Expected noise type**
Normal visitation	Daily visit	Variable age groups, gender, mobility.	Noise from human conversation, laughter, kids squeals and screams when at play, etc.
Periodic maintenance	A visit every other day – Weekly visit	Maintenance workers and supervisors	Cleaning, repair, replacement. Human conversation. Equipment noise, Mobile Elevated Work Platforms (MEWP), Chain-saw, Mower (hand-held, ride-on), leaf-blower-vacuum.
Renovation works	Highly variable/ Unpredictable	Renovation workers and supervisors	If co-located with an abutting human-focused function on the same roof garden (ex: F&B outlet, wherein it is common to have a change of tenancy, interior works upgrade, etc.), renovation is going to be frequent. Likely one major renovation every two to three years. Equipment noise, drills, hammering, chipping, etc.

3.6.3 In the architecture design, build in downstream mechanism/spatial strategies to allow building manager(s) to exercise control over human visitation/presence to sensitive parts of the roof gardens. In the same vein, occupant load requirements (related to fire safety) of roof gardens can be applied synergistically in design to manage the total number of human visitors in such sensitive zones of a roof garden.

3.6.4 A simple example of such spatial control is a designated rooftop 'biodiversity' corner with access controlled via a locked gateway (or via clever space zoning, and changes of level, etc.). The gate does not need to be very tall, serving more as a visual threshold to discourage human entry, than as an actual barrier.

DESIGN-SUGGESTIONS	
Limiting Human Access into the Protected Zone (of a garden)	Section 4.6
Noise Conditions (at Building-Manager Level)	Section 4.9
Shape of Biotic Water Body	Section 4.12

3.6.5 Human Presence/Disturbance on Intensive Roof Gardens

3.6.5.1 Protect the biodiversity-zone and be tolerant of the spontaneous vegetation

- This can be in the form of a protected zone in the roof garden reserved for caterpillars, with butterfly host plants and controlled-entry, etc.
- Vegetation within this special zone should be allowed to naturalise with tolerance towards the growth of weeds. Please refer to Section 3.5, Judicious Maintenance.
- Exercise infrequent judicious maintenance only when deemed necessary.
- Over time, such non-managed vegetation will provide food resources in the form of nectar, seeds, fruits and invertebrates for both birds and butterflies.
- The rest of the roof garden beyond this controlled zone can still be open to human visitation.

3.6.5.2 Separate the human zone from the biodiversity zone

- The visibility of this special zone to human users is dependent on the overall design intention – designers should decide if retaining visual-spatial connectivity between the different zones is important/necessary.
- It is to be noted that, with visual-spatial connectivity retained (without any physical barrier, such as solid walls, or the likes), anthropogenic noise generated can still travel and disturb the sensitive biodiversity zone.
- Spatial zoning is one way to control the level of human participation in spaces.
- Depending on the design intention, such zoning may not even be necessary.
- A naturalistic design concept wholly embraced by the developer/building-owner may result in a very different approach to the design of the intensive roof garden.

3.6.5.3 Larger roof garden area has more ecological design opportunities and variations

- In general, the larger the total roof garden area, the more design opportunities there are for exploring zonation, visitor-management and their interfaces.
- Optimise the absolute vegetated surface areas. Not just the total roof garden area.
- In the roof garden design, allow and encourage vegetation complexity to establish over time. Please refer to *Section 3.4, Complexity of Vegetation*.

3.6.5.4 Biodiversity zone(s) should always be open to the sky (exposed)

- Biodiversity-focused zones must be open to the sky, receiving full natural daylight daily.
- Avoid locating this zone under sheltered areas as the lack of natural daylight will impede blooms and fruiting, affecting food resources for biodiversity.
- Instead, leave the shadier rooftop locations for the human focused rooftop functions.
- In the city, neighbouring taller buildings and structures may block out daylight during certain stretch of the day.
- Light and shadow site study/simulation will be necessary during design phase to shortlist rooftop locations for the different zones.

- Where solar irradiance is too intense for delicate plant species, vegetation complexity (using a combination of suitable trees, palms and shrubs) should be an important landscape design quality to deploy.

3.6.6 In architecture design, where there is a need to exercise control over visual and acoustic separation/connection, suitable barriers may be deployed. Please refer to:

DESIGN-SUGGESTIONS	
Potential Barrier Types (visual & acoustic) on Roof Gardens	Section 4.5

3.6.7 Human Presence/Disturbance on Extensive Green Roofs

3.6.7.1 Excessive human presence is often not an issue on extensive green roof

- In general, extensive green roofs are not designed for active recreational use.
- Many forbid public access, allowing only periodic maintenance access by certified skilled workers for judicious maintenance.
- Excessive human presence (which can be a problem on an intensive roof garden) is usually not an issue at all for extensive green roof.
- Instead, extensive green roofs are, more often than not, highly isolated elevated locations.
- However, there are also some creative extensive green roof designs/solutions with controlled human access (i.e. small viewing platforms/decks/boardwalks, etc.) allowing green roofs to be designed as meadows or moorlands which are attractive to biodiversity, and visually pleasing to people.

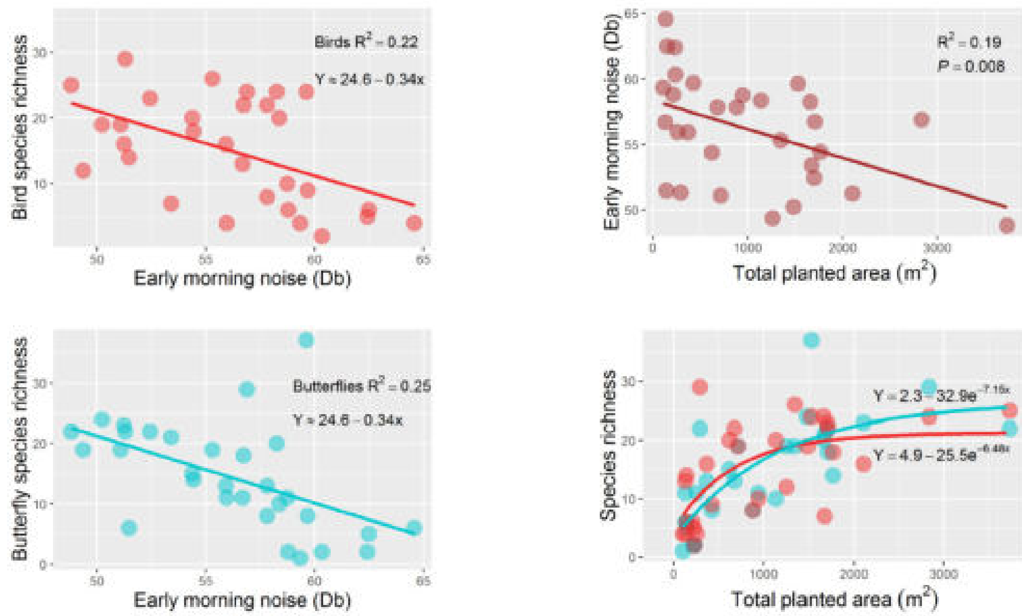
3.6.7.2 Allow extensive green roof to naturalise

- Where feasible, suitably plan and design such roof surfaces to allow planting of diverse flora species attractive to biodiversity. Spontaneous vegetation that appear over time should also be tolerated as these also provide resources and shelters to biodiversity.
- Allow such sites to mature and naturalise.
- Absolute non-management of the naturalised vegetation on a green roof is also not optimal for biodiversity enhancement. (*Yun Hye HWANG, 2015*) When uninterrupted over time, taller more dominant pioneer vegetation species will shade out the spaces below, reducing daylight penetration and affecting the vegetation structural diversity.
- To boost flora species diversity on green roofs, periodic trimming of tall overgrown shrubs, may be required to permit daylight penetration to promote understory spontaneous species establishment and variety. Over time, aggressive species will out-compete other species, rapidly altering the green roof plant composition. Trimming back dominate species will make room for growth of favoured species. This will help maintain certain species mixes for their ecosystem services. (*Yun Hye HWANG, 2015*)
- Dominant plant species should be identified and managed to allow for a more diverse meadow. Old green roofs can be studied and field trials conducted to identify the most dominant species, to help with early species detection and intervention.
- For public safety reasons, tall shrubs alongside roof edges will need to be trimmed back. (*CS E11:2014 – Guidelines on Design for Safety of Skyrise Greenery*)

3.6.8 Extensive green roofs being comparatively less disturbed by human-users than intensive roof gardens possess ecological potentials, especially when designed and allowed to naturalise over time. Please refer to:

DESIGN-SUGGESTIONS	
Naturalised Extensive Green Roof	Section 4.15

3.7 NOISE LEVEL ON ROOF GARDENS



Noise is likely a proxy of urban intensity, which reduces space for planted areas in roof gardens. Local planted area threshold are approximated to be 1200 m^2.

3.7.1 Phenomenon:

- Ambient noise can be regarded as a measure of traffic, urbanisation and disturbance (*Slabbekorn & Ripmeester, 2008; Barber et al., 2009*).

- In the local study, it is observed that as the early morning ambient noise increases the diversity and abundance of both birds and butterflies decrease (The time of noise level recording corresponds to the time of the surveys.). This observation is surprising for butterflies as there is no biological reasons to expect butterflies to be directly (and equally to that of birds) affected by urban noise. Moreover, the species abundance of an urban adapter bird species, *Acridotheres javanicus* (noted for its wide vocal range, and hence presumably least likely affected by increased urban noise), was surprisingly most affected by the increase in urban noise, contradicting survey expectations.

- It is hence postulated that the above observed negative effects of urban noise were most likely **proxy effects** of the close negative correlation between noise and total planted area. (Ex: *The noisier an urban area, the more built up that environment and hence the lower the total planted area is likely to be.*)

- Hence from the local study, **no direct effect** is found between urban noise and biodiversity on roof gardens.

- Having mentioned the above, multiple overseas studies have pointed towards the negative effects of urban noise on bird biodiversity and abundance nonetheless. (*Warren et al. 2006; Lowry, Lill & Wong 2013; Proppe, Sturdy & St Clair 2013*)

- Collectively, urban noise, as an urban factor, still warrants attention when biodiversity conservation/enhancement in a city is a concern/intention.

- Anthropogenic noise is also generated when operating certain maintenance equipment. These include, but are not limited to, leaf-blower-vacuum, mowing machines (both hand-held type and ride-on type), mobile-elevated-work-platform (when its safety alarm goes off as a warning during activation), chain-saw pruning, etc.

- Where feasible in design, pre-empt such foreseeable maintenance needs and their associated noise disturbances. Design the roof garden such that the need for such noise-generating equipment for maintenance can be minimised and/or made unnecessary.

3.7.2 Negative impacts of noise on biodiversity:

- The negative impacts of noise on different taxa have been well-documented in numerous studies around the world. Similar findings have also been noted for birds.

- Birds have to deal with the increased costs of vocalising at a higher volume in order to compensate for the disturbance caused by ambient noise (*Brumm, 2004; Leonard & Horn, 2008*).

- Anthropogenic noise, which is largely of low-frequency (e.g. traffic), masks the acoustic frequencies of certain songbirds (*Skiba, 2000*), leaving the species that vocalise at high frequencies to inhabit noisier areas (*Rheindt, 2003; Hu & Cardoso, 2009; Goodwin & Shriver, 2011*). Such environments potentially lower the reproductive success of these songbirds, as “singing” at altered frequencies not only is energetically more costly, but also is less recognizable by potential mates.

- Anthropogenic noise has also been observed to influence patterns of decline in bird diversity (*Slabbekorn & Ripmeester, 2008*), and this is also reflected in the results of the local study.

- Birds may avoid highly disturbed environments even if they contain potential food sources and shelter.

3.7.3 Please refer to:

DESIGN-SUGGESTIONS	
Noise Conditions (at Urban Planning Level)	Section 4.7
Noise Conditions (at Architecture Level)	Section 4.8
Noise Conditions (at Building-Manager Level)	Section 4.9

3.8 WATER PRESENCE ON ROOF GARDENS

3.8.1 Presence of water resource on a roof garden may attract biodiversity. Aside from flora resources, birds may make use of water bodies on the roof gardens (i.e. swimming pools, puddles after a rain, and other water features, etc.) to bathe and drink.

3.8.2 Design treatments of water edge have been observed to impact how birds and butterflies interact with the water surface. Depending on the design intention, these observations can be used to the advantage of human-users and/or biodiversity.

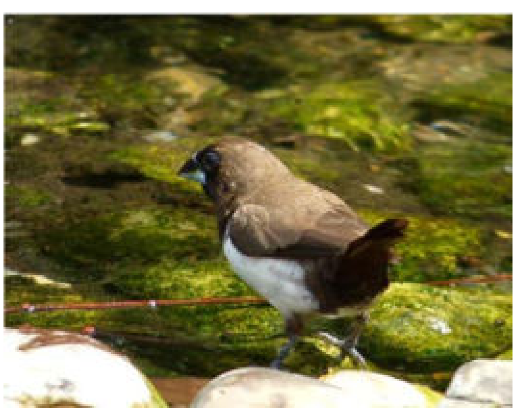
3.8.3 In design, swimming pool edges (and any other water bodies designed solely for human users wherein assurance of hygiene is of concern) should be raised with steep drop to impede birds' reach to drink and bathe along these edges.

3.8.4 Such water edges should be designed (1) to be higher than the water level and (2) with steep edges.

3.8.5 In contrast, naturalised ponds (and the likes, such as bird-bath, etc., designed to attract birds and butterflies and other creatures) should have gradual gradient/transition to the water edges, to encourage birds and butterflies to pause and interact with the water edge.

Above left: Spotted dove (*Spilopelia chinensis*) drinking from a swimming pool edge, that is gently sloping.
Above right: Swimming pool raised edge with steep drop that discourages bird visitation.

3.8.6 Along edges of feature steams and ponds, designers may incorporate gently sloping water edges to attract birds to linger, bathe and drink from.

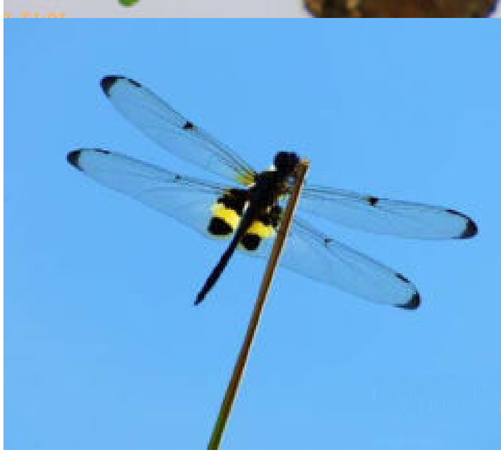


Above left: Javan munia (*Lonchura leucogastroides*) drinking from the gently sloping stream edge on a roof garden.
Above right: Yellow-vented bulbul (*Pycnonotus goiavier*) drinking from a small water puddle by a stream edge, on a roof garden.

3.8.7 Please refer to:

DESIGN-SUGGESTIONS	
Water Edge Treatments for Constructed Water Bodies	Section 4.10

3.8.8 Water has a density of 1000kg/m^3. Depending on the sizing of water body and its system design, a water body is a heavy component when on the roof. Subject to the roof structure's loading capacity, it is unlikely to find a water body on an extensive green roof, unless specially engineered for, with safe maintenance access allowing regular system checks (once every few days) to ensure no water stagnation, choking and mosquito breeding.



Some images documenting fauna-flora activities on roof gardens

A) Male Olive-backed sunbird feeding on the blooms of a Coral tree
B) A Black-naped oriole (an omnivore) picked a fruit
C) Scaly-breasted munia and a nondescript young feeding on grass seeds
D) A Pacific swallow (an aerial insectivore) perched on the parapet of a 50th floor roof garden
E) A female Olive-backed sunbird busy building her nest
F) A parent Long-tailed shrike feeding its fledgling a morning catch
G) A pair of Common grass yellow butterflies mating
H) Ladybird beetles are voracious predators of insect pests such as aphids
I) A Blue slim damselfly on a leaf after a rain
J) Yellow-barred flutterer dragonfly basking in the morning sunlight

A	B	C
D	E	F
G	H	I
J		

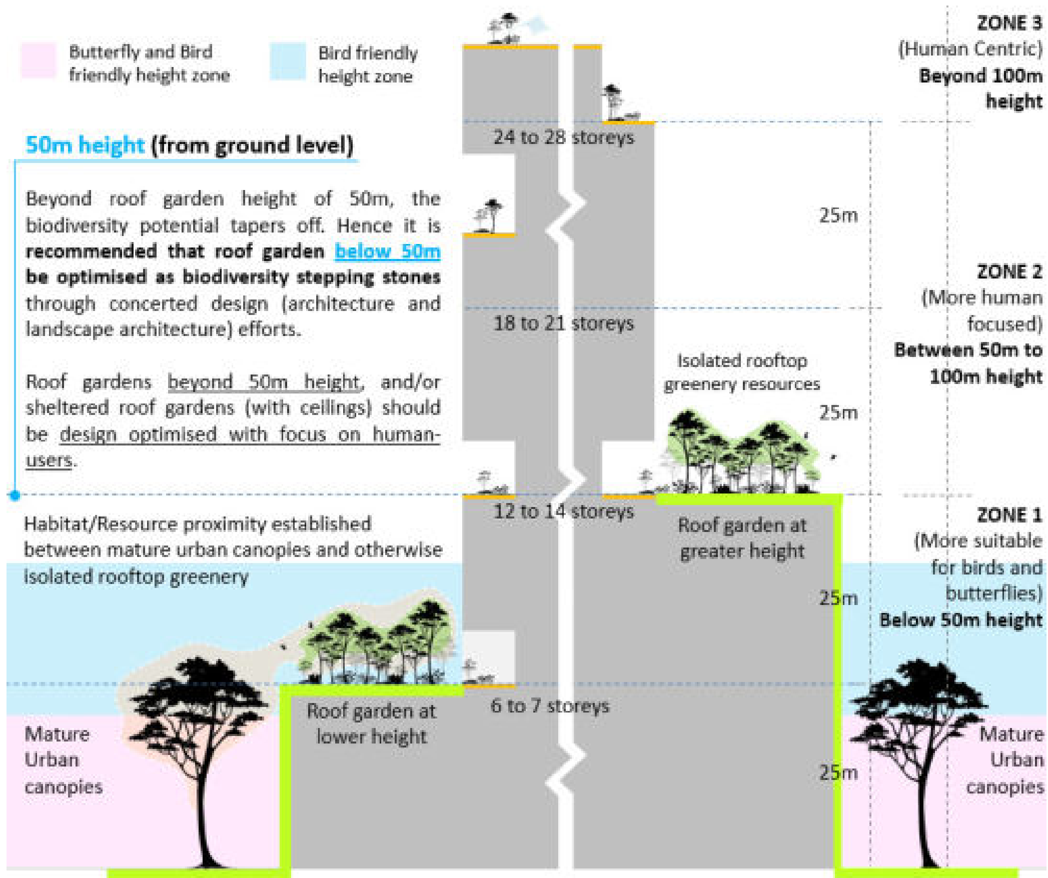
SECTION 4 DESIGN RECOMMENDATIONS

- The following Design-Suggestions for rooftop greenery are developed to facilitate communication and discussion across the various stakeholders (i.e. architects, landscape architects, designers, planners, developers, owners, users, etc.), in the planning and design of roof gardens, with the intention of creating roof garden spaces attractive to biodiversity (herein refers to birds and butterflies).

- The Design-Suggestions are in the following order for your reference:

Design-Suggestions		**Relevant To Design Principle**
4.1	Ecological potentials of roof gardens at various height zones	Height of Roof Gardens
4.2	Roof garden exposure types	Exposure of roof gardens
4.3	Height to depth ratio of non-exposed (sheltered) roof gardens	
4.4	Open perimeter percentage of non-exposed (sheltered) roof gardens	
4.5	Potential barrier types (visual & acoustic) on roof gardens	Human presence on roof gardens
4.6	Limiting human access into the protected zone (of a garden)	
4.7	Noise conditions (at urban planning level)	Noise level on roof gardens
4.8	Noise conditions (at architecture level)	
4.9	Noise conditions (at building-manager level)	
4.10	Water edge treatments for constructed water bodies	Water presence on roof gardens
4.11	Separation of biotic and abiotic water bodies	
4.12	Shape of biotic water body	
4.13	Recessed rooftop trees and palms	Complexity of vegetation on roof gardens
4.14	Network of vegetated refuges and passageways on a roof garden	
4.15	Naturalised extensive green roof	Judicious maintenance of roof gardens
4.16	Shrub/flower bed widths	
4.17	Bird-window strikes	-
4.18	Educational outreach	-

4.1 ECOLOGICAL POTENTIALS OF ROOF GARDENS AT VARIOUS HEIGHT ZONES



General observations on roof garden forms:

- In general, for tall buildings with multiple roof gardens at different levels, the higher roof gardens are often smaller compared to the lower ones.
- Roof gardens at altitude are also often designed as recessed niches (commonly termed as skyrise terraces; sky courts, in Singapore's context) cutting into building volumes, sheltered with ceiling. The ceiling reduces natural daylight significantly compared to an open roof garden site. This can affect plant growth.
- At altitude, wind conditions are often more extreme, with higher evapotranspiration loss, stressing plants out. With stronger winds, more energy is also needed for flight.
- These many factors often render the roof gardens at altitude less effective for planting and long term plant sustenance.
- Roof gardens at lower height tend to have larger planted areas with more greenery and open to the sky. However, the daylight received is also highly dependent on the surrounding urban masses and site orientation.
- Roof gardens below 50m height are more suitable for ecology-centric functions compared to roof gardens beyond 50m height.

Zone 1 (Roof Garden below 50m height)

- This height zone has higher potential to attract biodiversity (birds and butterflies).
- Roof gardens, and relevant vegetated surfaces (i.e. balconies, planters, green walls, etc.), in this height zone, should be design-optimised to facilitate as ecological stepping stones.
- Roof gardens **below 40m height** (from immediate ground level) are within the **bird friendly height zone**.
- Roof gardens **below 20m height** (from the ground level) are within the **bird and butterfly friendly height zone**.

