Centre for Urban Greenery & Ecology

SUSTAINABLE LANDSCAPE

CUGE
CENTRE FOR URBAN GREENERY AND ECOLOGY

BCA GREEN MARK

NATIONAL PARKS

SUSTAINABLE LANDSCAPE

Published by:
Centre for Urban Greenery & Ecology
National Parks Board Headquarters
1 Cluny Road
Singapore 259569

SUSTAINABLE LANDSCAPE

Published by
Centre for Urban Greenery & Ecology
National Parks Board
1 Cluny Road
Singapore 259569

ISBN: 978-981-09-5218-1

CONTENTS

INTRODUCTION

This book invites landscape developers, designers, installers and practitioners to take a closer look at managing urban landscape from a sustainability perspective. It addresses the major problems of sustainable landscape management which are labour shortage and productivity. By focusing on principles of productive maintenance for various landscape components and reviewing the infrastructure needed for equipment and machinery access, this book provides new and creative solutions for future design and upgrading works.

The expertise of managers, practitioners and researchers has been drawn upon in identifying common maintenance issues and offering alternatives for various scenarios. This book hopes to close gaps involving horticultural management techniques and technology between the stages of planning design, execution and subsequent maintenance; and open up the way for more sustainable approaches and practices for future new and upgrading project developments. It does not attempt to offer any direct one-on-one solutions or site specific situations, but seeks to pave the way forward to raise a better mechanised and more productive landscape maintenance workforce.

LAWNS

Sustainable Turf Design and Maintenance

1. Site Preparation and Turf Planting

1.1 Introduction

The planting medium is the most important factor that determines plant growth and stability. Site construction involves key steps such as choosing the right soil mix, grading and drainage. Any compromise in site preparation will incur more costs in terms of maintenance and manpower.

1.2 Grading and drainage

Grading and drainage are very important to ease turf maintenance. Grading enables uniform mowing and drainage helps to prevent waterlogging. Inadequate drainage can be a major problem. The drainage should be adequate to ensure root zone water infiltration rates of at least 50 mm/hour, and in high traffic areas it should be at least 100 mm/hour. Ultimately both grading and drainage will allow for a better turf root system, leading to a turf stand that is healthier and of higher quality.

There are several steps in the grading process:

- Remove and dispose of all existing onsite turf sod prior to grading.
- Eliminate undesirable weeds.
- Retain the original soil if it is in good condition.
- Grade the sub-base and add drainage layers and/or root zone layer when preparing for a high utility lawn.
- If a site has developed soil, save the valuable top soil (30 cm) for the turf root zone.
- Establish sub-base grading to provide an even and stable foundation for the root zone media.
- Ideally, a 2% grading should be incorporated into turf areas.
- Grading must be done away from existing structures.
- Remove all large rocks, construction debris and undecomposed organic matter during grading.

1.3 Soil mix

The right soil mix has to be chosen based on the following factors:

- Texture
- Water holding capacity
- Organic content
- Resilience to traffic.

Based on these properties, NParks has an Approved Soil Mix (ASM) recommended for turfing in Singapore. The ASM consists of 3 parts loamy soil, 2 parts mature compost and 1 part sand. The compost must be well matured before it is incorporated into the ASM. Studies conducted by CUGE have shown that this soil mix is suited for turfing in parks and streetscapes. However, it has to be altered depending on where it is used. For example, high traffic sites will need less loamy soil and more sand in the mix.

1.4 Soil compaction

Soil compaction is the compressing of soil particles to reduce pore space. Pore spaces are the gaps between the soil particles that are filled by air. Compaction due to human traffic and vehicle traffic reduces the pore space as well as the oxygen level in the soil. Turfgrass roots require oxygen for respiration. The growth of turfgrass can be affected by root zone anoxia

(when there is no oxygen in the soil) and hypoxia (when the oxygen level is low). A poor or inappropriate soil mix will be easily compacted and will need to be aerated frequently through different techniques.