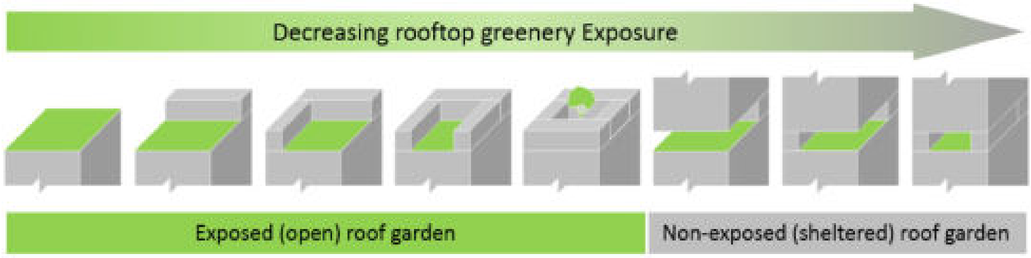
Zone 2 (Roof Garden between 50m to 100m height)

- This height zone still has potential to attract biodiversity. With increasing altitude, this potential tapers off.
- (In general) This height zone has more sheltered sky terraces, usually with smaller area, lesser planter spaces, and lower natural daylight.
- Sky terraces (denoted in orange in the illustration), should be design-optimised for human-centric functions.
- Nonetheless, any design efforts to attract biodiversity can still be attempted and <u>should not be discouraged</u>.

Zone 3 (Roof Garden beyond 100m height)

- This height zone has low potential to attract biodiversity. At this altitude, wind is strong, hence energetically challenging for birds and butterflies to reach.
- Roof gardens, in this height zone can focus on human-centric functions. Wind mitigation measures are necessary to hold rooftop greenery components in place against the higher wind loads.

4.2 ROOF GARDEN EXPOSURE TYPES



EXPOSED (OPEN) ROOF GARDENS	**NON-EXPOSED (SHELTERED) ROOF GARDEN**
• Exposed (open) roof gardens receive direct sunlight throughout the day, unless blocked by surrounding taller urban volumes. • Adequate sunlight allows photosynthesis, promising healthier long term plant growth and sustenance. • Full sun (with its full light spectrum) is needed to successfully trigger flowering and fruiting for many plant species. • Over time, these form the food resource/base to attract and support biodiversity.	• Non-exposed (sheltered) roof gardens receive low daylight level and penetration. • Many surfaces and corners are often in shade, and are not conducive for growth of flowering and fruiting plants. • Flowering and fruiting plant species, if any, should be planted alongside the edges where there is more sunlight. • Without flowers and nectar, pollinators such as butterflies, sunbirds and honey bees are not attracted.
RECOMMENDATION: • Exposed (open) roof gardens have good potential as viable ecological-stepping-stones.	**RECOMMENDATION:** • Non-exposed (sheltered) roof gardens have lower biodiversity potential. • Should be design-optimised with more focus on human usage and comfort.

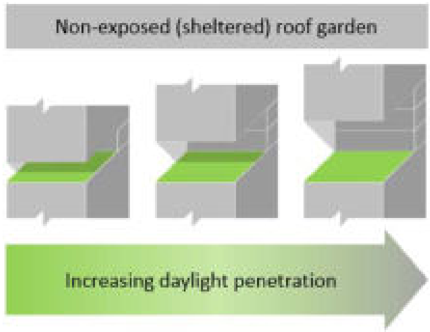
4.2.1 Roof garden site exposure affects butterflies greatly as they are heliotherms and derive heat almost exclusively from the sun (*Clench, 1966*).

4.2.2 The presence of a ceiling/roof over a roof garden therefore makes it unattractive to butterflies. From the study, the lack of exposure appears to deter most butterfly guilds.

4.2.3 It has been observed that exposed roof garden sites have significantly higher butterfly guild diversity than non-exposed roof garden sites.

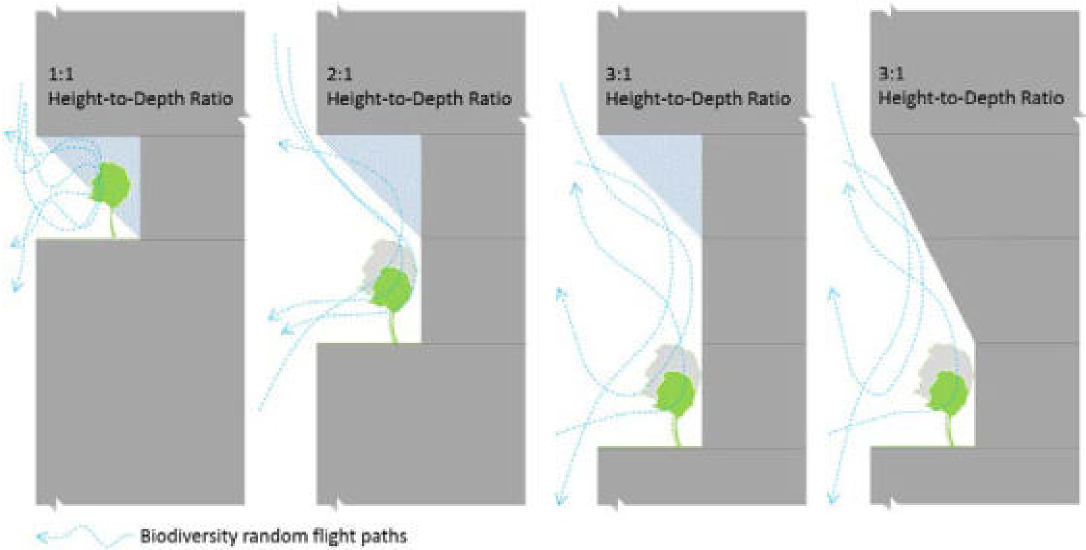
4.3 HEIGHT TO DEPTH RATIO OF NON-EXPOSED (SHELTERED) ROOF GARDENS

4.3.1 Increasing height-to-depth-ratio of sky terrace increases daylight penetration, to support photosynthesis and vegetative growth.



4.3.2 Depending on the building's orientation and surrounding urban massing, sky terraces often do not receive bright daylight throughout the day.

4.3.3 The sky terrace orientation and surrounding urban massing will have a huge influence on the mean light levels the sky terrace receives. For example, even if the sky terrace has a dramatically high height-to-depth-ratio, this may not improve the availability of direct light if the garden is on the wrong side of the building or blocked by a tall adjacent building.



The above two examples (on the right) with 3:1 Height-to-Depth-Ratio, with higher ceilings, receive more daylight for plant growth and possess more spatial visibility to biodiversity in flight.

4.3.4 Height-to-Depth-Ratio of sky terraces directly impacts:
- Vegetation's visibility to passing biodiversity in flight;
- The amount of solar irradiance the space receives for photosynthesis, flowering and fruiting;
- Escape-route opportunities for visiting biodiversity (birds and butterflies).

4.3.5 A vertically "spacious" (large height-to-depth ratio) sky terrace presents more escape-route-options when the need arises, such as when the birds and/or butterflies feel threatened by increase human presence/disturbance, etc. on the sky terraces.

4.3.6 Should the sky terrace be with the intention (1) to attract biodiversity and (2) is within the 100m height zone, it is recommended that the:
- **Ceiling height** be **no less than two residential storeys height** (approximately 5m to 6m), from the sky terrace finished level, **for daylight penetration**;

- Nectaring/seeding/fruiting **shrub species**, if any, **be planted within 3m** horizontal distance **from** the sky terrace **outer edge**, where light level is higher.

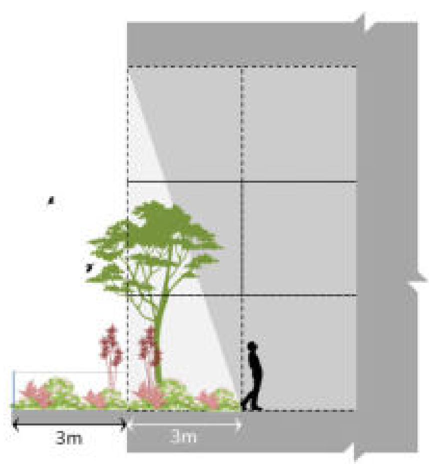
- Ideally, the vegetation should be planted closer to the outer edge, within the **3:1 Height-to-Depth-Ratio (light penetration)**, facing south, where light level is directionally more consistent throughout the day. Please see diagrams below.

- Sky terrace facing east receives only morning sun, while sky terrace facing west receives only afternoon sun. The duration of direct sunlight exposure is generally short for such orientations and may not be adequate to trigger blooms/fruits/seeds. Nonetheless, it is also useful to note that some shade tolerant plants do bloom in relatively shady conditions (such as *Costus* species). Suitable foliage plants can be used in such spaces for human-user-focused spatial intent.

The above illustrated are recommended greenery placements, within sky terraces of various Height-to-Depth-Ratios.

4.3.7 A sky terrace's **Height-to-Depth-Ratio** should be applied in synergy with its **Open-Perimeter-Percentage**, to effectively increase daylight penetration, to support vegetative growth.

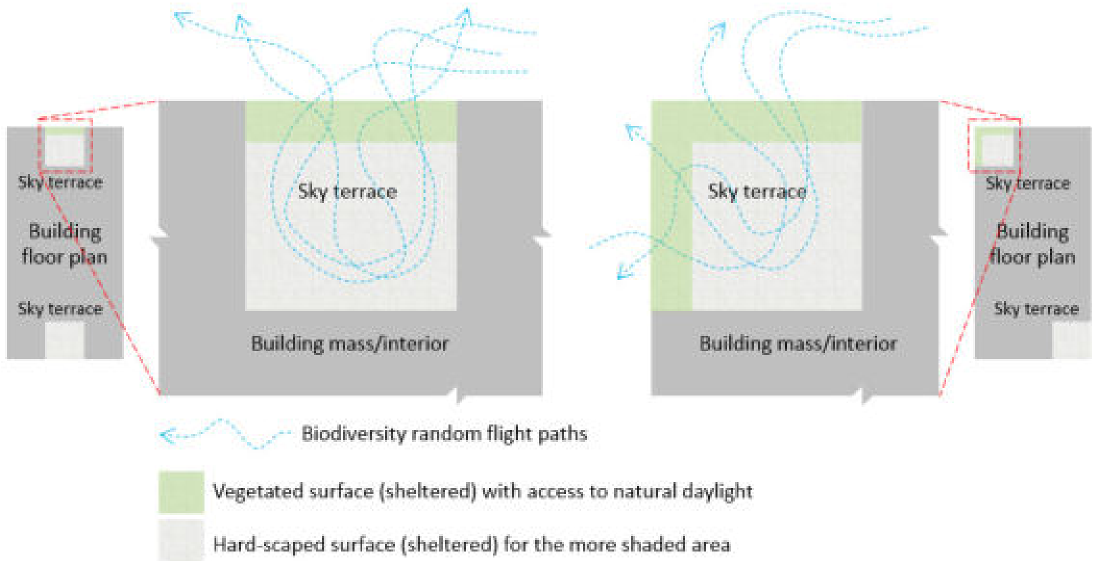
Sky terrace, being sheltered from daylight, is not able to support flowering/fruiting plant growth efficiently. To improve its efficiency in this aspect, outward expansion/cantilever of its floor surface area, will be able to improve its surface capture of daylight, and increase surface area for effective vegetation. When suitably sized and oriented, the space may even have adequate spatial set-back for a small tree (no more than 5m grown/maintained height). The illustrated example on the right demonstrates such a design possibility.



4.3.8 Please also refer to *CS E11:2014 – Guidelines on Design for Safety of Skyrise Greenery.*

4.4 OPEN PERIMETER PERCENTAGE OF NON-EXPOSED (SHELTERED) ROOF GARDENS

4.4.1 A sky terrace's open-perimeter-percentage, as the term implies, is the percentage of open perimeter edge to the total perimeter of the sky terrace. The higher this percentage, the more "open" the site's elevation is to receive daylight. Below are illustrated two examples.

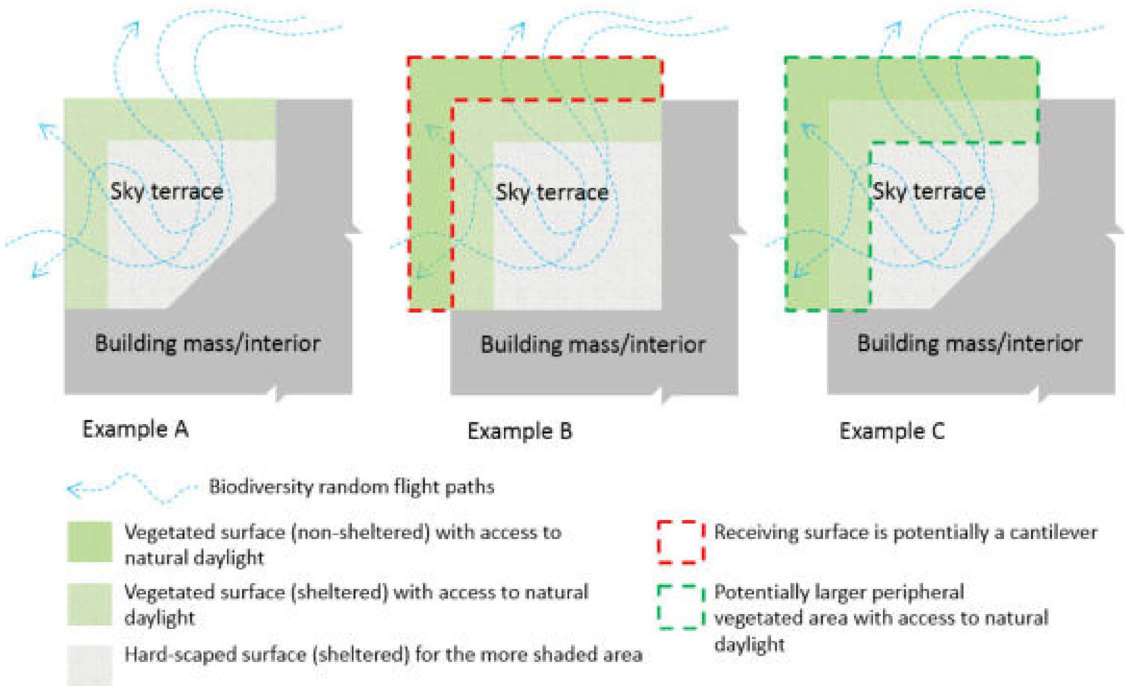


The above right plan-diagram is a sky terrace with parapet perimeter length 50% of the sky terrace total perimeter. Comparatively, the above left plan-diagram is only 25%. Both versions offer the same building foot print and sky terrace areas. Yet, through suitable placement of the sky terraces, the version on the right offers more openness in the sky terrace plan for biodiversity flight paths and daylight penetration for vegetative growth.

4.4.2 Depending on site location, site context, building forms and treatments, the version on the above right allows more outward view for human users, vegetation-visibility to passing birds and butterflies, air flow and deeper daylight penetration into the sky terrace, making it more conducive for vegetative growth hence improving its chances of attracting biodiversity.

4.4.3 It is recommended that the open perimeter length be no less than 50% of the total perimeter of the sky terrace, to promote:

- More air flow/wind movement/flight-paths through the sky terrace;
- Deeper daylight penetration to promote vegetative growth (This however depends greatly on the building's orientation and its surrounding urban massing);
- A more attractive outward view for the human users.



4.4.4 Where feasible, increase the sky terrace's open-perimeter-percentage beyond 50%. The above illustrated three examples have higher open-perimeter-percentage, with Example C scoring the highest open-perimeter-percentage, being a hybrid of Example A and B.

4.4.5 A sky terrace's **Open-Perimeter-Percentage** should be applied in synergy with its **Height-to-Depth Ratio**, to effectively increase daylight penetration, to support vegetative growth.

4.5 POTENTIAL BARRIER TYPES (VISUAL & ACOUSTIC) ON ROOF GARDENS

4.5.1 The objective of sound barriers on a roof garden is to have more control over potential on-site anthropogenic noise. The intention is to achieve a tranquil roof garden environment attractive to biodiversity, especially birds. (A noisy environment is energetically costly to a bird when it needs to sing/vocalise to attract potential mates.) Bird species, with more restricted vocal range will likely be most affected by urban noise (*Proppe, Sturdy & St Clair 2013*).

4.5.2 Existing urban noise (i.e. traffic noise from major roads, etc.) is challenging to avoid entirely. One approach is to face (or locate) the roof gardens away from major vehicular traffic zones. Building specialists/architects (together with acoustic engineers) may also consider co-developing suitable acoustic solutions that are design-integrated into the roof garden edges/parapets.

4.5.3 Below are the Sound Transmission Class (STC) rating of common party wall construction and the Outdoor Indoor Transmission Class (OITC) of common window construction.

4.5.4 Application example:

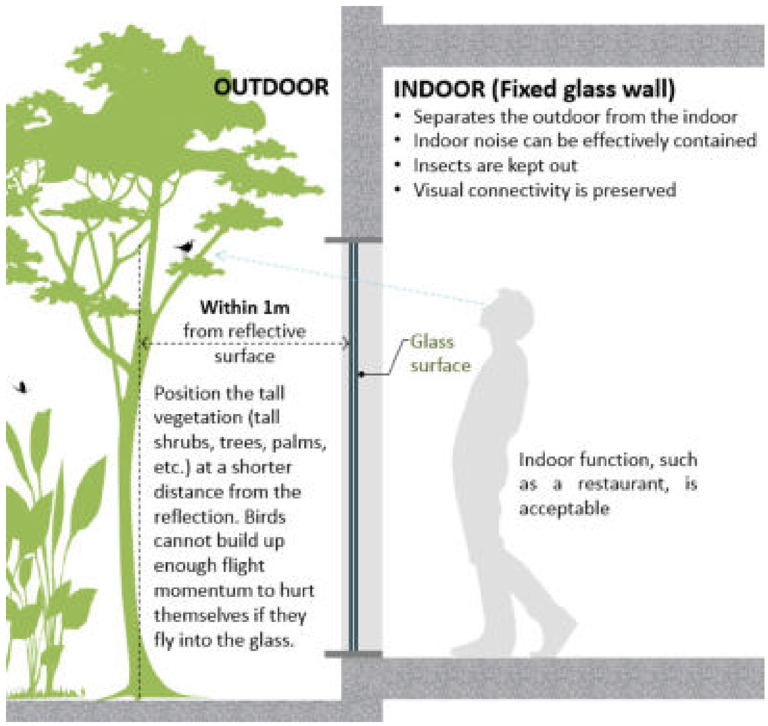
- Where the outside noise level is 75dBA and the building façade provides STC 35, the indoor noise level (at least near the façade in question), will be roughly 40dBA.
- Notice in the below tables that solid walls have STC ranging from 50 to 58 STC. Window systems have a lower OITC ranging from 10 to 33 OITC.
- In general, windows and/or glass doors form the weakest links in the noise insulation chain.

No.	Party Wall Types	STC[1]
1	Solid Concrete wall – 102 mm (4”) thick	53
2	Solid Concrete wall – 203 mm (8”) thick	58
3	Brick Wall 229 mm (9”) thick with 12 mm (1/2”) plaster finish both sides	52
4	Concrete block wall (dense aggregate) – 152 mm (6”) thick (painted)	50
5	Concrete block wall (dense aggregate) – 203 mm (8”) thick (painted)	54
1. Note that these STC results (Source; 1998 B.C. Building Code) were obtained from laboratory tests. In the field (actual residences) one can typically expect 3 to 5 points lower performance.		
Adapted from: http://vancouver.ca/files/cov/noise-control-manual.pdf		

Below are some OITC ratings of some common window types:

No.	Window Types / Conditions	OITC
1	Any window type, open slightly	10 to 15
2	Single-glazed (3 mm glass), openable window (no weather stripping)	17
3	Single-glazed (3 mm glass), openable window (good weather stripping)	19
4	Single-glazed (3 mm glass), fixed	21
5	Single-glazed (6 mm glass), fixed	23
6	Typical Openable Factory Double-glazed Units (3 mm glass–13 mm airspace–3 mm glass)	23-25
7	Double-glazed (3 mm glass–13 mm airspace–3 mm glass), fixed	24-26
8	Double-glazed (3 mm glass–25 mm airspace–3 mm glass), fixed	25-27
9	Double-glazed (3 mm glass–50 mm airspace–3 mm glass), fixed	27-29
10	Double-glazed (3 mm glass–100 mm airspace–3 mm glass), fixed	29-31
11	Double-glazed (6 mm glass–50 mm airspace–6 mm glass), fixed	29-31

12	Laminated Glass (6 mm), fixed	30
13	Laminated Glass (13 mm), fixed	33
14	Typical Factory Doubled-glazed Units with Storm Window added at 76 mm spacing	30 - 32
Sourced from: http://vancouver.ca/files/cov/noise-control-manual.pdf		



Acoustic:
Fixed double-glazed (and laminated) wall/window has higher acoustic insulating performance than fixed single-glazed types.

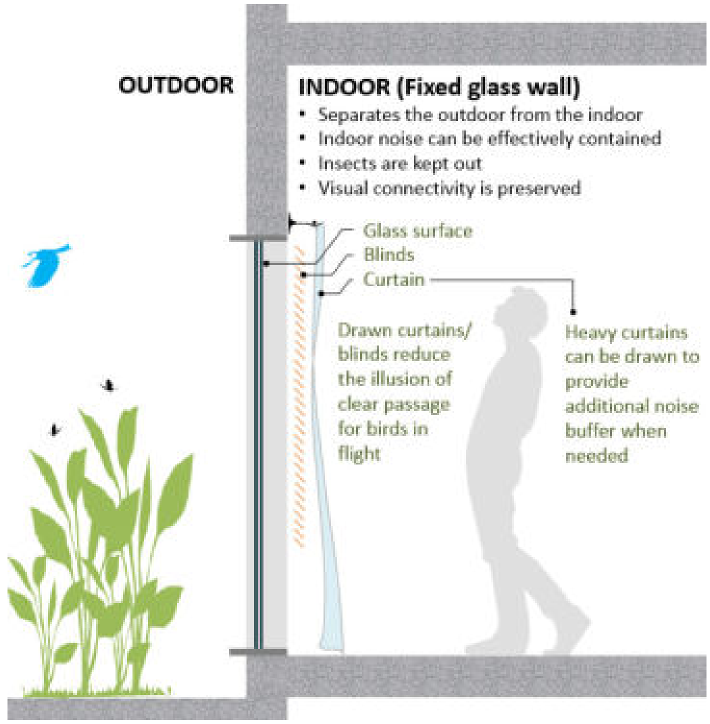
Visual:
Fixed glass wall permits view outwards into the roof garden.

Bird-Collision:
*Glass reflects the surrounding greenery. To reduce the risk of bird-window-collisions, glass walls (and any expansive transparent, reflective surface) should be suitably **surface-treated** to improve the perceived "surface-solidness" and to mute the reflections on these surfaces. Please refer to Section 4.17, Bird-Window Strikes.*

Acoustic:
When indoor functions are noisy, interior design treatments such as heavy curtains can be drawn close to provide additional noise insulation when needed.

Visual:
Interior design treatments, such as operable blinds and curtains, can manipulate the desired level of visual connectivity between the indoor and outdoor.

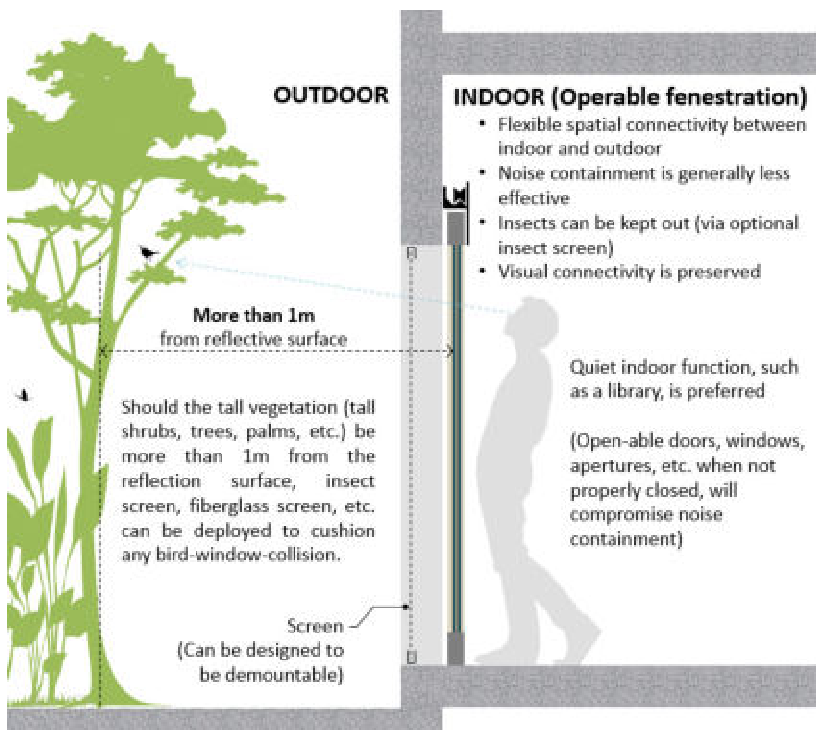
Bird-Window-Collision:
With the blinds and/or curtains drawn, the glass wall will appear less transparent to birds in flight from the outside.



Acoustic:
Open-able glass door/wall when open permits spatial connection with the roof garden, but fares poorly in acoustic insulation performance when not properly closed.

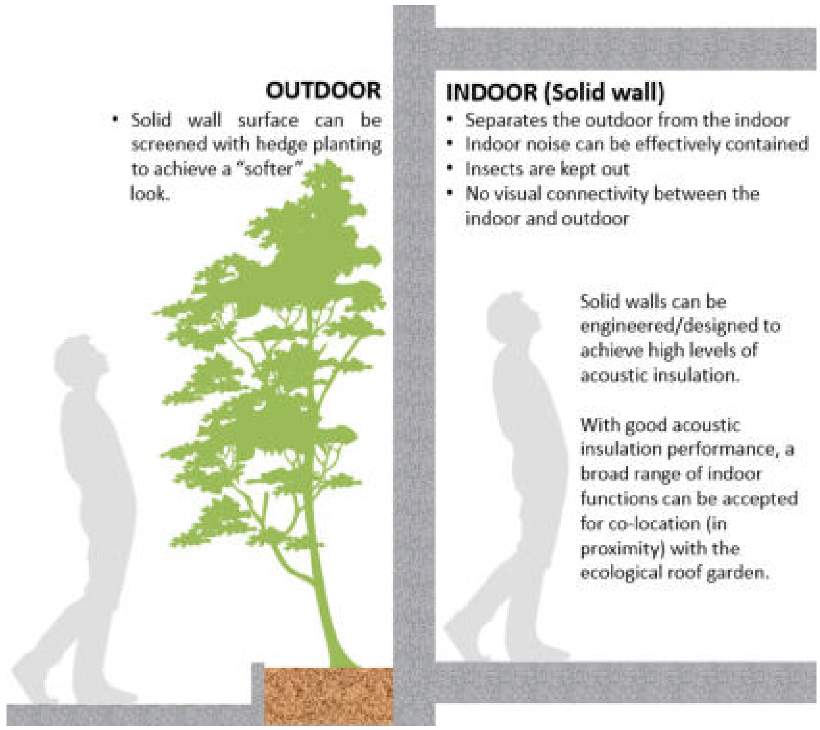
Visual:
Operable glass door/wall permits view outwards.

Bird-Window-Collision:
Exterior treatments, such as insect screen, fiberglass screen, etc. (spaced at least 50mm away from the glass surface), help cushion bird-collision, if any. The screens also reduce the perceived transparency of the glass from the outside.



Acoustic:
Solid concrete wall [ex: at 203mm (8”) thickness] has good acoustic insulating performance of about 58 STC.

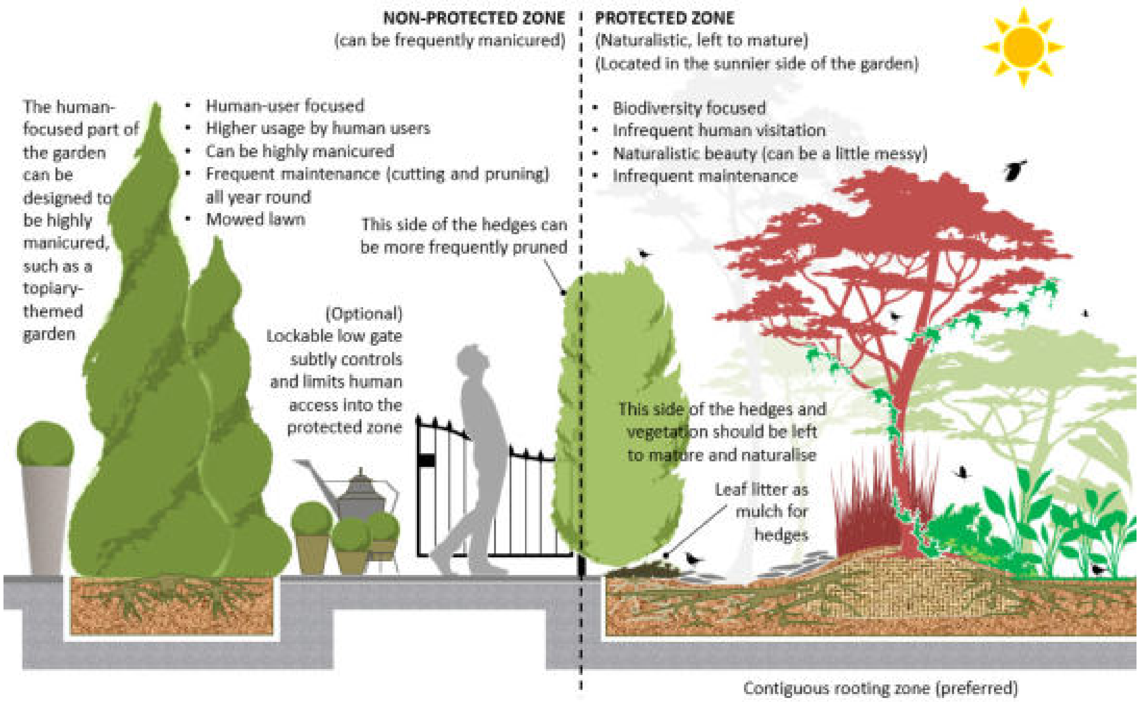
Visual:
There is no visual connection between the indoors and outdoors.



4.5.5 The following table is a non-exhaustive list of common scenarios/environments with the associated estimated noise levels for reference.

Decibel Scale (dBA)	Familiar noise sources in the home and community	Perception
0	Threshold of hearing	-
10	Whisper; Gentle breeze through the trees	Faint
20		
30	Quiet rural setting; A soft whisper at 1m; A quiet auditorium	Faint
40	Quiet living room; A quiet auditorium; Background music in a café, bar or restaurant	Faint
50	Suburban residential neighbourhood; Background music in a café, bar or restaurant	Moderate
60	Normal conversation at 1 to 2 m; Background music in a café, bar or restaurant; Typical conversation levels (from the listener’s position)	Moderate
70	Passenger car; Typical conversation levels (from the listener’s position); aircraft cabin during normal cruise conditions	Loud
80	Medium truck; Typical wedding or dinner-dance band (typical audience position)	Loud Noisy
90	Heavy truck; Loud orchestra (typical front row audience)	Very Loud
100	Jackhammer; Typical disco	Very Loud
110	Rock band (typical front row audience); Typical disco	Deafening
120	747 air bus on take off	Deafening
130	Threshold of pain (varies with frequency, and from person to person)	Deafening
140	Jet engine from 3 m; Artillery fire	Deafening
Adapted from: http://vancouver.ca/files/cov/noise-control-manual.pdf; www.djspacebar.com		

4.6 LIMITING HUMAN ACCESS INTO THE PROTECTED ZONE (OF A GARDEN)



4.6.1 A suitably located gateway (lockable) can visual-spatially exercise control and limit human disturbance to the protected zone.[2] The gateway/threshold can be creatively defined/designed in many different ways. Please also refer to Section 4.12, Shape of Biotic Water Body.

4.6.2 In the protected zone, a naturalistic landscape design approach can dominate, while in the non-protected zone, depending on the design intention, there are opportunities for the garden design theme to straddle between one that is highly manicured such as a topiary garden to that of a naturalistic theme (an extension of the protected zone) should the client/users be amenable towards engagement with biodiversity in their roof garden.

4.6.3 The protected zone should ideally be of contiguous rooting volume to foster a diverse rooting microbial environment that will be beneficial and attractive to invertebrates which in turn will become the food resource for many avian species.

4.6.4 Aesthetically, the protected zone should be allowed to naturalise and in essence become a little 'messy'. This zone is not programmed to be frequented by human users, except for periodic site inspection by the building/facility manager. Hence such 'messiness' should be intentionally tolerated. Please refer to Section 3.5, Judicious Maintenance.

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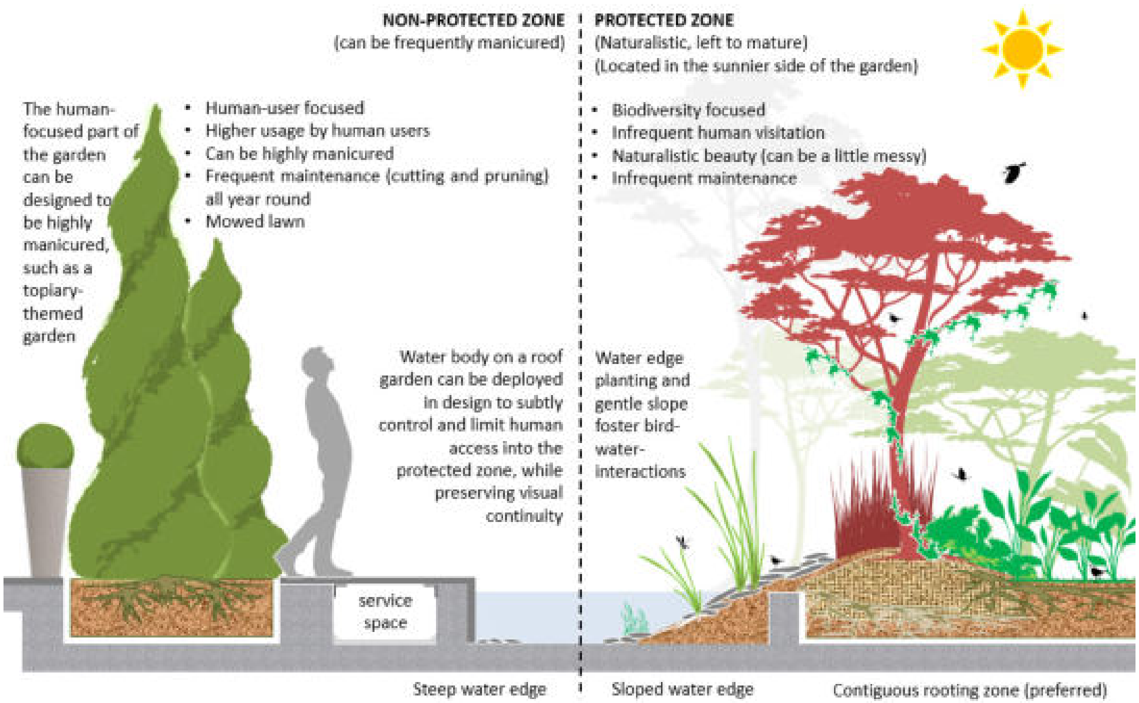
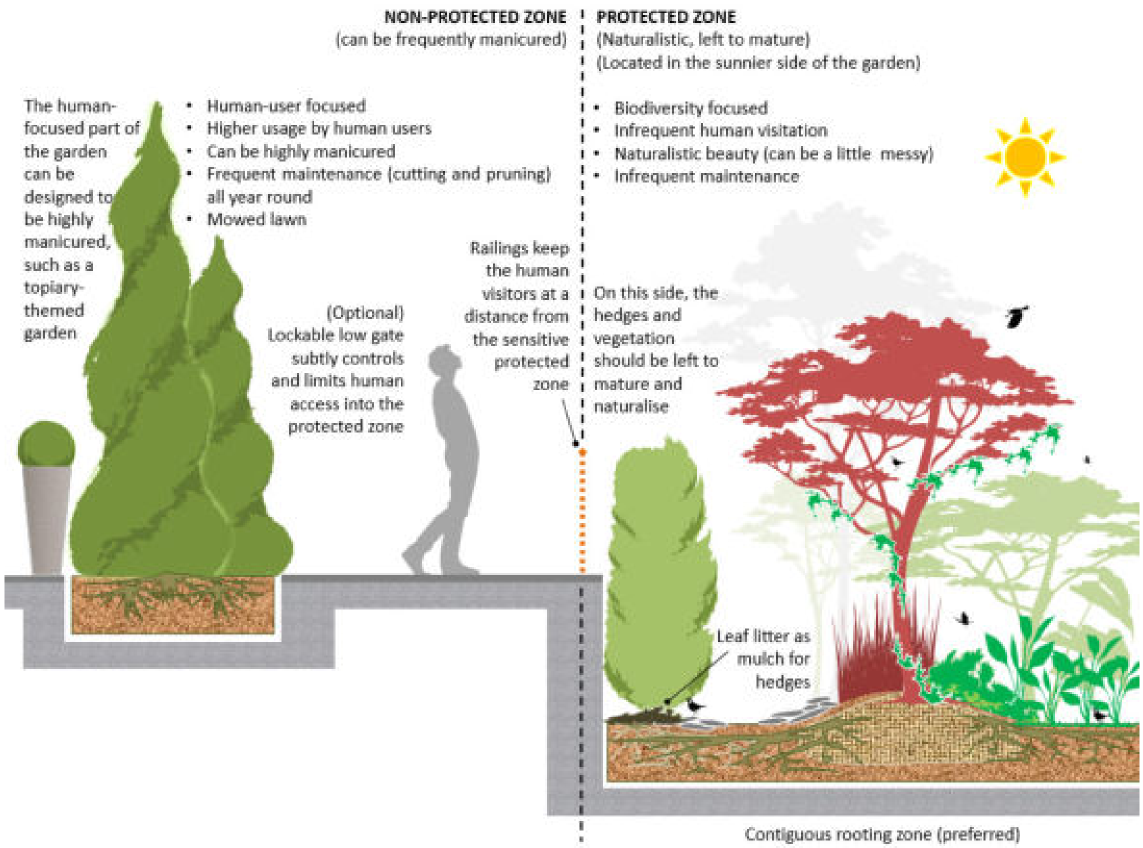
[2] *The proposed design option demarcating the protected and non-protected zones should be well-integrated within the overall landscaping scheme and should not adversely impact the overall spatial quality, accessibility and communal usability of the garden area.*

The above depicts the acceptable level of "messiness" of a roof garden. However many building managements are adverse to naturalistic landscapes. More educational outreach is necessary to promote/foster wider acceptance of naturalistic landscapes. The judicious maintenance of landscape requires skills with inspection and selective maintenance works.



Alternatively, isolate the protected zone with a continuous water body. The water edge of the protected zone should be sloped with suitable water edge planting to encourage bird-water-interactions. The water edge of the non-protected zone should be raised, with steep drop to the lower water level, to discourage bird-water-interactions. Please refer to Section 4.10, Water Edge Treatments for Constructed Water Bodies.



Alternatively, isolate the protected zone with railings to prevent all but the maintainers from entering. (One railing panel may be open-able/lockable by maintainers.) This can be enhanced by a change in level which allows view but not access into the protected zone.

Such design strategies can suitably limit human access into the protected zone, and may synergistically facilitate fire safety occupancy load calculations, by managing the number of human visitors on a given roof area whilst increasing greenery.

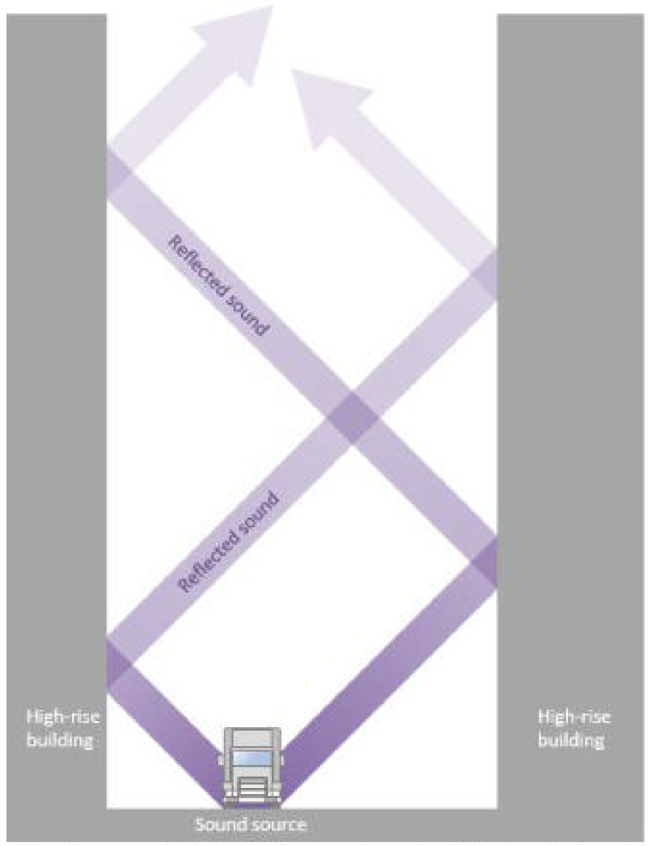
4.7 NOISE CONDITIONS (AT URBAN PLANNING LEVEL)

4.7.1 In the city centre, urban noise is largely of low-frequency (e.g. traffic) sound waves, mostly contributed by heavy continuous vehicular traffic. The noise level of an urban site is highly dependent on its site conditions and context.

4.7.2 From the study, recorded early morning (7am to 9am) noise level on a roof garden ranges from 48dB to 64dB. In late morning (10am to 12noon) recorded noise level ranges from 50dB to 66dB. While the mentioned ranges of noise levels may not be exhaustive, these nonetheless provide good estimates on the expected noise level on roof gardens in Singapore.

4.7.3 In the city core, the **"urban-canyon-effect"** is prevalent. The solid reflective façade surfaces of continuous stretches of tall buildings/structures, on both sides of major roads, "focus, confine and build-up" traffic noise and its reflections, channeling the noise energy upwards. The channeled traffic noise can be heard and measured on roof gardens.

4.7.4 The traditional planar planning of roads 'fragments/cuts-up' the ground plane, causing vehicular-pedestrian-conflicts for human-users, as well as vegetation fragmentation which is detrimental to existing ecology. Roads are major urban infrastructures in a city, which impact our urban environments tremendously in many ways.

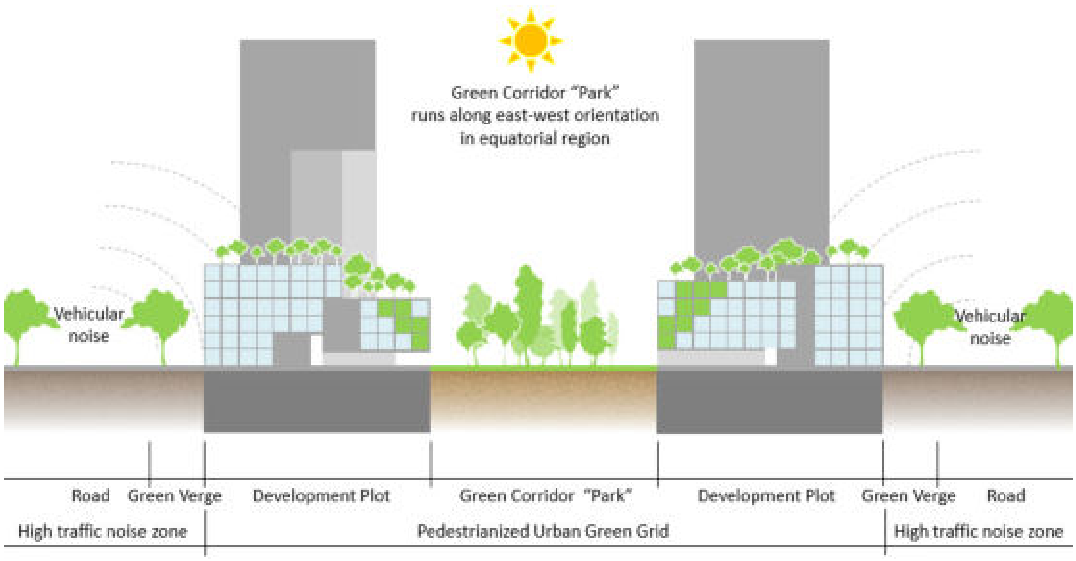


Urban Canyon Effect – Sound reflection between high-rise buildings

4.7.5 A city's urban noise-scape is a complex environment. Just as this is attributed by multiple human factors, mitigating this issue will also require a multi-factorial and multi-disciplinary approach towards city planning, architecture design and engineering.