1.5 Turf planting

There are many turf planting methods such as seeding, sodding, close turfing, plugging and hydrosprigging, depending on how quickly and effectively a lawn needs to be established. Seeding is not recommended for commercial turf planting as it takes more time for establishment compared to vegetative propagation. Sodding and close turfing are more common and effective methods in Singapore. Sodding is done using turf sods of dense and thatchy species. Close turfing is similar to sodding, but uses turf species like Cowgrass that does not form dense sods and thatch. Buying clean and quality sods plays a vital role in turf planting and post-planting maintenance. When low quality sods are used, there will be compatibility problems between the turf root and soil mix. A quality sod must be free of weeds and soil (loamy) that was raised in sand-based nursery beds. Turf root and soil mix incompatibility problems arise when low quality sods are used.

Compacted soil

Good sod with good roots and less soil, grown on sand

Poor quality sod with clay soil

1.6 Hydrosprigging

Hydrosprigging is a planting method that utilises a slurry of mulch, grass sprigs, fertiliser, tackifier, dye (optional) and water. The slurry is usually sprayed using a hose pipe with high pressure. Hydrosprigging is widely used for turf planting in golf courses, roadside planting and larger areas, especially on slopes where there is a significant risk of erosion occurring during the period of initial turf establishment. Besides the major slurry components (mulch, grass sprigs, fertiliser, tackifier and water), other additives used to stimulate and sustain growth can also be included. Commonly used mulches are either wood fibre mulch or paper mulch.

The main role of the mulch is to hold moisture, act as a substrate, protect the sprigs and improve the soil quality as it breaks down. Depending on the availability and cost, any kind of cellulose-rich mulch can be evaluated and incorporated. Common cellulose-rich mulches include coco peat, sugarcane baggase and paddy straw. The mulch particle size must not exceed 20mm so that the spray's nozzle will not be clogged.

Grass sprigs are nothing but live stolons and rhizomes harvested and processed to achieve the desired size (mm diameter) in order to pass through the spray nozzle. The sprigs can either be mixed in the slurry and applied or spread over the soil followed by the slurry application (excluding sprigs), depending on one's convenience. Nutrient demand is fulfilled by adding a starter fertiliser (with an NPK ratio of 1:2:1) at the recommended dosage.

Tackifiers or tackifying agents are horticultural glue that binds together the various compounds of the slurry and "stick" it to the soil. It prevents the slurry from being washed away from the soil. One of the most commonly used organic tackifier is guar gum, which is extracted from the seeds of cluster beans (*Cyamopsis tetragonolobus*).

Hydrosprigging has many advantages over conventional planting methods like sodding and close turfing, such as:

- Time saving
- Labour saving
- Increased productivity
- Unaffected by terrain, soil moisture or obstacles
- Even planting with higher survivability
- Lower cost
- Faster turf coverage.

Hydrosprigging application using cocopeat mulch slurry

2. Soil Fertility Management

2.1 Introduction

Turfgrass health and tolerance to stress (both biotic and abiotic/environmental stress) depends on the health of the soil, which includes both soil physical and chemical properties. The importance of the physical properties of soil has been already covered under "Site preparation and turf planting". Soil chemical properties include nutrient status, pH, electrical conductivity (EC), etc. Turfgrasses need nitrogen (N), phosphorus (P) and potassium (K) for normal growth like all other plants. Turfgrasses require high N compared to other ornamental plants. Lack of these major nutrients will make turfgrasses more susceptible to stress factors indirectly leading to high maintenance for achieving a quality lawn.

2.2 Major sources of nutrients

The two major sources of nutrients are the soil mix (mainly compost) and regular fertiliser application. Studies conducted by CUGE have shown that turf grown on a nutrient rich ASM with well-matured compost can sustain quality growth even without any fertiliser application for a period of 15 months. For most of the sites where soil conditions are poor, a monthly application of fertiliser is a must. Slow release nitrogenous turf fertilisers with NPK 4:1:2 must be used. The application rate varies from 0.1 kg N/100m^2 to 0.4 kg N/100 m^2, depending on the soil status and lawn usage.

3. Species Selection

3.1 Introduction

Turfgrass species growth and sustainability depends on climate, soil pH, environmental stress and maintenance level. Turfgrass species are broadly classified into warm season and cool season turfgrasses. Warm season turfgrasses perform well in tropical places like Singapore. There are around 12 common warm season turfgrass species. The most common ones in Singapore are *Axonopus compressus* (cowgrass), *Axonopus sp.* (pearlgrass), *Paspalum vaginatum* (seashore paspalum), *Stenotaphrum secundatum* (St. Augustinegrass) and *Zoysia matrella* (Manilagrass or carpetgrass). These turfgrass species differ in characteristics and environmental preference (stress tolerance). Selecting the right turfgrass species for the right site condition solves many problems related to maintenance. This ultimately paves the way for a productive turf and sustainable turf maintenance.