4.7.6 Proposed Vegetated Pedestrianised Boulevard (an Ecological-Corridor) – New Green Grid over Existing Grey Grid

Recent urban planning strategies and trends towards a **pedestrianised-city** (i.e. car-lite, "walkable" public spaces, etc.), is in the same vein as the drive towards **pervasive-urban-greenery**, with synergistic environmental possibilities benefitting both human-users and the ecological network.



Vegetated Pedestrianised Boulevard
This should be design-integrated with contiguous/connective urban greenery spaces/systems, serving both pedestrian movement and the ecological-network, connecting otherwise fragmented green patches, facilitating biodiversity movement through the city.

East-West Orientation of these "Vegetated-Urban-Canyons"
During urban planning phase, such major vegetated-pedestrianised-boulevard should ideally be aligned length-wise in east-west orientation in order to receive ample sunlight penetration throughout the year into these "urban-canyons", to support vegetation growth. There is the possibility that building masses alongside major roads can be sensibly designed and planned to block, channel and/or dampen urban surface-traffic-noise.

Roof gardens can be designed and planned to turn its back against the major roads with its front oriented towards these "Vegetated-Urban-Canyons", where surface roads and vehicular traffic are prohibited.

4.8 NOISE CONDITIONS (AT ARCHITECTURE LEVEL)

4.8.1 During the design and planning phase, where feasible, conduct predictive sound simulation of the development design. Where possible, locate the roof gardens in the quieter locations of the development site.

4.8.2 In consultation with acoustic engineers, there are architecture design opportunities for managing urban noise. Architects may explore the following three aspects:

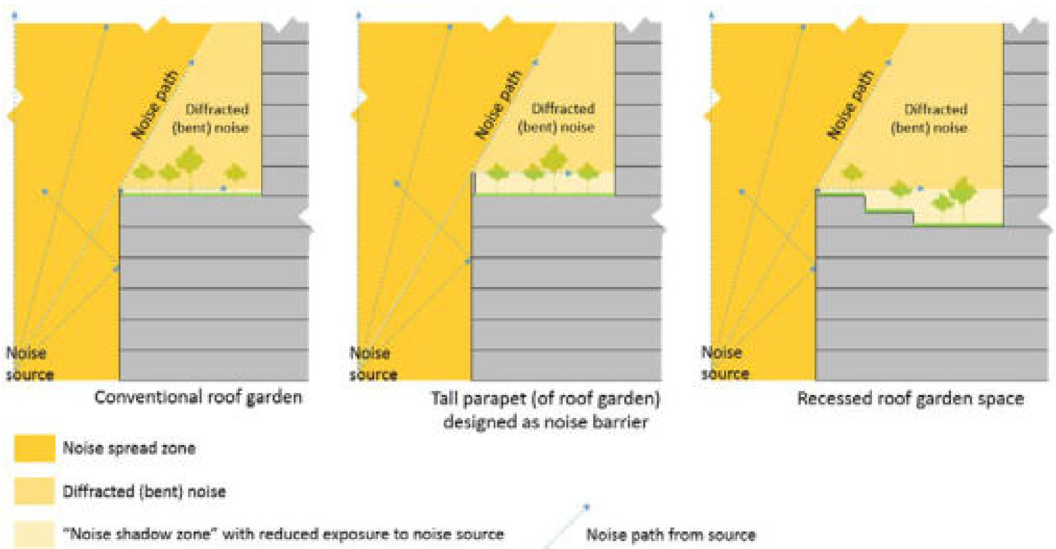
<u>Design of parapet</u> <u>(A Design and Material strategy)</u>

- Together with acoustic consultants, explore parapet design attributes such as (1) sizing, (2) height, (3) surface continuity, (4) surface-inclination, (5) material mass, etc. and/or a combination of these.

- Please refer to Section 4.5, Potential Barrier Types (visual & acoustical) on roof gardens.

<u>Roof garden level change</u> <u>(A spatial strategy)</u>

Architects may explore recessing roof garden level to **steer clear of the noise path**.



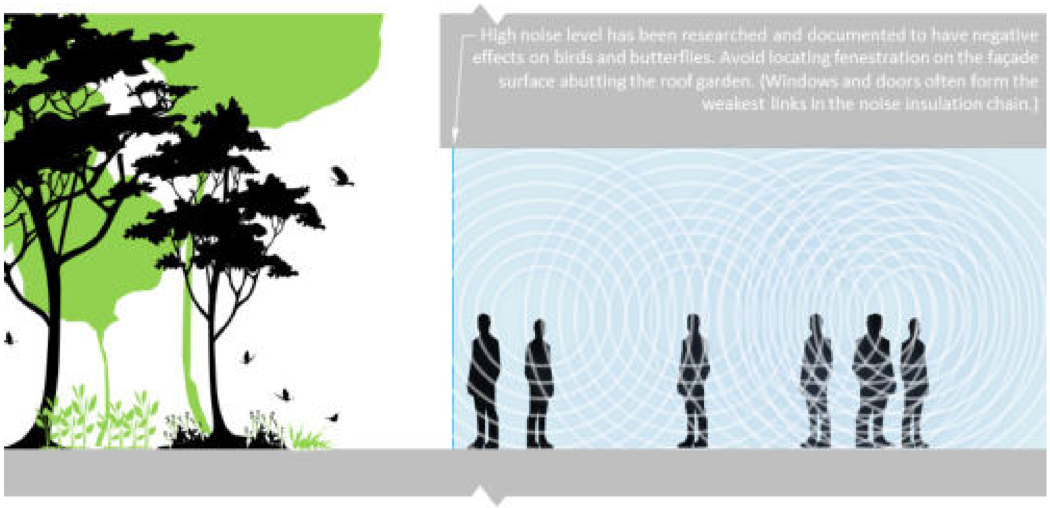
The above examples demonstrate the design possibilities of utilizing parapet sizing/design and change of roof garden level to create zones of reduced noise exposure. A combination of strategies can be explored.

<u>Avoid collocating noisy functions on (or near to) biodiversity roof gardens</u> <u>(A planning strategy)</u>

- Noisy spaces (such as Food & Beverage outlets and the likes) exhibit high human-presence and high noise disturbances, which discourage biodiversity visitation.
- Wherever such collocation exist, suitable acoustic planning and compartmentalization via architecture (and/or interior design) will be necessary to manage and reduce potential anthropogenic noise disturbances, spilling into the garden space.

4.8.3 On ecological roof gardens, collocated human spaces (i.e. library, gym, meeting rooms, F&B outlets, etc.) should be compartmentalized/isolated as indoor spaces. This avoids spillage of anthropogenic noise into the sensitive roof garden spaces. Designers should pay due attention to the design, detailing, placement and orientation of openings (doors and windows), as these apertures/fenestrations are the weakest links in the noise insulation chain. Spatial functions can be ranked and organized by the designers to steer noisier functions away from the sensitive roof garden. Quieter indoor functions can be oriented towards the garden to optimize its view.

4.8.4 Please refer to Section 4.5, Potential Barrier Types (visual & acoustic) on roof gardens.



The above illustration depicts glass walls as potential acoustic and spatial partition while permitting visual-connectivity between indoor and outdoor spaces. Subject to wall system design and detailing, with minimal fenestrations (openings, vents and the likes), noise containment/isolation can be effective.

4.8.5 Glass surfaces abound in the dense built-up urban environment. The resultant surface transparency and reflections can be visual-spatially confusing to birds. Bird-window collisions are very common in the urban environment and is in fact one of the primary causes of bird fatality globally.

4.8.6 Please refer to Section 4.17, Bird-window strikes.

4.9 NOISE CONDITIONS (AT BUILDING-MANAGER LEVEL)

4.9.1 Anthropogenic noise within roof gardens can be further controlled by the building-manager through:

Educational Approach (using well-designed information signage)

- Educate building users on the unique design features and ecological-functions on the roof garden, etc.
- In more sensitive garden locations, have suitably designed informative signage highlighting to visitors to keep noise volume down.

An example of a signage along a footpath, elaborating on the wildlife in the garden.

Spatial Approach (using controlled access to certain spaces)

- By way of zonation (for example, using a lockable entry way, a water body as a spatial barrier, etc.) building-manager can exercise control over human visitation to the 'sensitive' locations on the roof garden, such as the "caterpillar-nursery", "butterfly-garden", etc.
- Please refer to Section 4.6, Limiting Human Access into the Protected Area (of a garden).
- Please refer to Section 4.12, Shape of Biotic Water Body.

On the right, a low garden gate subtly demarcates the butterfly garden from the rest of the garden landscape, without impeding views.

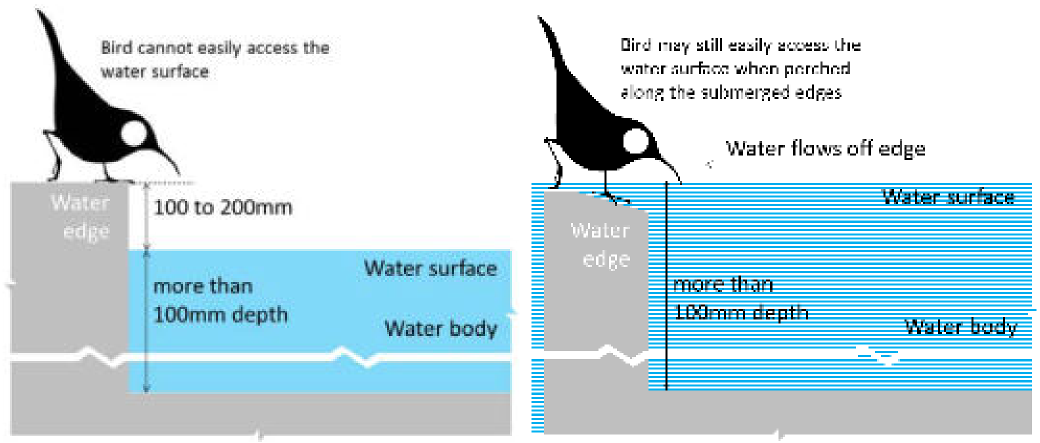
4.10 WATER EDGE TREATMENTS FOR CONSTRUCTED WATER BODIES

4.10.1 Water bodies on roof gardens can be purposefully designed to serve as nodes of water resource to attract/enhance biodiversity (birds, butterflies, frogs, dragonflies, fishes, etc.). Such water bodies can be part of the constructed ecological systems on a roof garden.

4.10.2 Constructed water bodies on a roof garden are broadly categorised as:

- **Abiotic** constructed water bodies (ex: chlorinated swimming pools, kids' chlorinated wading pool, fountains, etc.)
- **Biotic** constructed water bodies (ex: non-chlorinated water bodies with fishes, aquatic plants and aquatic invertebrates.)

4.10.3 Abiotic constructed water bodies are designed solely for human use. For these, the assurance of hygiene is of great concern. Water edge can be designed and dimensioned to discourage biodiversity (bird species) participation. The below suggestions are independent of water body shapes.



Raised water edge, with a steep drop

- Raised water edge, with steep drop (of no less than 100mm) to the lower water level, discourages birds from perching and drinking along the water. The birds cannot easily reach the water surface to drink.

- The water depth alongside this steep edge should be more than 100mm deep, to avoid the birds standing in the water.

Infinity pool water edge

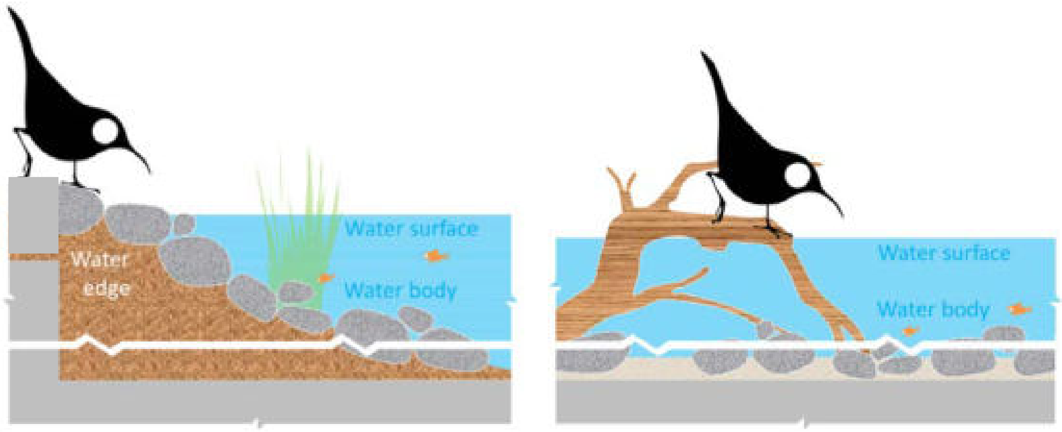
- Along infinity pool, water flows over the edges. In general, a wider flatter version of such pool edge offers more perching opportunities for birds, compared to a narrower steeper one.

- Smaller sized birds may be deterred by the constant flow of water over the edge. Larger sized birds however may not be deterred especially during hot dry days.

- The water depth alongside this steep edge should be more than 100mm deep, to avoid the birds standing in the water.

- An experienced landscape architect's design opinion is needed.

4.10.4 For biotic constructed water bodies (i.e. naturalised ponds, etc.), water edge can be designed and dimensioned to encourage biodiversity (bird species) participation. The below suggestions are independent of water body shapes.



Gently sloped water edge

- Birds in general do not drink in large quantity, and most acquire their daily water through food (i.e. nectar, fruits, berries and insects). They do however seek out clean water to drink and to dampen their feathers while preening.

- Gently sloped water edge, a mimicry of a stream's littoral zone, creates a variety of spatial niches and rough surfaces that the birds and butterflies can choose as approaches to the water. This encourages the birds and butterflies to explore, drink and linger along the water edge.

- Birds will access the shallow waters, at depths ranging from 25mm to maximum 100mm. Depending on design and intent, these shallow areas can be suitably sized and shaped.

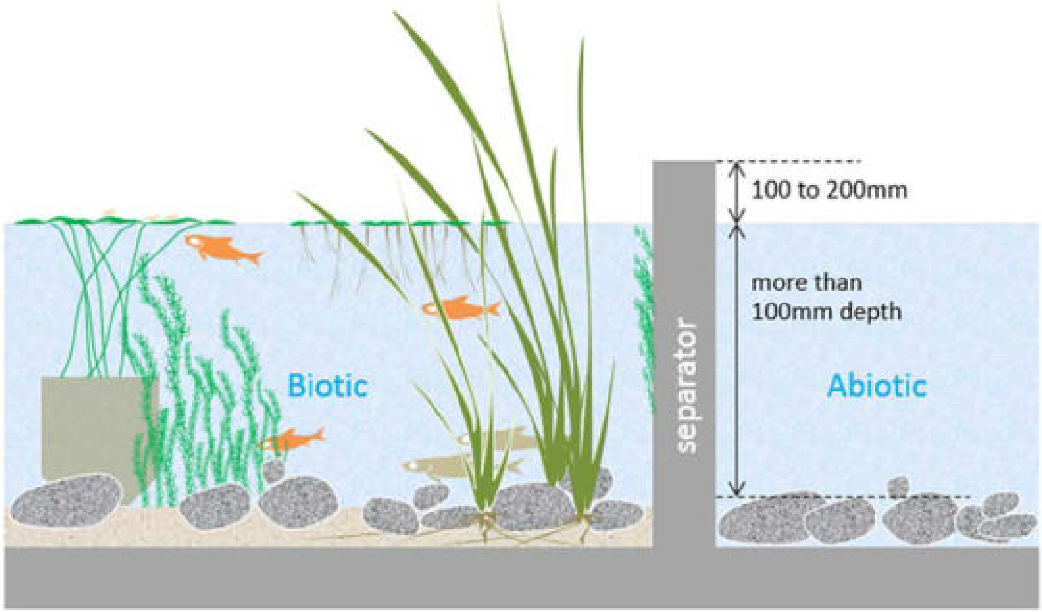
- In general, such area is often on the lower finished level of the landscape and should not be overly planted, to avoid impeding the birds' surveillance of their immediate surroundings when bathing. This is so that any approaching predator can be spotted by the birds. A location perceived to be safer will likely be more attractive to the birds.

Perching surfaces touching/emerging from water surface

- Perching surfaces emerging from water (such as a dead low branch positioned in a pond) can be easily introduced to an existing water body. This provides surfaces for visiting birds to grip onto when reaching for the water.

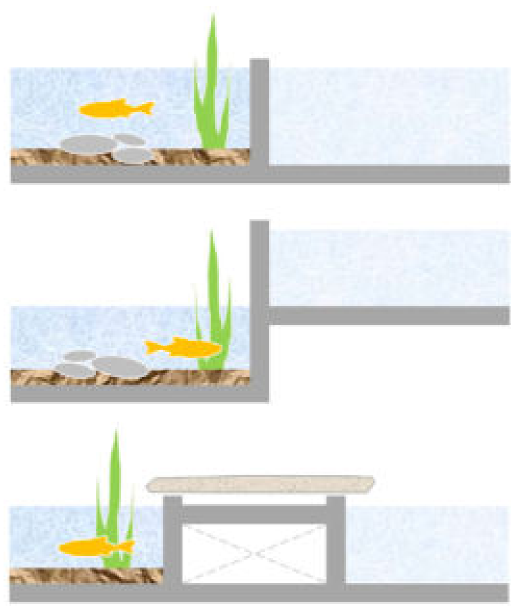
- Aesthetically, this adds a naturalistic look to the water feature.

4.11 SEPARATION OF BIOTIC AND ABIOTIC WATER BODIES



- Biotic water bodies are aquatic environments that allow organisms (micro-organisms, plants, fishes, aquatic invertebrates, etc.) to inhabit. On roof gardens, these are man-made and intentionally non-chlorinated. The water is not for human consumption.

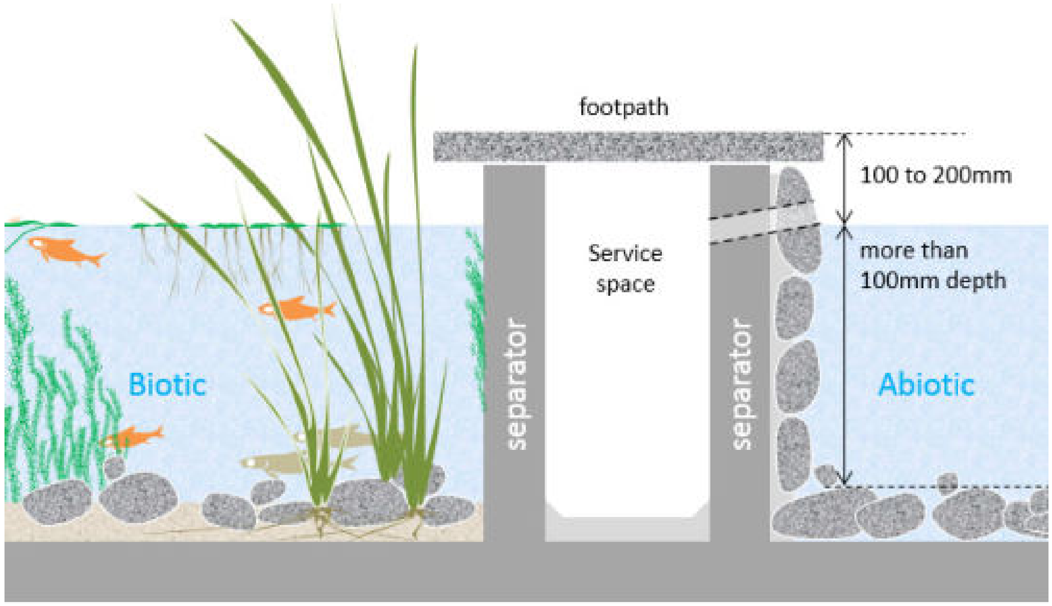
- Abiotic water bodies are chlorinated for hygiene and to stave off micro-organisms. A chlorinated swimming pool is a good example. Chlorine effectively kills/inactivates a large variety of simple microbial waterborne pathogens. While the chlorine concentrations in swimming pool are probably too low to cause gastrointestinal injury when ingested, the water is not for human consumption.



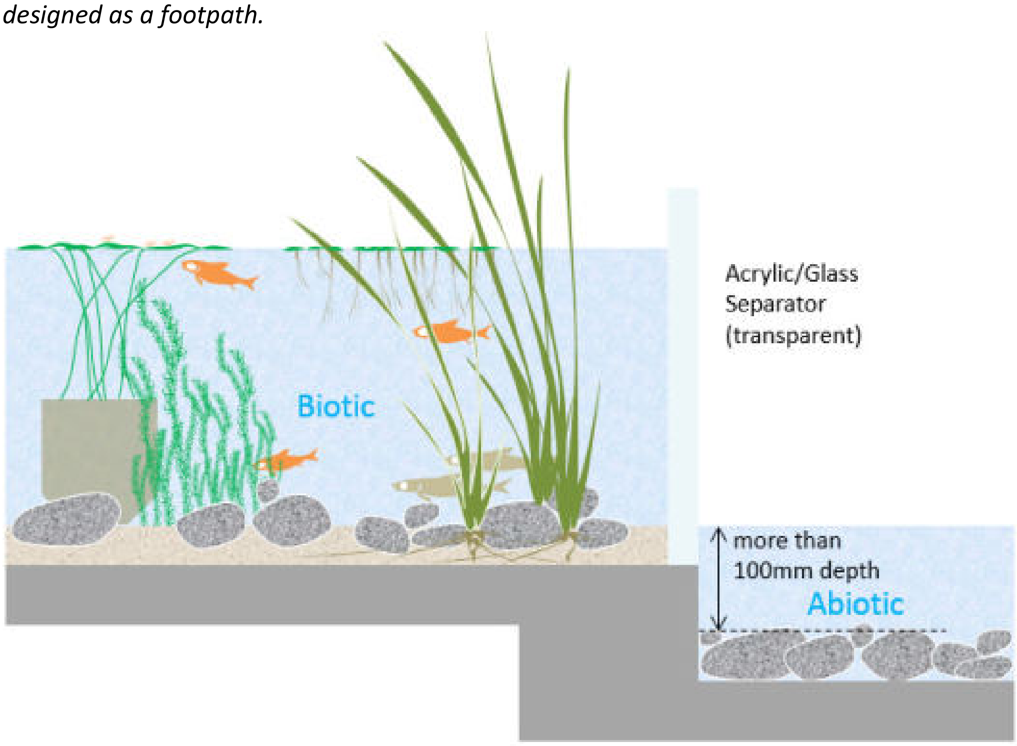
- Biotic and abiotic water bodies, can be positioned side by side, but must not mix. Deliberate separation can be achieved through a low wall no less than the water depth(s). This separator can be designed to create differences in water levels between the two water types.

- The substrate, if any, in biotic water body (ex: pond) need not pervade the full area. Potted aquatic plants can be conveniently submerged and strategically located for easy maintenance.

- Large biotic water body can take the form of a rooftop water garden complete with an array of aquatic and terrestrial plant communities. The smallest ones can take the form of an adequately deep pot of water supporting a single species of aquatic plant with small fishes to keep the mosquitoes in check.



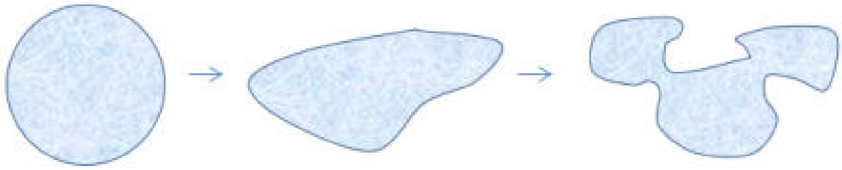
Illustrated above, the biotic and abiotic water bodies can be of similar water level such that users perceive the two water bodies as connected and of the same water source, when in actuality the two different water types/volumes are separated by a service space – in the above case, a service drain for over-flow from the abiotic water body only, with the drain cover designed as a footpath.



Illustrated above, the separator can be made of strong materials, such as concrete, glass, acrylic, fiber-glass (of suitable engineered dimensions and material quality). The biotic and abiotic water bodies can be of dissimilar water levels. A transparent separator, where designed, allows an interesting sectional view into the biotic water body, teeming with aquatic organisms and their activities. This can be entertaining and educational to both children and adults alike. Regular correct cleaning of the acrylic/glass by skilled staff/contractor is needed to manage algae growth on these surfaces and avoid scratching of surface.

4.12 SHAPE OF BIOTIC WATER BODY

4.12.1 A biotic water body, with gentle littoral zones, should ideally have longer perimeter (achievable by convoluting the water edge) to create more water edge conditions. Different materials, such as various grades of sand, gravels, pebbles, water plant species, etc. can be used to create different water edge habitats. When naturalised over time, such interfaces can support flora and fauna communities and contribute to biodiversity enhancement.

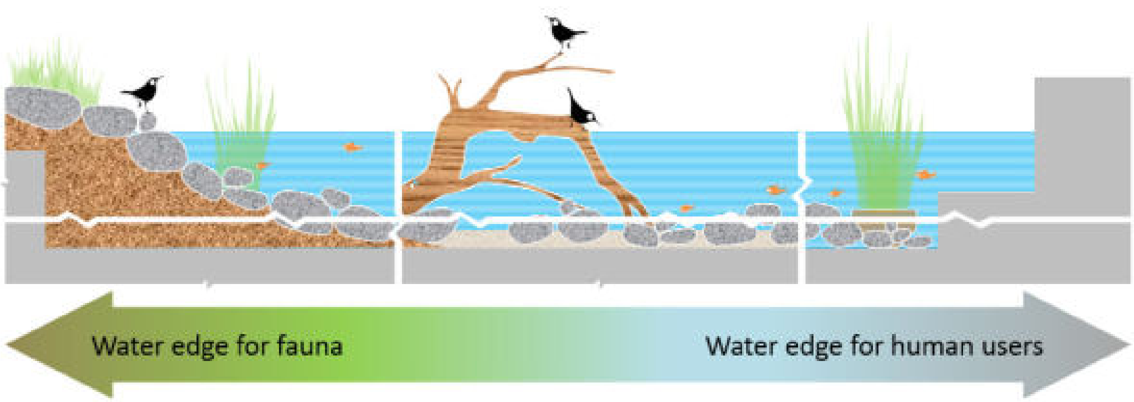


4.12.2 An increased water perimeter creates more surfaces for both humans and faunas to interact with the water.

4.12.3 Where birds are to be discouraged, water edges can be raised with steep drop to the water surface. Please refer to Section 4.10.

4.12.4 Where birds are to be encouraged to approach the water, have gently sloped water edges. Please refer to Section 4.10.

4.12.5 The following is a design suggestion of a biotic water body on a roof garden. The left naturalised, gently sloped water edge caters to attract bird-water interactions. The right water edge (with a steep drop) makes it difficult for birds to reach the water, hence catering more to human-users.



4.12.6 The above design suggestion can be used as a form of zonation (a form of spatial control) to subtly separate the more “biodiversity focused” part of the garden from the more “human focused” areas. Please refer to Section 4.6, Limiting Human Access into the Protected Zone (of a garden).

4.13 RECESSED ROOFTOP TREES AND PALMS

- Compared to tree saplings, a pre-grown tree with established crown has more–structural complexity. When applied on a roof garden, this creates instant micro-environments and resources (i.e. food, shelter, nesting materials, etc.) to biodiversity. This potentially heightens the roof garden's attractiveness to biodiversity.

- Mature tree/palm canopies can also be achieved over time, should the rooftop tree/palm saplings be (1) in good health and be (2) allowed to mature. Such efforts will require a number of years (3 to 10 years or more) for the saplings to mature.

- Mature trees can be tall (more than 5m height) in a roof garden context. Tall vegetation with large canopies are susceptible to wind gusts and risk being de-stabilised. This is a genuine rooftop safety concern, especially when such tall plants are near rooftop edges. Should a rooftop tree/palm snap in parts or in whole, the falling bio-debris can jeopardise public safety. Building owner, developer and/or designer can be liable for such negligence.

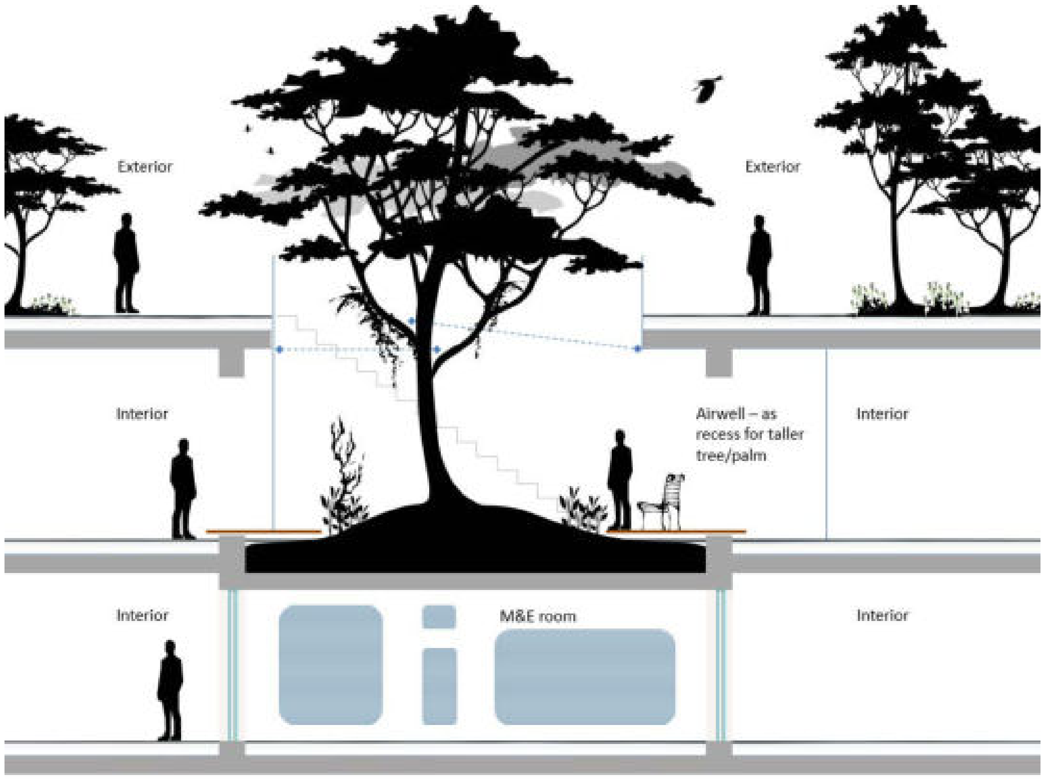
- Design decisions (i.e. the placement of tall plants, their grown/maintained height limits, root-ball anchorages, permanent-staking, etc.) will need to address expected wind gust, wind loads and all foreseeable design loads and design risks.

- Please refer to *CS E11:2014 – Guidelines on Design for Safety of Skyrise Greenery* and *CS E09:2012 – Guidelines on Planting of trees, palms and tall shrubs on rooftop*.

- On a roof garden context, a tall tree canopy (more than 5m in grown/maintained height) cannot be easily reached for periodic judicious maintenance/pruning, unless suitable Mobile Elevated Work Platform (MEWP) is deployed under suitable conditions and supervision.

- In design, such tall plants can be suitably located to accommodate the expected crown growth, associated crown maintenance in the future, equipment and equipment access.

- Mature canopies provide resources attractive to biodiversity. The following is a design suggestion accommodative to a maturing and spreading rooftop tree crown, while providing the spatial proximity should the need for crown pruning arise in future.



- Rooftop planter holding tree/palm specimen more than 5m in grown/maintained height, can be designed to recess one floor lower. Such spatial strategy provides the much needed space for canopy growth and spread.

- Staking, via permanent anchor points, to the building structures is feasible, to lend further stability to the rooftop tree/palm. This should be planned and designed for, in collaboration with engineers, during design phase.

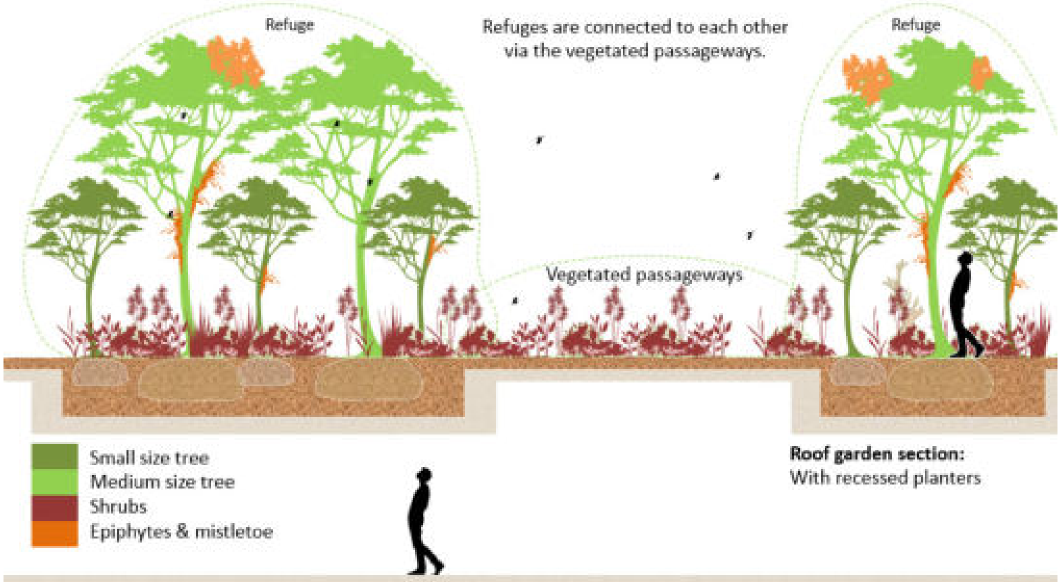
- Maintenance access to the tree/palm canopy is also possible from the rooftop level, where the canopy emerges. When suitably planned and dimensioned, such access may be possible without the need for vertical access equipment.

- In general, under such design strategy, the rooftop tree/palm should be maintained to be no taller than 8m in grown/maintained height.

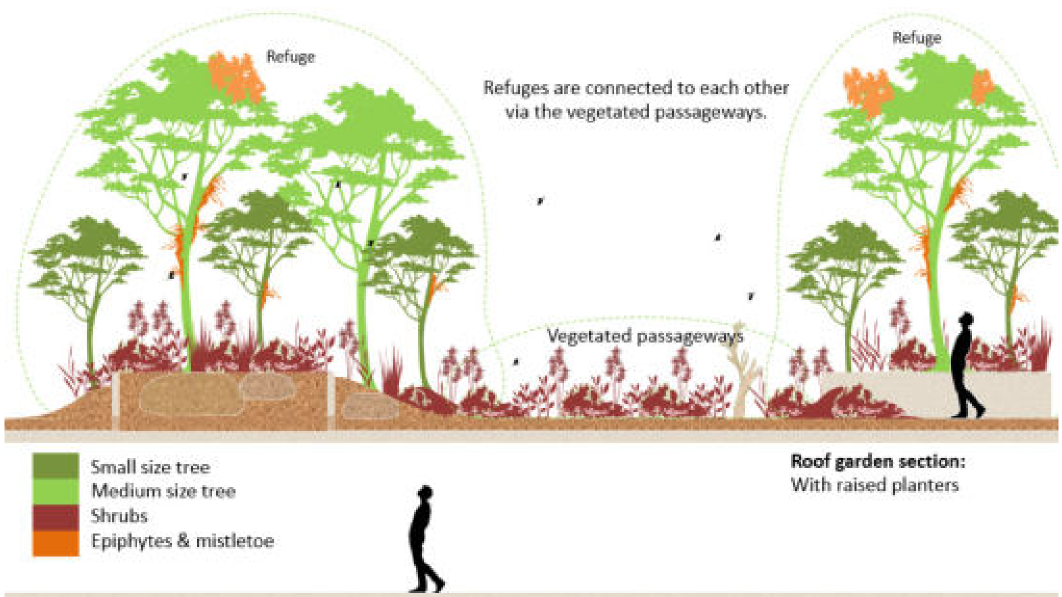
- Larger rooftop tree/palm will need strong healthy roots. For the soil volume sizing and quality, please refer to *CS E9:2012 – Guidelines on planting trees, palms and tall shrubs on rooftop*.

- The associated design loads of such design strategy will need to be suitably transferred through the building structures to the foundations. For design load calculations of rooftop tree/palm assembly, please refer to *CS E9:2012 – Guidelines on planting trees, palms and tall shrubs on rooftop* and *CS E10:2014 – Guidelines on design loads for skyrise greenery*.

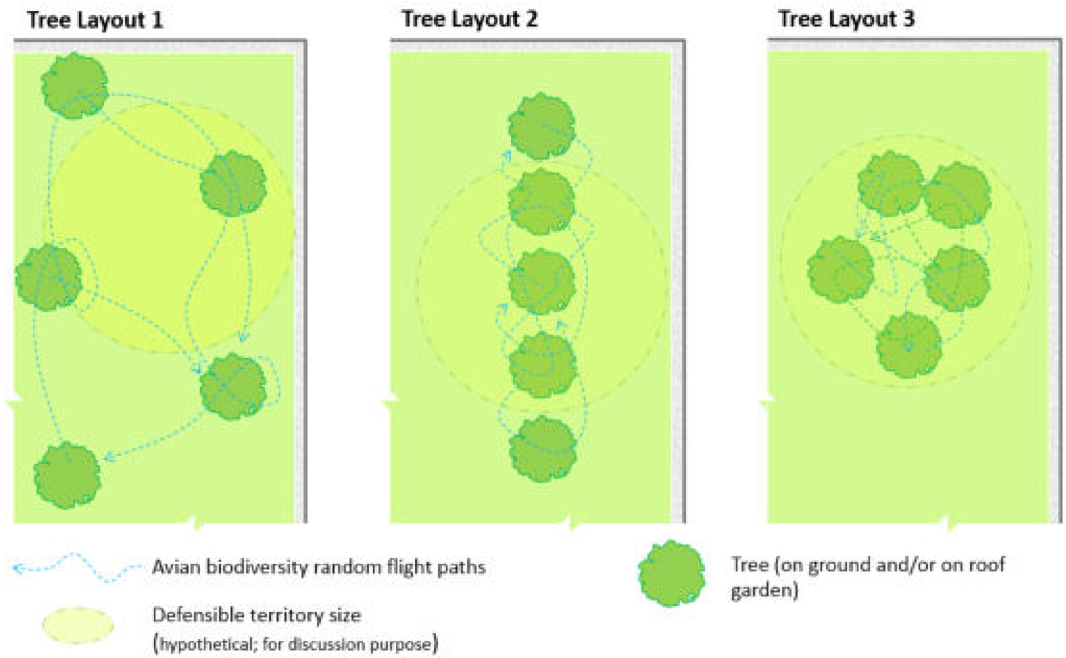
4.14 NETWORK OF VEGETATED REFUGES & PASSAGEWAYS ON A ROOF GARDEN



In the above example, the roof garden achieved vegetation structural complexity, via tree clusters (in recessed planters), that serve as refuge for birds and wildlife, and connective vegetated passageways, that facilitate wildlife movement between refuges. Many birds have an upper limit to the size of defend-able territory. Clustering the trees/vegetation of diverse species together creates spatially compact resource nodes/niches attractive to birds and wildlife.



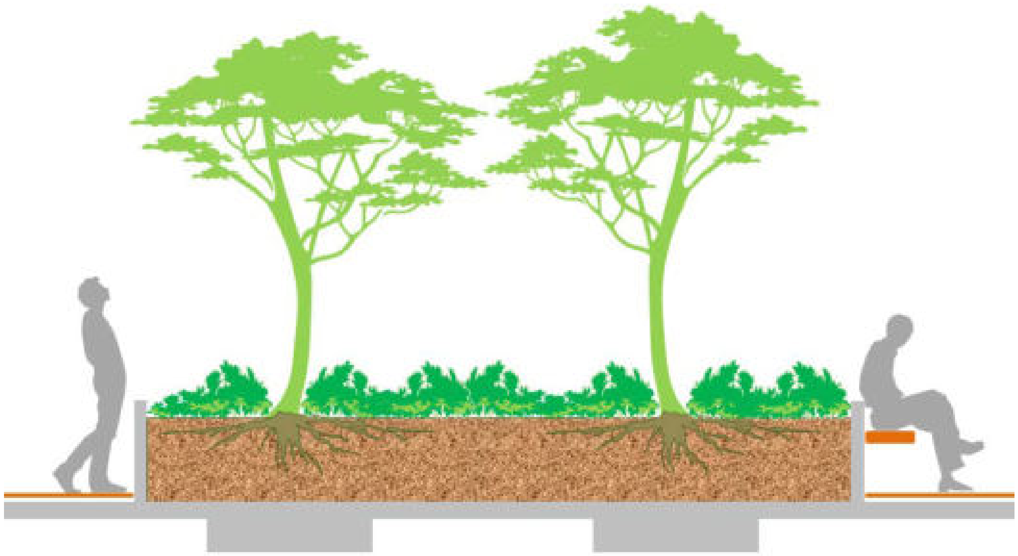
In the above example, the same vegetation achieved further structural complexity, with the help of raised planters (both concealed type and exposed type). The concealed raised planter is designed to help create a somewhat undulating topography of varying substrate depths, which further enhances the complexity of the landscape.



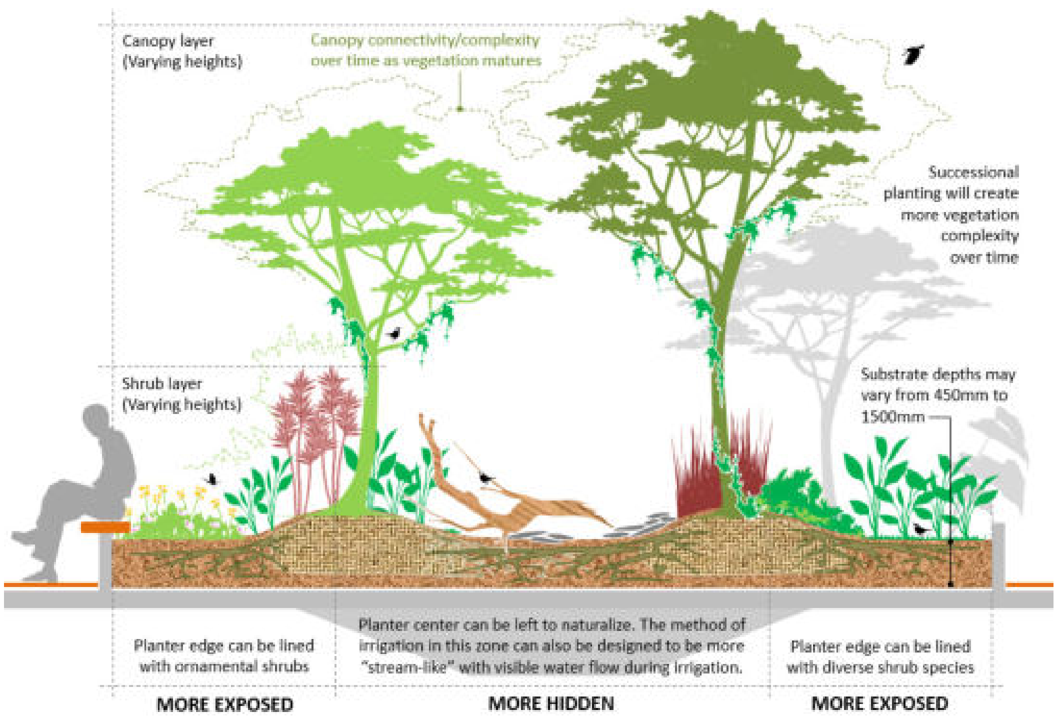
Many birds have an upper limit to the size of territory which can be defended and within this they require a finite amount of resources. If the resources required in this example can only be met by five trees, only layout 3 (above right) would enable the bird to live in this group of trees. (Adapted from "Bring Back The Birds!" Christopher J. Hails, Mikaail Kavanagh, The Raffles Bulletin of Zoology 2013 29: 243-258)

In short, clustering trees and vegetation of diverse species together creates spatially compact/efficient resource nodes/niches attractive to birds and wildlife. Such refuges can be connected to each other via connective vegetated passageways.