3.2 Stress tolerance

Some of the common warm season turfgrasses have the ability to overcome certain environmental stresses and exhibit acceptable turf quality. This is made possible through morphological, physiological and anatomical adaptations which occur in these turfgrass species through their unique, naturally in-built genotype. These stress-tolerant behaviours can also be found in some of the improved cultivars that are bred for such qualities.

3.3 Low maintenance

Low turf maintenance, in a practical sense, means a reduction in mowing frequency. Other low maintenance practices are only secondary. A selection of turf species suited for low maintenance should be considered before planning for fewer mowing frequencies. Slow-growing turf species that

exhibit good turf quality even under very low frequency of mowing are best suited. Common turf species with a low vertical growth rate are pearlgrass (*Axonopus compressus*), Manilagrass (*Zoysia matrella*) and Serangoongrass (*Digitaria didactyla*). The selected turf species must also be accompanied by special management practices (low inputs).

4. Weed Management

4.1 Introduction

Anything other than the main intended turf species is referred to as a weed. Weeds compete with the main turf for nutrients, water, space and light. Weeds affect the uniformity of a lawn and make it aesthetically poor. Weeding needs to be done effectively by uprooting completely (manual weeding) and killing completely (chemical weeding). Improper weeding will result in an increase in the weed population instead of decreasing or controlling it.

4.2 Major sources of weeds

Weeds are usually propagated and spread through seeds, stolons and rhizomes. The major sources of weeds are:

- Seeds and stolons in the parent soil (existing site)
- Sod material
- Soil tools
- Soil mix
- Compost.

4.3 Sustainable weed control

Sustainable weed control starts right from the site preparation by checking on all major weed sources. This will lead to a low maintenance (in terms of weeding) and high productivity (time and labour savings).

Steps to be followed for a sustainable weed control:

- Existing weeds in a site must be killed completely before site preparation.
- The ingredients in the soil mix must be free of weeds.
- The compost used for topping and also in the soil mix must be well matured (free of weeds).
- Sod materials must be weed free and purchased from standard nurseries.
- Clean tools must be used during site preparation and maintenance.
- During maintenance, regular weeding must be done before the weeds start to flower.

5. Environmental Stress Management

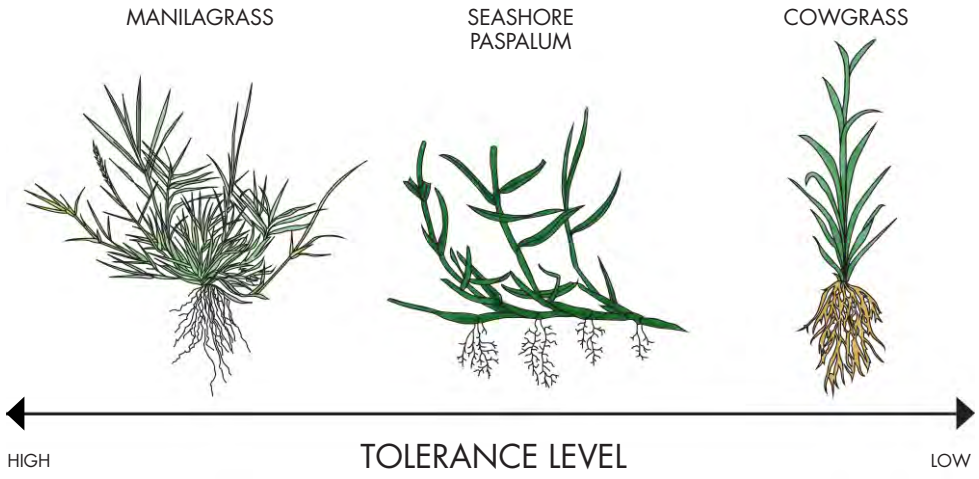
5.1 Introduction

Turfgrasses need to undergo various stress factors especially in an urban environment. Plant stresses are broadly classified into two — biotic and abiotic stress. Biotic stress is mostly caused by biotic agents such as pests and diseases. Abiotic stress is caused by various environmental factors such as shade, water, traffic and temperature. These environmental stresses cannot be altered and can only be overcome by species selection and special management practices.