This principle is applicable to landscaping efforts on both ground level and roof gardens. On a smaller spatial scale, this principle when applied to the placement/grouping of shrub clusters, will also benefit butterflies and birds.

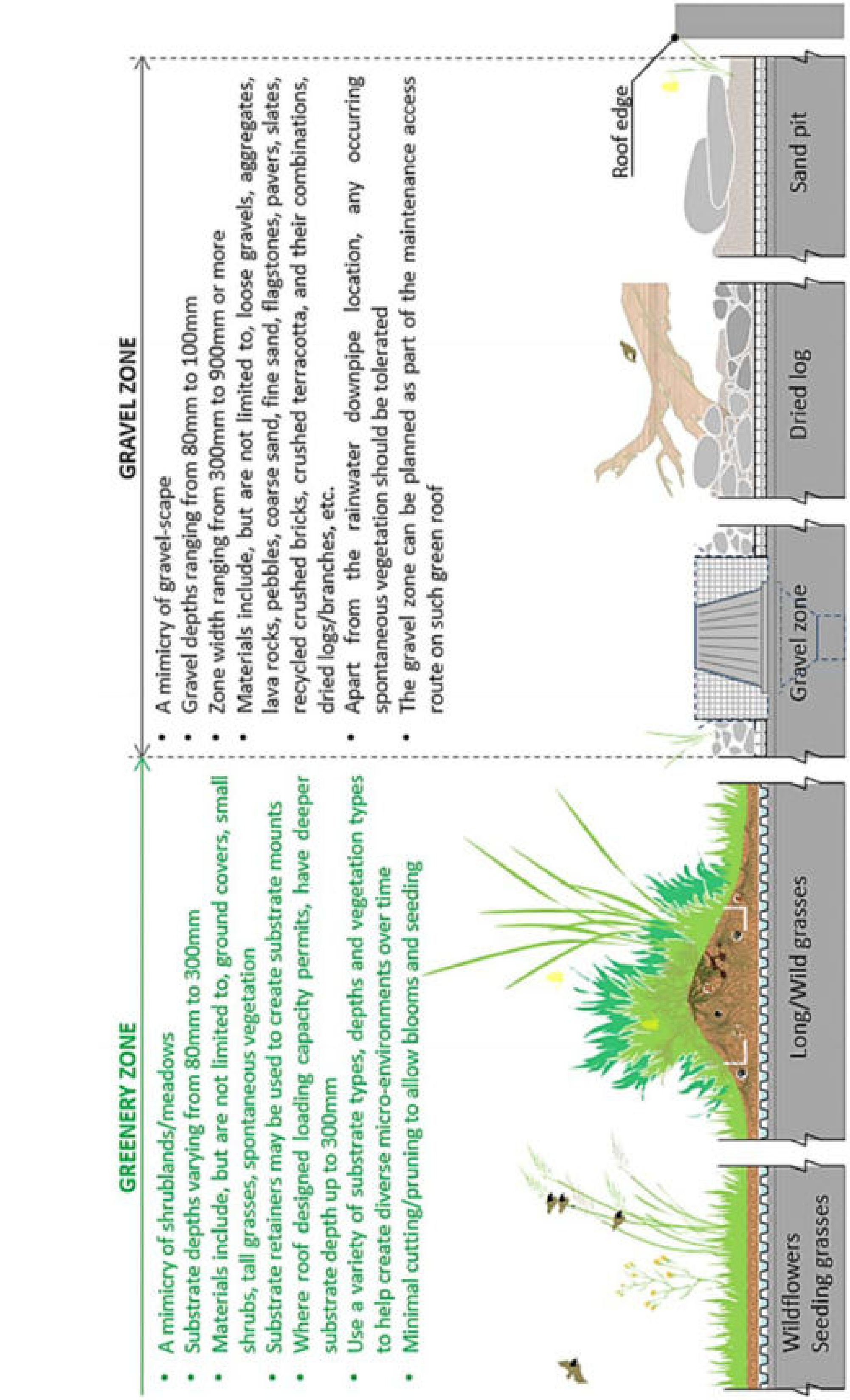


The above example is a typical tree planter design, with one tree species and one ground cover species. This example lacks both vegetation structural complexity and species diversity.



The above tree planter design is intentionally broader (width varying from 5 to 7m or more) with varying substrate depths and materials (ex: soil mixtures, loose-laid flagstones, sand, pebbles, aggregates, etc.) Over time, such design can achieve more plant species diversity and vegetation structural complexity. The outer edges can be lined with ornamental shrubs. Hidden from direct view, the center can be left more naturalistic. With more habitat heterogeneity, such example is expected to mature into resource niches attractive to birds and wildlife. This diagrammatic section is applicable as both (1) isolated planter and (2) vegetated passageway connecting otherwise separate vegetated refuges (tree clusters) of roof gardens.

4.15 NATURALISED EXTENSIVE GREEN ROOF



Greenery zone:

- Both deliberately planted butterfly nectar plant species and spontaneous species (wild grasses and wild flowers) are observed to be equally visited by butterflies. Both are viable resources for butterflies.

- Wherever feasible in design, allow specific areas (or the full extensive green roof) to naturalise, with infrequent judicious maintenance.

- Balding patches, when left undisturbed, will be readily taken over by spontaneous vegetation (wild grasses and wild flowers). Spontaneous vegetation provides valuable food resources (i.e. nectar, fruits, seeds and invertebrates) to biodiversity. Adding of self-propagating plants will also get the process moving. Judicious fertilising will also help with speeding up the process.

- Extensive green roofs can be designed from the onset as mimetic "shrublands" and "meadows".

- Field trials are needed. Unlike conventional gardens, the greenery in such landscape should not be excessively trimmed. Where necessary, aggressive dominate flora species should be suitably trimmed back periodically to promote flora species diversity. Please refer to Section 3.6.7.

Gravel zone:

- In general, the gravel zone runs along the roof perimeter, as a buffer between the greenery zone and the roof parapet.

- The gravel zone may also be designed to weave into the greenery zone as access footpath and/or as fire-break (of 450 to 600mm width) for both extensive green roof and intensive roof garden. This minimises the need to walk over established vegetation, reducing human disturbance and mechanical damage to the established plants during inspection and maintenance.

- In more sheltered locations (such as when footpaths weave through tall shrubs/grasses), organic mulch can be used in place or in conjunction with gravels.

- The gravel zone can be designed as part of the roof's drainage route. Within the gravel zone, the location of the rainwater downpipe can be made more visible to allow easy identification and maintenance inspection. Accumulated biomass around the rainwater downpipe can be easily spotted and removed during periodic maintenance, facilitating drainage.

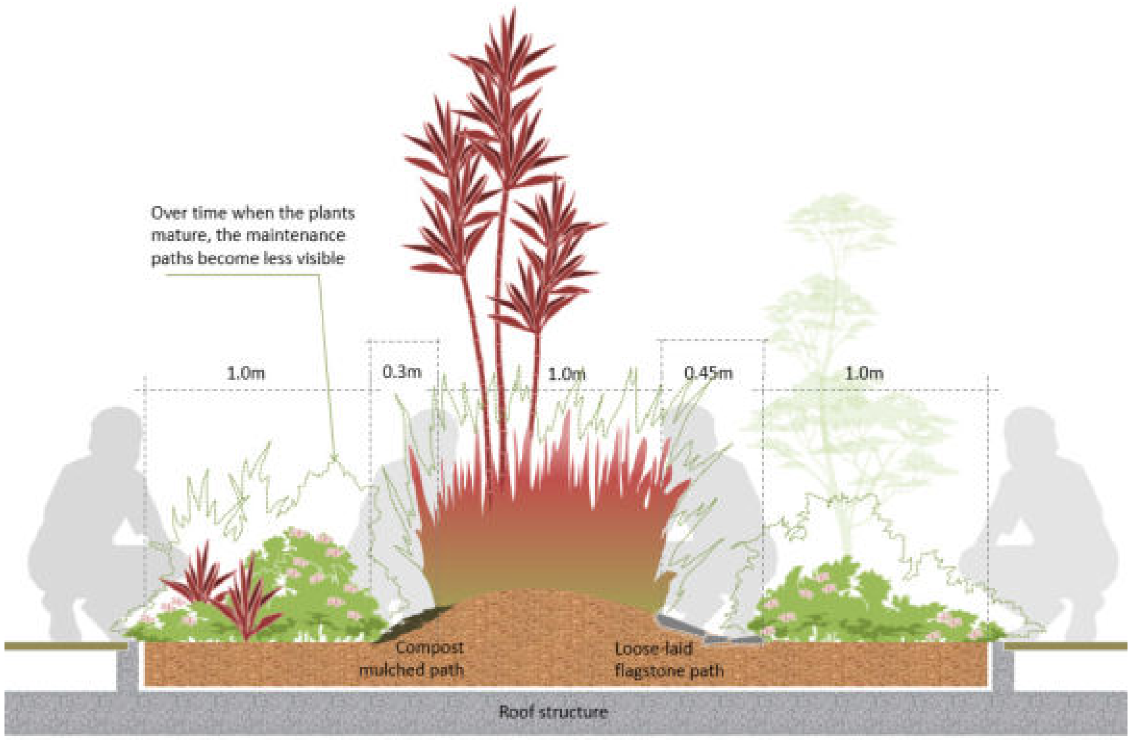
- Over time, spontaneous vegetation will sprout from the gravels. Spontaneous vegetation around the rainwater downpipe (drainage point) must be removed (at least once every quarterly) to avoid choking the drainage. Spontaneous vegetation in the gravel zone (away from the drainage point) may be tolerated and suitably retained as resources for biodiversity.

- Within the gravel zones, under-laying water retentive layer(s) is optional. Where used, these improve moisture reserves, facilitating spontaneous vegetation growth.

- Gravel materials include, but are not limited to, coarse sand, fine aggregates, pebbles, flagstones, granite chips, lava rocks. Materials should be selected in conjunction with the parapet design and parapet height, so as to avoid materials being blown off the roof edge by strong wind gusts.

- Suitably sized dead branches, subject to the roof load bearing capacity, can be appropriately positioned (and/or piled) on the rooftop landscape to mimic natural habitats. Eventually, invertebrates will occupy such niches and in turn attract carnivorous bird species.

4.16 SHRUB/FLOWER BED WIDTHS



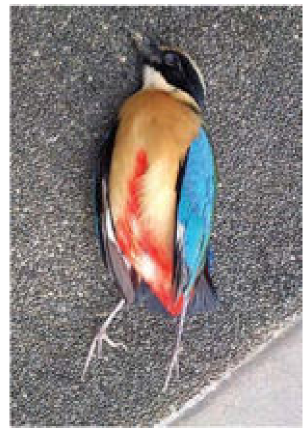
- The above exemplifies a wide planter bed with maintenance paths (150mm to 300mm wide, or more where deemed necessary by the landscape architect) to guide maintenance access and reduce trampling/mechanical-damage to the established foliage and food sources (blooms, fruits, seeds, invertebrates, etc.) for biodiversity. Design to reduce visibility of these paths, with emphasis on creating lush vegetation clusters.

- The maintenance paths can be compost/mulched path and/or alternatives. Where loose-laid flagstones and/or loose aggregates (such as pebbles, fine aggregates, etc.) are used, these should have an underlying geotextile layer to avoid the aggregates being trampled into the rooting substrate over time.

- This sectional design suggestion potentially allows maintenance worker to conduct more thorough inspections of the vegetation and systems. Affected plants and systems can also be more easily reached. These spatial provisions can facilitate workers in better decision-making during judicious maintenance. Such maintenance path can be integrated as part of the planter bed design, especially between different shrub species in the layout.

- Irrigation nodes (spray nozzles, drip lines, etc.) require periodic inspection and maintenance. Such items should run alongside these internal maintenance paths and/or the planter's outer edges, so as to allow easy inspection and access without having to walk into the foliage. Given time, the foliage with form dense clusters, concealing the paths from view. The overall achieved clustered vegetation can be attractive to biodiversity.

4.17 BIRD-WINDOW STRIKES



Bird casualty by bird-window strikes is one primary cause of bird mortality globally, in particular affecting night-migrating birds.

In the case of Singapore, the island-nation lies in the East Asian Migratory Flyway, an important route for many thousands of migratory birds. Many of these birds fly at night and rely on the stars to orientate their migratory flight paths. The many points of light from buildings and in the city can disorientate night-migrating birds. Day-flying birds may also crash into the glass windows when they cannot differentiate the reflections of green spaces from the real thing. Recent surveys have identified Blue-winged Pitta as among the most prone migratory species. (*Low, B.W. et al., 2017*) Anyone finding dead or injured birds should submit their observations to the Nature Society (Singapore) on www.tinyurl.com/sgbirdcrash.

In contemporary architecture design, the sought after transparent and reflective glazed facades can in fact be deadly to birds. Birds-of-prey in flight may also mistake their own reflections as competing rivals and trigger assault. Often these avian behaviours lead to casualties from head trauma, claiming the fittest individuals of species which is very unfortunate.

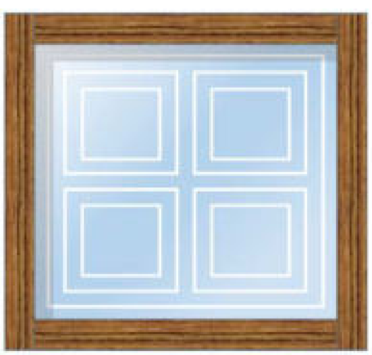
4.17.1 While bird-window-conflict in the urban environment requires more scientific studies and is currently without definitive solution, the following are suggestions to consider nonetheless. Mitigation methods include, but are not limited to, using visual markers and muting reflections on glass surfaces. These suggestions have been adapted from:

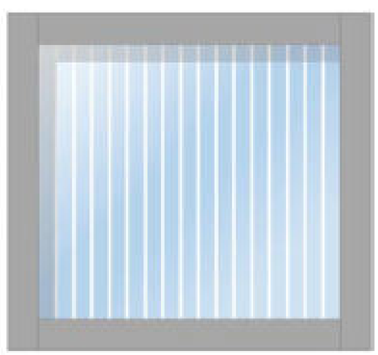
- Standards for Bird-Safe Buildings (2011) San Francisco Planning Department http://sf-planning.org/standards-bird-safe-buildings
- Bird-Friendly Development Guidelines (2007) City of Toronto Green Development Standard http://www1.toronto.ca

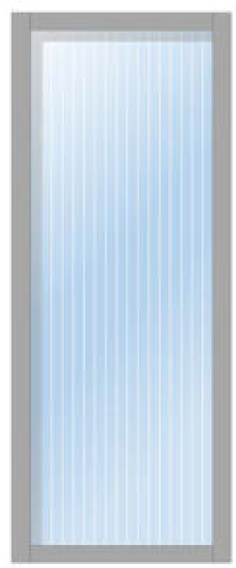
Bird-Window-Collision Mitigation Approaches: Window/Façade Treatments				
No.	**Possible Methods**	**Descriptions**	**New building/ Retrofitting**	**Existing building**
01	Patterned or "fritted" glass	Designs can be "printed" onto the glass surface as part of the glass panel fabrication process.	✓	
02	UV reflective coating	The UV coating is visible to birds and invisible to human eyes.	✓	
03	Film and Decal	Printed designs can be pasted onto the glass surface.	✓	✓
04	Fenestration patterns	Frames and glass surfaces of fenestrations can be designed to look less transparent, for birds to perceive these as solid surfaces.	✓	
05	Translucent glass products	Glass products with materials such as screen, net, fabric, blinds, etc. already integrated into the glass panel.	✓	
06	Interior Design	Interior operable shades/blinds/curtains/ etc. as part of interior-design.	✓	✓

07	Exterior Screen	Exterior insect-screen/fiberglass screen/ etc. which can be part of the architectural design.	✓	✓
08	Exterior louvres/shades	Horizontal sun-shading devices, such as awnings and overhangs. Vertical louvres. These block out reflections from certain angles.	✓	

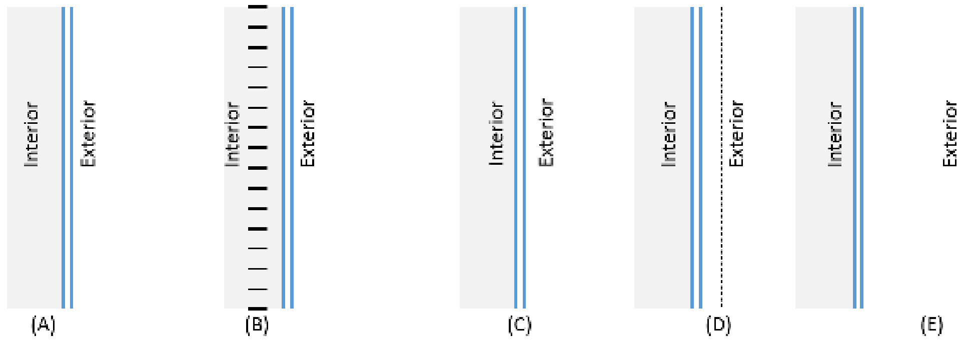
Patterned Glass *- Methods, such as digital ceramic printing on glass, allow the application of images, patterns or texts onto flat glass surfaces. There are opportunities for high levels of customization for translucency, opacity, light diffusion and transmission, etc. The prints render the glass surface less transparent, offering more privacy to the human users indoor and may improve the perceived "solidness" of the glass plane to birds in flight.*







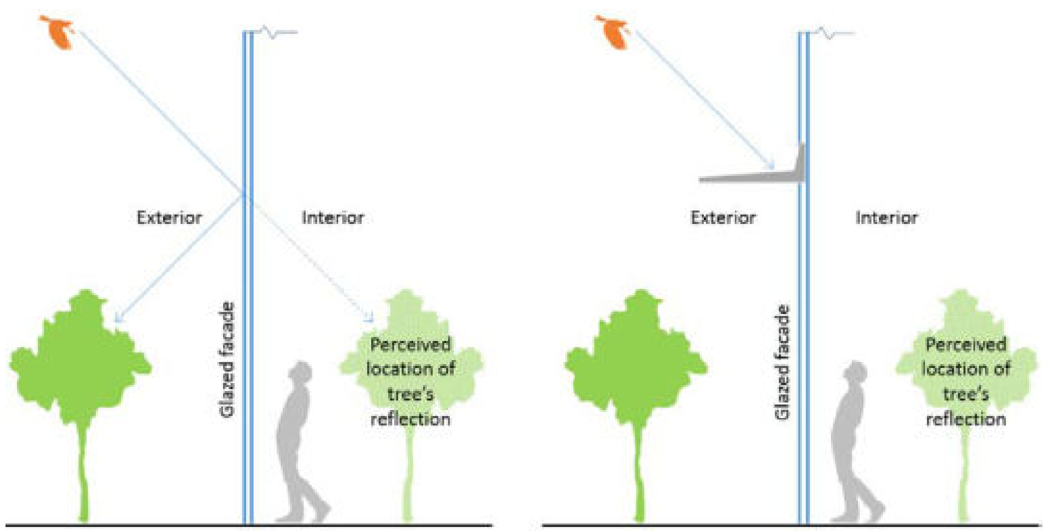
Fenestration Patterns as Visual Markers *– Large glass window panes appear transparent to birds. Fenestration frame sizing and design can help to improve the perceived solidness of these surfaces to birds. Ideally, the pattern spacing should range from 10cm to 28cm or less. Denser pattern is preferred.*



(A) Screen material, installed behind glass panel, such as conventional blinds (and equivalent)
(B) Screen material, installed behind glass panel, such as louvre-blinds (vertical or horizontal, and equivalent)
(C) Screen material (metal, mesh, etc.) embedded within the glass panel system
(D) Screen material (metal, mesh, etc.) installed in front of glass panel
(E) Screen material (metal, mesh, etc.) installed in front and away from glass panel

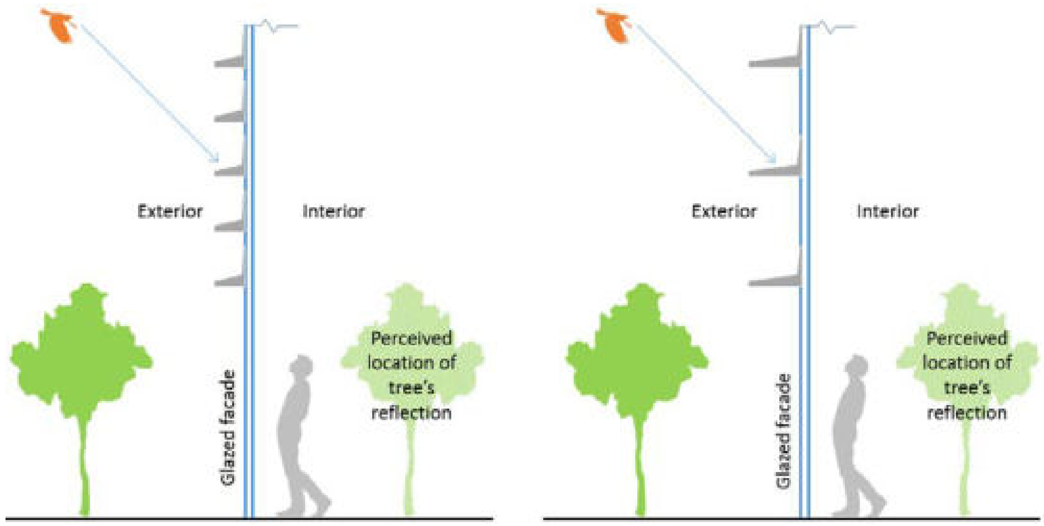
Screen materials – *Internal screens and/or blinds (as well as other forms of operable and/or non-operable sun-shading devices) can be explored to reduce the transparency of glass. Internal screens however may not reduce the reflections perceived by birds in flight from the outside. However, external screens are more effective both to reduce reflections and to cushion the impact of a bird-window strike.*

Sunshades/Awnings – *Sunshades and awnings provide shade, by blocking out solar irradiance. While these improve microclimate within a building, these architecture devices can also help block/breakup reflections from certain angles.*



Above left example: The glazed façade creates reflections of the surrounding green spaces. Birds in flight can perceive the reflections from multiple angles. Birds in flight may fly directly into the glazed surface.