5.2 Traffic stress

Traffic stress is a major issue for utility turf. Utility or recreational turf refers to turfgrass sites that are not only developed for aesthetic purposes but also for human activities. All parks, sports fields and golf courses come under utility turfgrass sites. The prime objective of laying turfgrasses in parks is to provide space for recreational activities and to hold events. There is thus a challenge of maintaining good quality turf under severe traffic stress.

Traffic stress is the result of soil compaction and turfgrass wear and tear caused by human activities and vehicle movement. Traffic stress is influenced by various factors including soil type, turfgrass species and soil fertility. Both the selection of traffic-tolerant turfgrass species and suitable soil types (during site establishment) must be given equal importance and attention. The traffic tolerance of common warm season grasses, based on a study conducted by CUGE, is given in the diagram below.



Impact of traffic stress on three different turfgrass species
Manilagrass (left), Seashore paspalum (middle) and Cowgrass (right)

Special management practices turf under traffic stress:

- Fertiliser application must be regular (0.2–0.4 kg N/100 m^2/month).
- Optimum moisture level must be maintained in the soil through proper drainage.
- Regular aeration must be practised (*please refer to CUGE Guidelines for Tropical Turfgrass Installation and Management*).

Turfgrass traffic stress in parks (above) and streetscapes (below)

A landscape designer must be able to observe human preference and avoid human access points (shortcuts) when designing a lawn. Failing to do so will result in man-made paths (bare patches or exposed soil surface) as a result of high traffic. More emphasis must be given to this aspect rather than landscape symmetry and aesthetics, as failing to do so will ultimately spoil the aesthetics and increase maintenance.

5.3 Shade stress

Shade is another key issue for turfgrasses in Singapore, both in parks and streetscapes with a high tree population. Turfgrasses are also an essential component of urban greenery as they act as groundcovers. This imposes challenges when establishing and maintaining turfgrasses under tree shade that cannot be avoided.

Shade stress imposed by trees (left) and concrete structures (right)

Selecting shade-tolerant turfgrass species is the best solution. Most warm season turfgrass species can tolerate partial shade but under full shade, only few turfgrass species can do well. Partial shade and full shade refer to the number of light hours per day that sites receive. If a site receives full sunlight for only 6 hours or less per day, it is in partial shade. Sites that are in full shade do not receive full sunlight throughout the day. In general terms, shade stress refers to full shade. Improved cultivars of shade-tolerant turfgrass species have better shade tolerance. Under intense shade (>70%), it is recommended to use shade-tolerant groundcover plants. The shade tolerance of common warm season grasses, based on research by CUGE, is given in the table below.

SHADE LEVEL				
50%		***70%***		***80%***
St. Augustinegrass	**HIGH**	**St. Augustinegrass**	**HIGH**	**Pearlgrass**
Pearlgrass	↑	**Pearlgrass**	↑	**St. Augustinegrass**
Cowgrass		**Cowgrass**		Cowgrass
Serangoongrass		**Serangoongrass**		Serangoongrass
US carpetgrass		**US carpetgrass**		US carpetgrass
Seashore paspalum		Seashore paspalum		Seashore paspalum
Manilagrass		Manilagrass		Manilagrass
Japanese lawngrass		Japanese lawngrass		Japanese lawngrass
Templegrass		Templegrass		Templegrass
Bahiagrass		Bahiagrass		Bahiagrass
Bermudagrass	↓	Bermudagrass	↓	Bermudagrass
Kikuyugrass	**LOW**	Kikuyugrass	**LOW**	Kikuyugrass

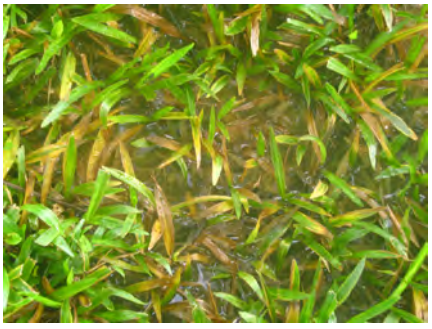
The turfgrass species which showed acceptable turf quality under various shade levels are highlighted above. Under 50% and 70% shade, Pearlgrass was rated lower than St. Augustinegrass and was on par with Cowgrass because of its slow growth and spread. Under 80% shade, however, Pearlgrass was a better performer compared to all other turfgrass species.