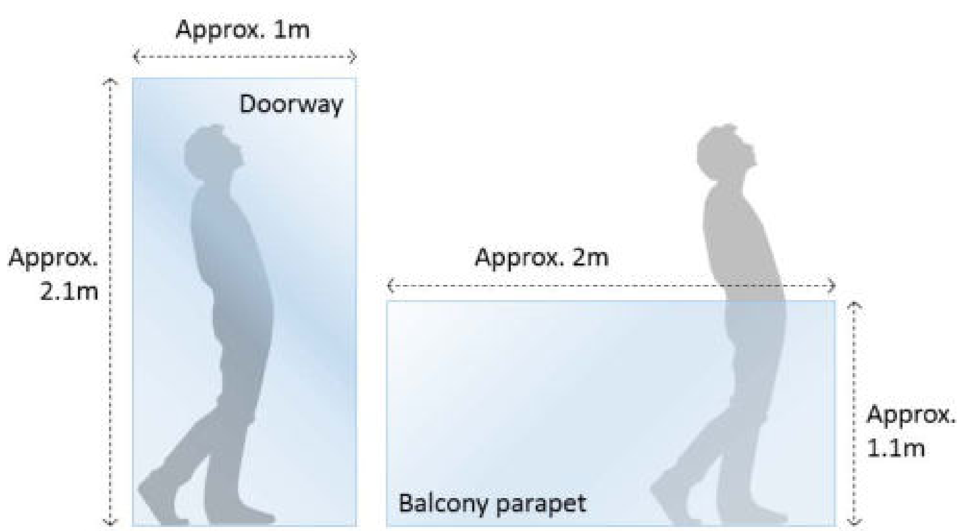
Above right example: The sunshade/awning block out the reflections from certain angles, while providing shade and preserving outward view. From certain angles, the birds in flight cannot perceive the reflections. The sunshade/awning can be made from a variety of materials (not limited to fritted/patterned treated glass, aluminium, lightweight pre-stressed concrete, treated wood-derived products, ceramic, etc.) and can even be designed as operable louvres and/or perforated surfaces.



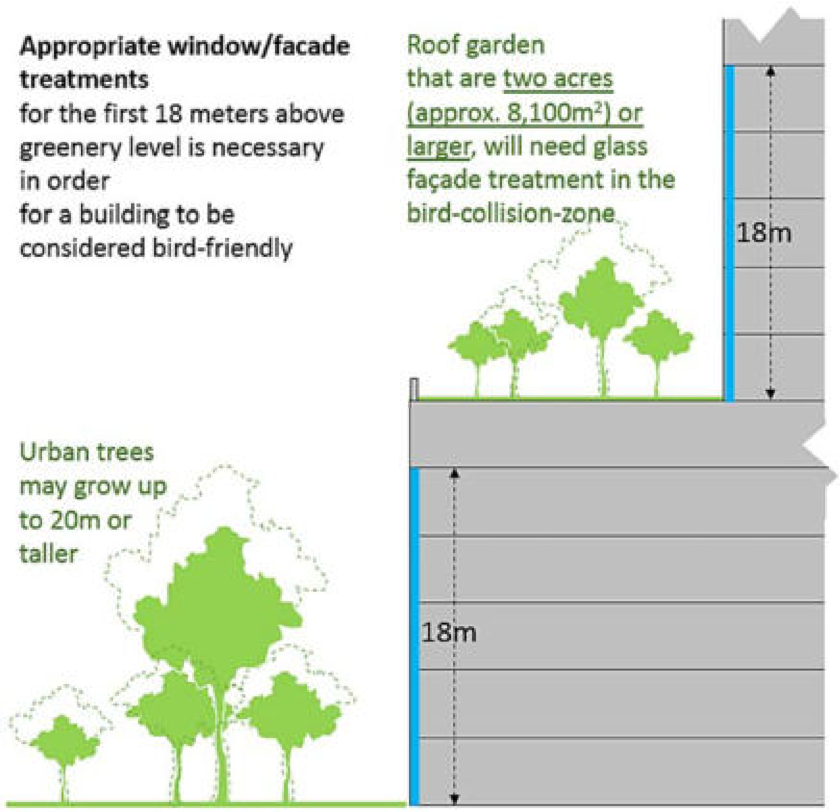
Sunshade/awning dimensions and spacing can also be varied. The above two examples deploy shallower shades but with closer spacing.

Wherever the glazed portions of the façade are large and expansive, surface treatments (such as using glass panels with printed patterns, applying films and decals, etc.) should be deployed to make the glass surface less transparent, less reflective, and more visible to birds in flight.

4.17.2 Unbroken clear glazed segments 24 square feet (approximately 2.23 m^2) and larger can pose as building-specific hazard for birds in flight. The following are examples of glazed doorway and balcony parapet of the mentioned critical size. These features, any larger, will require treatments. (Please refer to section 4.17.1)



4.17.3 Large glazed windows/facades adjacent to green landscaped open spaces (both on ground level as well as on roof gardens) will have a lot of greenery reflections. These reflections are potential hazards to birds in flight.



*The glazed windows/facades facing green open spaces must be suitably designed and treated <u>up to a suggested height of **no less than 18m** from the level of the subject green landscaped surface</u>. (Facades' height classified as potential bird-collision-zones are as denoted by the blue lines in the above diagram.)*

4.18 EDUCATIONAL OUTREACH

- A vegetated landscape is a dynamic living landscape supporting diverse biological communities and systems. In order for an ecological designed garden space to truly work, the long term landscape management has to be carried out with understanding of its underpinning ecological principles and their sustenance over time.

- **On the personnel level**, building-managers can widen their understanding and capability in managing ecological gardens, by reading up and/or attending relevant courses on gardening and ecology. Proper handing-over of maintenance protocols and knowledge is highly important during any change of building management. This will assure continued correct sustenance of the design through the years.

- **On the community level**, interest-groups and committee can be organised amongst interested building users/residences to fully optimise the operation and explore the educational potentials of such unique garden designs.

- **On the design level**, tools such as signage denoting "*This roof is an evolving landscape that changes with the seasons*" can be educational to users on the ecological design intent of the garden. This help builds understanding and tolerance towards the seasonal changes that both the managed and non-managed (spontaneous) vegetation undergo. Most users are very accustomed to the culture of highly manicured landscape, and the somewhat "less-managed" overall appearance of ecological garden spaces will require a gradual cultural shift over time. Ecological garden design plays an important role in facilitating this cultural shift, as it reaches out to different user groups in society.

- Designers may use the following listed ecosystem services as a guide to develop design content and establish ecological associations to enrich users' experiences.

Ecosystem Services (source: www.nwf.org)	
Provisioning	Along with food, other types of provisioning services include: • Drinking water • Timber • Wood fuel, natural gas and oils • Plants that can be made into clothes and other materials • Medicinal benefits
Regulating	Regulating services include: • Pollination • Decomposition • Water purification • Erosion and flood control • Carbon storage and climate regulation
Cultural	A cultural service is a non-material benefit that contributes to the development and cultural advancement of people including, • How ecosystems play a role in local, national and global cultures • The building of knowledge and the spreading of ideas • Creativity born from interactions with nature (music, art, architecture) • Recreation

Supporting	The natural world provides many services. Often, we overlook the most fundamental. Ecosystems cannot be sustained without the consistency of underlying natural processes, such as: • photosynthesis, • nutrient cycling, • creation of soils and • water cycle. These processes allow the Earth to sustain basic life forms, whole ecosystems and humans. Without supporting services, provisional, regulating and cultural services would not exist.

➢ Wherever feasible, design processes of such garden spaces and components (signage, mural walls, art-relief finishes, displays, interactive-benches, etc.) should creatively involve collaborations with students, senior-communities and/or any other interested groups/organizations/institutions. These help foster collective memories and appreciation for nature/ecology.

➢ The following are some non-exhaustive suggestions for such collaborations:
- Collaboration with nature photography societies and avid nature photographers and artists in the display (temporary/permanent) of their art-works in designated locations within (and/or nearby) the garden.
- Garden hard-surfaces (i.e. walls, floors, finishes, furniture, etc.) can be co-designed to creatively express or narrate (in text and/or visuals) the ecological functions and creatures of the garden.
- Students' artistic involvement (i.e. biodiversity inspired ceramic artworks, etc.) can contribute as actual finishes for designated garden/building surfaces. This may serve as an actual real-world application of the participating school art curriculum/program. Such involvement is both academically and publicly engaging and can be particularly purposeful to the art students involved.

➢ The above are possible avenues to associate elements of education/outreach to the final constructed ecological garden space. Inspirations can stem from our appreciation for nature, its biodiversity and ecosystems.

Students' ceramic artworks which are inspired by nature and biodiversity.

These are purposefully utilised as beautiful outdoor murals that continue to inspire passersby with its beauty.

SECTION 5 PLANT SPECIES LISTS

- The following are compilations of plant species used/documented on roof gardens (and in gardens on ground) in Singapore to date. The duty is on the landscape consultants (and/or any other relevant greenery consultants) to practice caution and ensure the choice, placement and access to rooftop vegetation are sensible and do not compromise safety. (The below compilations are for references only, and are not to be construed as recommendations.)

- The onus is on building owners to ensure no rooftop tree/palm/plant compromises public safety. Notable rooftop greenery scenarios are the planting of tall trees/palms/plants (of more than 2m grown/maintained height) near edge-conditions where risks of falling debris and Fall-From-Height (FFH) are high.

- Plant specimens from different sources may vary in quality. Selected specimens are to be suitable for the relevant rooftop environment. Landscape architect to advise.

- There will be continuous efforts in expanding the below lists and we welcome suggestions on plant species from members of the public, the industry and the scientific communities, etc., who have had positive experiences with planting them in their roof gardens.

TABLE 01
BIRD NECTAR AND FRUIT PLANTS

No.	Plant Species	Status in Singapore	Plant Form	Nectar	Fruit
01	*Averrhoa carambola*	Introduced	Tree	✓	✓
02	*Bauhinia* x *blakeana*	Introduced	Tree	✓	
03	*Caesalpinia ferrea*	Introduced	Tree	✓	
04	*Calliandra tergemina*	Introduced	Tree	✓	
05	*Callistemon citrinus*	Introduced	Tree	✓	
06	*Carica papaya*	Introduced	Tree	✓	✓
07	*Caryota mitis*	Native	Tree		✓
08	*Coccoloba uvifera*	Introduced	Tree	✓	✓
09	*Cratoxylum cochinchinense*	Native	Tree	✓	
10	*Dypsis lutescens*	Introduced	Palm		✓
11	*Erythrina fusca*	Introduced	Tree	✓	
12	*Lophanthera lactescens*	Introduced	Tree	✓	
13	*Muntingia calabura*	Introduced	Tree		✓
14	*Murraya paniculata*	Introduced	Shrub	✓	✓
15	*Pithecellobium dulce*	Introduced	Tree	✓	✓
16	*Plumeria rubra*	Introduced	Tree	✓	
17	*Ptychosperma macarthurii*	Introduced	Tree		✓
18	*Schefflera actinophylla*	Introduced	Tree	✓	
19	*Talipariti tiliaceum*	Native	Tree	✓	
20	*Xanthostemon chrysanthus*	Introduced	Tree	✓	
Data extracted from James Wang et al. 2016. Bird and butterfly diversity on 32 roof gardens in Singapore. NUS-NParks Skyrise Biodiversity Project. National Parks Board, Singapore.					

TABLE 02
NATIVE PLANT SPECIES (ATTRACTIVE TO NECTARIVOROUS AND FRUGIVOROUS BIRDS)

No.	Plant Species	Common Name	Plant Form	Nectar	Fruit
01	*Epipremnum pinnatum*	Dragon's tail	Climber		✓
02	*Ficus fistulosa*	Yellow-stemmed fig	Tree		✓
03	*Ficus grossularioides*	White-leaved fig	Tree		✓
04	*Gnetum gnemon*	Belinjau	Tree		✓
05	*Lumnitzera littorea*	Teruntum merah	Tree	✓	
06	*Macaranga bancana*	Common mahang	Tree		✓
07	*Macaranga heynei*	Blue mahang	Tree		✓
08	*Olea brachiata*	Sea olive	Tree		✓
09	*Syzygium polyanthum*	Salam tree	Tree		✓
Data adapted from Tan EH (2014) Flora selection to attract birds and butterflies to rooftop gardens in Singapore. Unpublished Honours Thesis. National University of Singapore, Singapore. 70pp.					

Table 03
PLANT SPECIES LIST (USED BY BIRDS FOR NESTING)

No.	Plant Species	Bird Species	Plant Form
01	*Calliandra surinamensis*	*Cinnyris jugularis*	Shrub
02	*Filicium decipiens*		Tree
03	*Melaleuca bracteata*		Tree
04	*Quisqualis indica*		Climber
05	*Tabernaemontana divaricata*		Shrub
06	*Terminalia mantaly*		Tree
07	*Coccoloba uvifera*	*Lanius schach*	Tree
08	*Lagerstroemia indica*		Shrub
09	*Xanthostemon chrysanthus*		Tree
10	*Adonidia merrillii*	*Lonchura leucogastroides*	Tree
11	*Cyrtostachys renda*	*Lonchura punctulata*	Shrub
12	*Codiaeum variegatum*	*Pycnonotus goiavier*	Shrub
13	*Rhapis excelsa*		Shrub
14	*Syzygium myrtifolium*		Tree
15	*Phoenix sylvestris*	*Streptopelia chinensis*	Tree
16	*Passiflora* sp.	*Treron vernans*	Climber
17	*Pyrrosia longifolia*		Epiphyte
Data extracted from James Wang et al. 2016. Bird and butterfly diversity on 32 roof gardens in Singapore. NUS-NParks Skyrise Biodiversity Project. National Parks Board, Singapore.			

TABLE 04
BUTTERFLY NECTAR PLANTS

No.	Plant Species (Flowering)	Status in Singapore	Plant Form
01	*Averrhoa carambola*	Introduced	Tree
02	*Bauhinia kockiana*	Introduced	Climber
03	*Bougainvillea* cv.	Introduced	Shrub
04	*Calliandra tergemina*	Introduced	Shrub
05	*Callistemon citrinus*	Introduced	Tree
06	*Carmona retusa*	Introduced	Shrub
07	*Ixora* cv.	Introduced	Shrub
08	*Jatropha integerrima*	Introduced	Shrub

09	*Murraya paniculata*	Introduced	Shrub
10	*Plumeria rubra*	Introduced	Tree
11	*Pseuderanthemum carruthersii*	Introduced	Shrub
12	*Quisqualis indica*	Introduced	Climber
13	*Sphagneticola trilobata*	Introduced	Herb
14	*Tabernaemontana divaricata*	Introduced	Shrub
15	*Turnera subulata*	Introduced	Herb
16	*Turnera ulmifolia*	Introduced	Shrub
17	*Wrightia religiosa*	Introduced	Shrub
18	*Xanthostemon chrysanthus*	Introduced	Tree
No.	**Weed Species (Flowering)**		**Plant Form**
01	*Ageratum conyzoides*		Herb
02	*Arachis pintoi*		Herb
03	*Asystasia gangetica*		Herb
04	*Cleome rutidosperma*		Herb
05	*Cyanthillium cinereum*		Herb
06	*Elephantopus scaber*		Herb
07	*Emilia sonchifolia*		Herb
08	*Gomphrena globosa*		Herb
09	*Heliotropium indicum*		Shrub
10	*Kyllinga nemoralis*		Herb
11	*Legazpia polygonoides*		Herb
12	*Lindernia crustacea*		Herb
13	*Mikania micrantha*		Climber
14	*Oxalis barrelieri*		Herb
15	*Oxalis corniculata*		Herb
16	*Ruellia repens*		Herb
17	*Tridax procumbens*		Herb
18	*Youngja japonica*		Herb
Data extracted from James Wang et al. 2016. Bird and butterfly diversity on 32 roof gardens in Singapore. NUS-NParks Skyrise Biodiversity Project. National Parks Board, Singapore. *Data extracted from Jain et al. 2016. Flower specialization of butterflies and impacts of non-native nectar use in a transformed tropical landscape. Biological Conservation 201: 184 - 191.*			
No.	**Plant Species (Flowering)**	**Status in Singapore**	**Plant Form**
01	*Andira inermis*	Introduced	Tree
02	*Arachnothryx leucophylla*	Introduced	Shrub
03	*Archidendron clypearia*	Native	Tree
04	*Asclepias currasavica*	Naturalised; introduced	Shrub
05	*Asystasia intrusa*	Naturalised; introduced	Herb
06	*Averrhoa bilimbi*	Introduced	Tree
07	*Bidens* spp.	Naturalised; introduced	Shrub
08	*Bridelia tomentosa*	Native	Tree
09	*Citharexylum spinosum*	Introduced	Tree
10	*Clerodendrum paniculatum*	Introduced	Shrub
11	*Cnidoscolus chayamansa*	Introduced	Shrub
12	*Cordia cylindristachya*	Introduced	Shrub
13	*Cuphea hyssopifolia*	Introduced	Shrub
14	*Dalbergia latifolia*	Introduced	Tree
15	*Duranta erecta*	introduced	Shrub
16	*Elaeocarpus petiolatus*	Native	Tree

17	*Hibiscus rosa-sinensis*	Introduced	Shrub
18	*Ixora* spp.	Introduced	Shrub
19	*Lantana camara*	Naturalised; introduced	Shrub
20	*Leea indica*	Native	Shrub
21	*Leea rubra*	Native	Shrub
22	*Melanthera biflora*	Native	Herb
23	*Melastoma malabathricum*	Native	Shrub
24	*Mussaenda philippica*	Introduced	Shrub
25	*Pseuderanthemum reticulatum*	Introduced	Shrub
26	*Saraca thaipingensis*	Introduced	Tree
27	*Stachytarpheta indica*	Naturalised; introduced	Shrub
28	*Syzygium glaucum*	Native	Tree
29	*Syzygium grande*	Native	Tree
30	*Syzygium lineatum*	Native	Tree
31	*Syzygium myrtifolium*	Native	Tree
32	*Syzygium zeylanicum*	Native	Tree
33	*Vernonia arborea*	Native; vulnerable	Tree

Data extracted from Jain et al. 2016. Flower specialization of butterflies and impacts of non-native nectar use in a transformed tropical landscape. Biological Conservation 201: 184 - 191.