Special management practices turf for under shade stress conditions:

- For turfgrass species under shade stress conditions, close mowing must be avoided.
- Mowing height can be fixed at 50–70 mm from soil surface.
- Fertiliser application must be moderate (0.2 kg N/100 m^2/ year) as excess nitrogen will lead to a high incidence of diseases.

5.4 Wet soils (waterlogging stress)

Wet soils and flooded conditions are generally not suitable for plants except aquatic and semi-aquatic plants. Still, planting has to be done in wet soils to obtain a uniform green cover. In addition to the aesthetic value of a site, turfgrasses also contribute to biodiversity enhancement and phytoremediation.

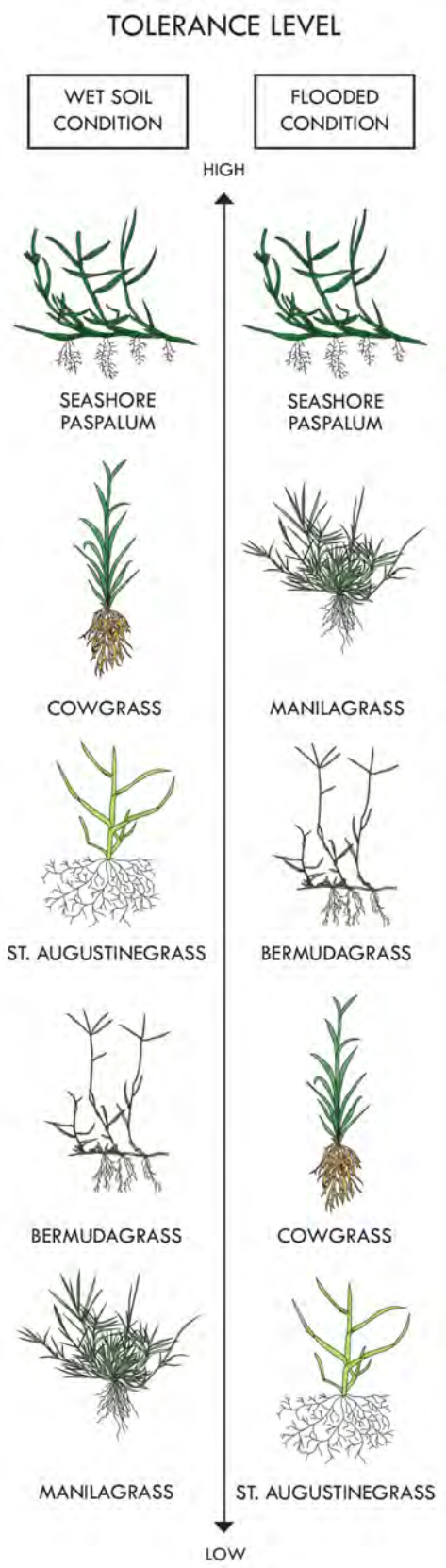


Waterlogged conditions

Ameliorating wet conditions and selecting tolerant turf species are the two important points to be considered before planting turf in wet soils. Between these two, priority must be given to soil amelioration. Selecting tolerant turf species gains more importance under circumstances where soil amelioration is not possible. For example, soil amelioration is not possible at sites near lakes and rivers where wet soil conditions will occur irrespective of the soil type and drainage. Turf quality on par with a well-maintained turf (normal aerated soils) cannot be expected under wet soils even with tolerant turf species. The waterlogging tolerance of common warm season grasses based on a study by CUGE is given in the table on the right.

Special management practices for turf under wet soil conditions:

- For these turfgrass species (under wet conditions), mowing has to be done at a minimum level.
- To reduce flooding injury, at least a portion (30–40%) of the turfgrass must be exposed to atmospheric oxygen because atmospheric oxygen needs to be passed to the roots through aerenchyma.
- Mowing height can be fixed by leaving 50 mm of live shoots above the water level or above the wet soil surface.
- Fertiliser application must be minimal (0.1–0.2 kg N/100 m^2/ year) as the nutrient uptake will be less. Also, excess fertiliser might injure the turf.