TABLE 05
BUTTERFLY HOST PLANT SPECIES LIST

No.	**Plant Species**	**Host Butterfly Species**	**Plant Form**
01	*Annona muricata*	*Graphium agamemnon agamemnon*	Tree
02	*Aristolochia acuminata*	*Troides helena cerberus, Pachliopta aristolochiae asteris, Pachliopta antiphus*	Climber
03	*Asclepias curassavica*	*Danaus chrysippus chrysippus*	Shrub
04	*Asystasia gangetica*	Hypolimnas bolina bolina, Junonia orithya wallacei, *Doleschallia bisaltide, Hypolimnas bolina jacintha*	Herb
05	*Breynia disticha* 'Roseo-picta'	*Eurema hecabe contubernalis*	Shrub
06	*Caesalpinia pulcherrima*	*Eurema hecabe contubernalis*	Shrub
07	*Calliandra tergemina* var. *emarginata*	*Eurema hecabe contubernalis*	Tree
08	*Calliandra haematocephala*	*Eurema hecabe contubernalis*	Tree
09	*Calotropis gigantea*	*Danaus chrysippus chrysippus*	Shrub
10	*Cassia fistula*	*Catopsilia pomona pomona, Catopsilia pyranthe, Catopsilia Scylla cornelia*	Tree
11	*Cassia mimosoides*	*Eurema brigitta senna*	Shrub
12	*Citrus* spp.	*Papilio demoleus malayanus*	Shrub
13	*Cleome rutidosperma*	*Pieris rapae, Leptosia nina malayana, Appias libythea olferna*	Herb
14	*Cordia cylindristachya*	*Appias libythea olferna*	Shrub
15	*Crotalaria retusa*	*Lampides boeticus*	Shrub
16	*Curcuma longa*	*Udaspes folus*	Herb
17	*Cycas revoluta*	*Chilades pandava pandava*	Tree

18	*Flacourtia inermis*	*Phalanta phalantha, Cupha erymanthis lotis*	Tree
19	*Graptophyllum pictum* cultivars	*Doleschallia bisaltide*	Shrub
20	*Hoya* spp.	*Parantica agleoides agleoides, Ideopsis vulgaris macrina*	Climber
21	*Ixora* spp. (big leaved varieties)	*Lebadea martha parkeri, Hypolycaena erylus teatus*	Shrub
22	*Lantana camara*	*Zizula hylax pygmaea, Rapala manea chozeba*	Shrub
23	*Lindernia sessiliflora*	*Junonia almanac*	Herb
24	*Magnolia* x *alba*	*Graphium agamemnon agamemnon*	Tree
25	*Murraya koenigii*	*Papilio polytes romulus*	Shrub
26	*Parsonsia helicandra*	*Euploea crameri bremeri*	Climber
27	*Passiflora foetida*	*Cethosia cyane, Acraea violae*	Climber
28	*Pseuderanthemum* spp. & cultivars	*Doleschallia bisaltide*	Shrub
29	*Psophocarpus tetragonolobus*	*Neptis hylas*	Climber
30	*Ruellia repens*	*Junonia almanac, Junonia iphita*	Herb
31	*Salix babylonica*	*Phalanta phalantha*	Tree
32	*Senna alata*	*Neptis hylas, Catopsilia pyranthe*	Shrub
33	*Senna biflora*	*Catopsilia scylla cornelia*	Shrub
Data extracted from Gary Chua. 2010. Creating butterfly habitats and gardens to enhance urban biodiversity. City Green. Biodiversity in the Urban Landscape. Issue 4: 110 - 119			

TABLE 06
NATIVE HOST PLANT SPECIES LIST (ATTRACTIVE TO BUTTERFLIES)

No.	Native Plant Species	Host Butterfly Species	Plant Form
01	*Ardisia elliptica*	*Abisara saturata kausambioides ,* *Taxila haquinus haquinus*	Tree
02	*Caesalpinia bonduc*	*Eurema hecabe contubernalis*	Climber
03	*Cerbera odollam*	*Euploea phaenareta castelnaui*	Tree
04	*Cinnamomum iners*	*Graphium sarpedon, Papilio clytia*	Tree
05	*Clausena excavata*	*Papilio polytes romulus*	Shrub
06	*Cynanchum ovalifolium*	*Danaus chrysippus chrysippus* *Danaus genutia genutia*	Climber
07	*Derris trifoliata*	*Hypolycaena erylus teatus* *Jamides bochus nabonassar* *Phaedyma columella singa*	Climber
08	*Flacourtia rukam*	*Phalanta phalantha phalantha*	Tree
09	*Ixora congesta*	*Lebadea Martha parkeri*	Shrub
10	*Melastoma malabathricum*	*Tanaecia iapis puseda*	Shrub
11	*Merope angulata*	*Papilio polytes romulus*	Shrub
12	*Smilax setosa*	*Anthene emolus goberus*	Climber
13	*Syzygium myrtifolium*	*Anthene emolus goberus*	Tree
14	*Tylophora flexuosa*	*Parantica agleoides agleoides*	Climber
15	*Ventilago malaccensis*	*Eurema andersonii andersonii*	Climber
16	*Volkameria inermis*	*Hypolycaena erylus teatus*	Climber
Data extracted from Tan EH (2014) Flora selection to attract birds and butterflies to rooftop gardens in Singapore. Unpublished Honours Thesis. National University of Singapore, Singapore. 70pp. *Data extracted from Gary Chua. 2010. Creating butterfly habitats and gardens to enhance urban biodiversity. City Green. Biodiversity in the Urban Landscape. Issue 4: 110 - 119*			

TABLE 07
EPIPHYTE SPECIES LIST

No.	EPIPHYTE SPECIES (Common ones on roof garden)	Status in Singapore
01	*Asplenium nidus*	Native
02	*Davallia denticulata*	Native
03	*Dischidia nummularia*	Native
04	*Drynaria quercifolia*	Native
05	*Ficus deltoidea*	Native
06	*Hoya verticillata*	Native
07	*Microsorum punctatum*	Native
08	*Nephrolepis acutifolia*	Native
09	*Phymatosorus scolopendria*	Native
10	*Platycerium coronarium*	Native
11	*Pyrrosia longifolia*	Native
12	*Pyrrosia piloselloides*	Native
Data extracted from James Wang et al. 2016. Bird and butterfly diversity on 32 roof gardens in Singapore. NUS-NParks Skyrise Biodiversity Project. National Parks Board, Singapore.		

SECTION 6 CASE STUDIES

Case Study 01 - bird attracting roof garden – Subaru Motor Image

A commercial roof garden (for vehicle)

Over 20 monthly-surveys, 29 bird species and 22 butterfly species were observed.

Principles	Descriptions
Height	25 to 26m (from immediate ground level) At approximately 25.5m roof garden height (6th level), this roof garden is considered a marginally high roof garden.
Planted/Herb area	~290m^2 (total herb cover)
Exposure	The site is open and exposed to full sunlight throughout the day, which benefits vegetation growth.
Complexity of vegetation	The above site demonstrates vegetation complexity, with relatively established trees/palms, mid shrubs and pervasive ground covers.
Judicious maintenance	The landscape looks naturalistic. The vegetation is allowed to mature and naturalise.
Human presence	The roof garden is designed as a man-made "rough terrain" trial site for potential car-buyers to try out their vehicles along the gravel paths. Such "human presence" is however not deterring birds from this roof garden, with an anecdotal sighting of a purple heron (*Ardea purpurea*) on the roof garden.
Noise level	Averaging 51 to 57 dB
Water presence	There are water bodies on this roof garden.

Case Study 02 - bird attracting roof garden – Punggol 180

A residential roof garden

Over 20 monthly-surveys, 25 bird species and 22 butterfly species were observed.

Principles	Descriptions
Height	12m (from immediate ground level) At approximately 12m roof garden height (4^{th} level), this roof garden is considered a low roof garden.
Planted/Herb area	~3700m^2 (total herb cover)
Exposure	The site is open and exposed to full sunlight throughout the day, which benefits vegetation growth.
Complexity of vegetation	The above site demonstrates vegetation complexity, with relatively established trees/palms, mid shrubs and pervasive ground covers. There are also some flowering shrubs.
Judicious maintenance	In general, the landscape looks somewhat manicured, with some shrubs well-pruned, but not excessively. Most plants appear established and not overly trimmed back. Some vegetation patches and turf areas are observed with non-managed (spontaneous) vegetation and flowering weeds.
Human presence	Although a roof garden designed to serve surrounding residential blocks and units, visitation by human users is low during the survey hours in the morning.
Noise level	Averaging 49 to 61 dB
Water presence	There are no water body on this roof garden.

Case Study 03 - butterfly attracting roof garden – Khoo Teck Puat Hospital

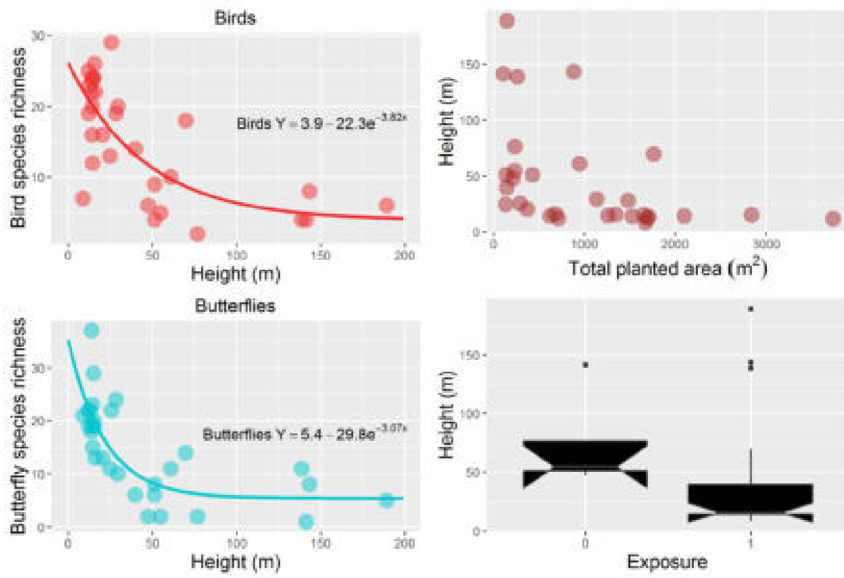
A lush community accessible garden

Over 20 monthly-surveys, 24 bird species and 37 butterfly species were observed.
The management of the development has purposefully introduced butterfly host plants into the landscape. Educational signage boards are also located within the landscape to inform the public on the sighted butterfly species.

Principles	Descriptions
Height	14m (from immediate ground level) At approximately 14m roof garden height (4^{th} level), this roof garden is considered a low roof garden. (The location of study, is only one of the many landscaped zones in this highly landscaped medical-institution.)
Planted/Herb area	~1530m^2 (total herb cover) at the location of study
Exposure	The site is open and exposed to full sunlight throughout the day, which benefits vegetation growth.
Complexity of vegetation	The above site demonstrates vegetation complexity, with relatively established trees/palms, mid shrubs and pervasive ground covers. There are also pervasive and extensive use of flowering shrubs. In some locations the vegetation complexity appear highly optimised. (The space feels encapsulated in greenery.)
Judicious maintenance	In general, the landscape looks well cared for without appearing overly managed. Most plants appear established and not overly trimmed back. Lots of flowering shrubs.
Human presence	Visitation by human users, at the location of study, is low during the survey hours.
Noise level	Averaging 60 to 63 dB
Water presence	There are no water body on this location of study.

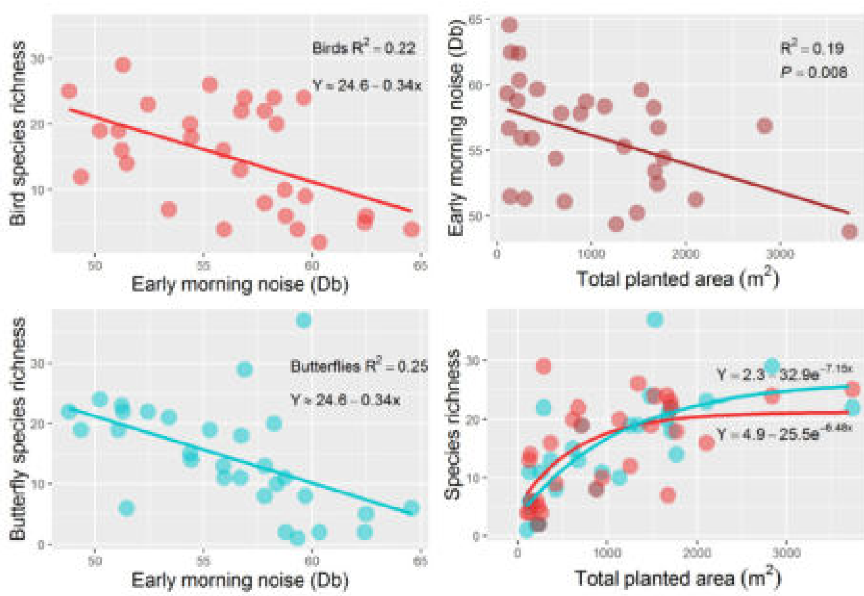
ANNEX

Statistical results of the local study



Height reduces biodiversity

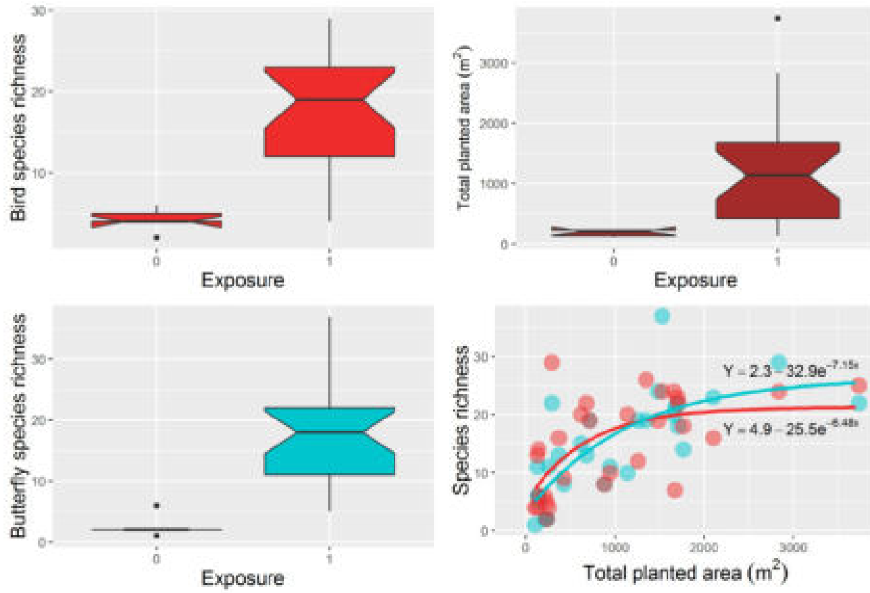
1) (Hypothesis) Height reduces biodiversity potential because it is energetically more expensive to reach higher roof gardens due to greater wind speeds at height.
2) Approximate height thresholds are 50m for butterflies, and 70m for birds.



Noise

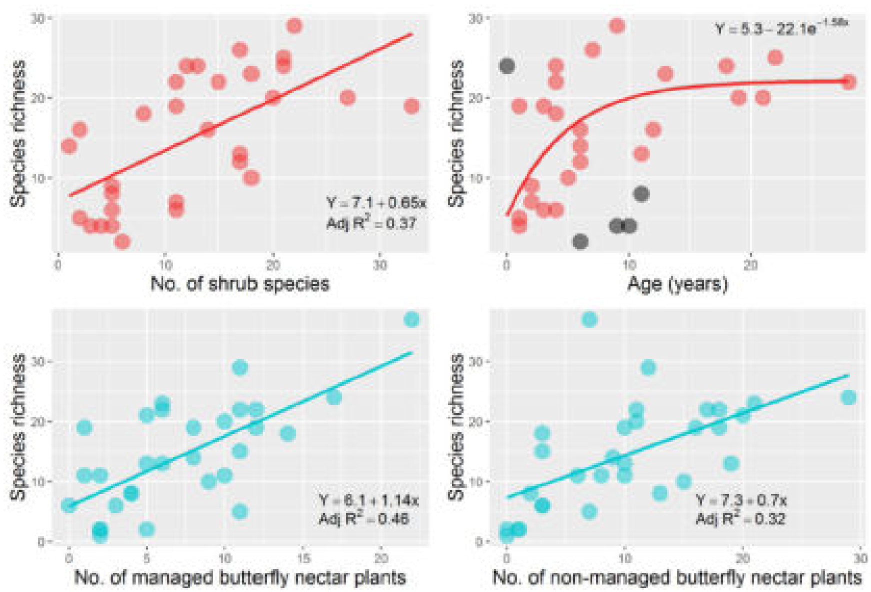
1) Noise is likely a proxy of urban intensity, which reduces space for planted areas in roof gardens.
2) Local planted area thresholds are approximated to be 1200 m^2.

Species	ρ	P
Acridotheres.javanicus	-0.485	0.008
Lanius.schach	-0.880	0.021
Zosterops.palpebrosus	-0.387	0.113
Lonchura.leucogastroides	0.506	0.136
Treron.vernans	0.311	0.242



Exposure

1) Non-exposed sites supported much lower planted areas than exposed sites.
2) Approximate area thresholds for species richness are 1100m^2 for birds, and 1300m^2 for butterflies.



Plant management

1) For birds, shrub species richness and site age are important, with an approximate threshold of 6 years.
2) For butterflies, species richness of both managed and non-managed plants is important.

Observed bird and butterfly species lists

List of bird species recorded in descending order of the number of sites they were recorded in the ecological survey on roof gardens.

Scientific name	Common name	No. of sites recorded
Acridotheres javanicus	Javan myna	31
Cinnyris jugularis	Olive-backed sunbird	30
Pycnonotus goiavier	Yellow-vented bulbul	27
Aplonis panayensis	Asian glossy starling	25
Aerodramus spp.	Swifts	24
Oriolus chinensis	Black-naped oriole	23
Streptopelia chinensis	Spotted dove	23
Hirundo spp.	Swallows	22
Zosterops palpebrosus	Oriental white-eye	20
Anthreptes malacensis	Brown-throated sunbird	19
Treron vernans	Pink-necked green pigeon	18
Columba livia	Rock pigeon	16
Dicaeum cruentatum	Scarlet-backed flowerpecker	16
Lonchura punctulata	Scaly-breasted munia	15
Muscicapa latirostris	Asian brown flycatcher	15
Corvus splendens	House crow	13
Eudynamys scolopaceus	Asian koel	13
Orthotomus sutorius	Common tailorbird	13
Passer montanus	Eurasian tree sparrow	12
Lanius cristatus	Brown shrike	11
Lonchura leucogastroides	Javan munia	11
Dendrocopos moluccensis	Sunda pygmy woodpecker	10
Loriculus galgulus	Blue-crowned hanging parrot	10
Geopelia striata	Zebra dove	9
Lanius tigrinus	Tiger shrike	9
Lanius schach	Long-tailed shrike	7
Acridotheres tristis	Indian myna	6
Copsychus saularis	Oriental magpie-robin	6
Phylloscopus borealis	Arctic warbler	4
Psittacula alexandri	Red-breasted parakeet	4
Dinopium javanense	Common flameback	3
Halcyon smyrnensis	White-throated kingfisher	3
Lalage nigra	Pied triller	3
Psittacula krameri	Rose-ringed parakeet	3
Todiramphus chloris	Collared kingfisher	3
Monticola solitarius	Blue rock thrush	2
Psittacula longicauda	Long-tailed parakeet	2
Pycnonotus jocosus	Red-whiskered bulbul	2
Accipitridae	Hawk/eagle	1
Aegithina tiphia	Common iora	1
Agropsar sturnius	Daurian starling	1
Ardea purpurea	Purple heron	1
Cecropis daurica	Red-rumped swallow	1
Chalcophaps indica	Common emerald dove	1

Copsychus malabaricus	White-rumped shama	1
Cuculus micropterus	Indian cuckoo	1
Ficedula mugimaki	Mugimaki flycatcher	1
Ficedula zanthopygia	Yellow-rumped flycatcher	1
Hemiprocne longipennis	Grey-rumped treeswift	1
Psilopogon hemacephalus	Coppersmith barbet	1
Terpsiphone incei	Asian paradise flycatcher	1
Trichoglossus haematodus	Coconut lorikeet	1

List of butterfly species recorded in descending number of sites they were recorded at.

Scientific name	**Common name**	**No. of sites recorded**
Delias hyparete metarete	Painted jezebel	31
Catopsilia pomona pomona	Lemon emigrant	27
Papilio demoleus malayanus	Lime butterfly	25
Eurema spp.	Grass yellow	23
Zizina otis lampa	Lesser grass blue	23
Zizula hylax pygmaea	Pygmy grass blue	22
Appias libythea olferna	Striped albatross	21
Chilades pandava pandava	Cycad blue	19
Junonia hedonia ida	Chocolate pansy	19
Pelopidas mathias mathias	Small branded swift	18
Catopsilia pyranthe pyranthe	Mottled emigrant	17
Phalanta phalantha phalantha	Leopard	16
Zizeeria maha serica	Pale grass blue	16
Acraea violae	Tawny coster	11
Elymnias hypermnestra agina	Common palmfly	11
Danaus chrysippus chrysippus	Plain tiger	10
Catopsilia scylla cornelia	Orange emigrant	9
Chilasa clytia clytia	Common mime	9
Prosotas dubiosa lumpura	Tailless line blue	9
Graphium agamemnon agamemnon	Tailed jay	8
Pelopidas assamensis	Great swift	8
Euthalia aconthea gurda	Baron	7
Hypolycaena erylus teatus	Common tit	7
Phaedyma columella singa	Short banded sailor	7
Suastus gremius gremius	Palm bob	7
Anthene emolus goberus	Ciliate blue	6
Papilio polytes romulus	Common mormon	6
Tajuria cippus maxentius	Peacock royal	6
Euploea spp.	Crows	4
Hypolimnas bolina bolina	Great eggfly	4
Anthene lycaenina miya	Pointed ciliate blue	3
Cephrenes trichopepla	Yellow palm dart	3
Doleschallia bisaltide bisaltide	Autumn leaf	3
Graphium sarpedon luctatius	Common bluebottle	3
Hypolimnas anomala anomala	Malayan eggfly	3
Junonia almana javana	Peacock pansy	3

Junonia orithya wallacei	Blue pansy	3
Neptis hylas papaja	Common sailor	3
Pachliopta aristolochiae asteris	Common rose	3
Catopyrops ancyra	Ancyra blue	2
Hasora chromus chromus	Common branded awl	2
Ideopsis vulgaris macrina	Blue glassy tiger	2
Iraota rochana boswelliana	Scarce silverstreak	2
Jamides bochus nabonassar	Dark caerulean	2
Troides helena cerberus	Common birdwing	2
Arhopala centaurus nakula	Centaur oakblue	1
Cupha erymanthis lotis	Rustic	1
Euthalia adonia pinwilli	Green baron	1
Iambrix salsala salsala	Chestnut bob	1
Leptosia nina malayana	Psyche	1
Lexias pardalis dirteana	Archduke	1
Nacaduba berenice icena	Rounded six-line blue	1
Polyura schreiber tisamenus	Blue nawab	1
Potanthus omaha omaha	Lesser dart	1
Rapala manea chozeba	Slate flash	1
Spalgis epius epius	Apefly	1
Tajuria dominus dominus	Sovereign royal	1

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Standards and Guidelines:

- Standards for Bird-Safe Buildings (2011) San Francisco Planning Department
- Bird-Friendly Development Guidelines (2007) City of Toronto Green Development Standard
- CS E9:2012 – Guidelines on planting trees, palms and tall shrubs on rooftop
- CS E10:2014 – Guidelines on Planting of trees, palms and tall shrubs on rooftop
- CS E11:2014 – Guidelines on Design for Safety of Skyrise Greenery

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- http://www1.toronto.ca
- www.nwf.org
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Relevant bodies and NGOs:

- Nature Society Singapore (NSS)
- Butterfly Circle
- Singapore Association of Environmental Companies (SAFECO)
- Singapore Environment Council (SEC)

Relevant Acts, Regulations and Masterplan:

- Nature Reserves Recreational Masterplan
- Singapore Green Plan
- URA Concept Plan and 50++ Development Guide Plans (DGPs)
- The Land Acquisition Act
- National Parks Act
- Singapore Red List