5.5 Combined stress

Urban environments often have conditions where complex stresses prevail. The most common complex stress is a combination of shade and traffic stress. Singapore's parks are mainly for recreation and have a high tree population. As a result, there is both traffic and shade stress. To overcome such problems, species selection has to be done by choosing a turfgrass species that is moderate to highly tolerant to both these stresses.

6. Productive Turf Mowing

6.1 Introduction

Mowing is the most important turf maintenance activity that determines productivity in terms of cost and manpower. Regular mowing and grass cutting is a must for an aesthetically pleasing, accessible and quality lawn. Mowing frequency cannot be fixed based on standards. It should be guided by utility and growth rate of turfgrass, which can vary depending on the following aspects:

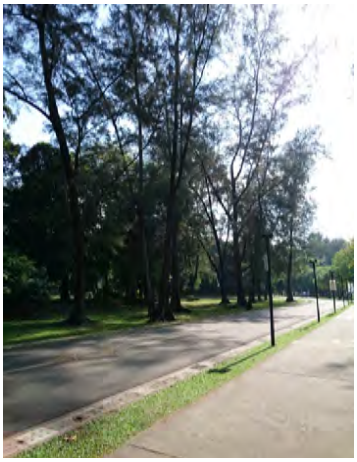
- Utility:
  - ♦ Type of sports
  - ♦ Park lawns
  - ♦ Streetscape turf
  - ♦ Event lawns.

- Turfgrass growth rate:
  - ♦ Turfgrass species
  - ♦ Soil fertility
  - ♦ Irrigation
  - ♦ Climatic factors.

Mowing has to be done based on the turf's conditions and needs. This way, an effective mowing schedule will help to increase productivity. A selection of slow-growing (vertical growth) turfgrass species is also important for productive turf maintenance.

6.2 Designing lawns for effective mowing and grass cutting

In landscape design, the lawn or turf should be well integrated with other components such as trees, shrubs, rocks, hard surfaces, furniture, etc., to ease maintenance. Otherwise, these components can become major hurdles for turf mowing and ultimately lead to high turf maintenance. The following criteria must be followed while designing to integrate the turf with other components:



- Grass surface must be on par or slightly higher than hard surfaces (pavements or paths) to ease turf mowing.
- Narrow strips of grass and small grass patches must be avoided as they can incur significant maintenance.
- Planting a turf close to a tree base and trees with shallow roots must be avoided. The tree base can instead be covered with mulch until a certain diameter.
- Mowing hurdles such as rocks, trees and shrubs must be minimal to ease mowing. Continuous and uniform lawns are more desirable.
- Turf planting on steep slopes where grass cutting can be performed only by using backpack grass cutters must be avoided. Low maintenance ground covers can be planted instead.
- The ground underneath benches/seats must have a hard surface instead of

grass to reduce maintenance.
- Turf components must have a proper access for mowing machines.

Apart from designing, proper site construction and planting also play a vital role in promoting effective mowing. As discussed previously under site construction, grading and levelling are very much important. Uneven planting, uneven ground and poor site restoration will lead to uneven mowing.

6.3 Reducing mowing frequency through PGR application

Mowing requires the use of manpower and fuel. Coupled with the frequency required, it incurs a significant cost. The application of plant growth regulators (PGR) helps to reduce the vertical growth of turfgrass, hence reducing mowing frequency.

An anti-gibberellin compound (plant hormone that promotes shoot elongation) can be applied to regulate the growth and development of turfgrass by reducing the synthesis of gibberellins in a plant system and regulating it. Trinexapacethyl is an anti-gibberellin compound that can be applied on turfgrass to keep the leaf blades short as it restricts vertical growth. Through PGR application, the mowing frequency of a lawn can be reduced.

One PGR application on turf can replace 4 times of mowing (5 times for streetscape). Translated into cost reduction, PGR application can save about 30% of total mowing costs and 70% of manpower requirements. As a result, landscape productivity can be enhanced by a reduction in labour requirement.

TURF SPECIES	*AXONOPUS COMPRESSUS*	*PASPALUM VAGINATUM*	*ZOYSIA MATRELLA*
CONCENTRATION OF PGR	1.5 L/ha	1.2 L/ha	1 L/ha

Recommended rate of PGR (Trinexapacethyl) application

Untreated **Treated**

PGR application in *Zoysia matrella* resulted in reduction of leaf sizes, hence reducing mowing frequency

PARKS

Park Maintenance Productivity

1. Softscape
   - *1.1 Plants*
   - *1.2 Mulching*
2. Hardscape
   - *2.1 Paving materials*
   - *2.2 Park amenities*
   - *2.3 Other park features*
3. Themed Gardens
   - *3.1 Butterfly gardens*
   - *3.2 Dragonfly ponds*
   - *3.3 Fragrant gardens*
   - *3.4 Herb gardens*

1. Softscape

1.1 Plants

Plants are key softscape components of landscape design. Being living organisms, their maintenance methodology and regime are very different from that of hardscapes like shelters and benches. Plants change in form, shape, size and behaviour over time and seasons. These changes have to be taken into consideration during the design and planning stages so that future maintenance issues can be reduced to a minimum.

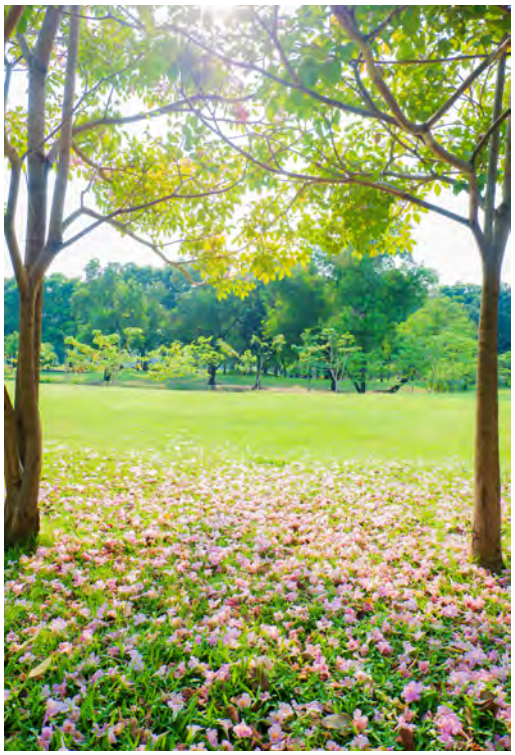
1.1.1 Trees

Tree maintenance tends to be site and species specific. Different species of trees behave differently under different site conditions. It is important during the design stage to ensure that plants are placed at the best planting locations.

a) *Deciduous plants*: These plants shed their leaves seasonally and can cause leaf-littering problems to their surroundings. Special attention must be given in proposing the locations of these trees at the planning and design stages, to deal with the effects of falling leaves and flower petals.

Deciduous trees should be located away from water bodies as leaves that fall in the water will need to be removed, increasing maintenance work. Pumps and filters that are choked by fallen leaves will incur costly repairs. The planting of deciduous trees near surface drains will also result in drains being choked as well as stagnant water, which can lead to mosquito breeding. Extra effort would have to be put in to clear the chokage.

Deciduous trees should not be selected along the roads as fallen leaves on the roads will be a maintenance issue. This applies to trees with big or heavy fruits as well as these fruits may fall on passing vehicles or pedestrians. Deciduous trees should be planted away from footpaths and areas where there is pedestrian movement to prevent accidents. Fallen flower petals, for instance, may cause slip and fall. They may also be aesthetically unpleasant.



Deciduous trees (*Tabebuia rosea*) shed leaves and flowers

b) *Design for tree pruning*: Trees that require regular pruning in parks should be located near an access way for trucks (at least 4m wide). This is to facilitate the use of cranes for pruning and eliminate the need for tree climbing. A sufficient turning radius should also be provided when planning the access way in order to bring the trucks and cranes in and out of the park easily.

The ground must also be able to withstand the weight of the crane to carry out tree pruning

1.1.2 Palms

a) *Cluster palms*: Cluster palms are often used as hedges or for screening in parks. They are often planted in areas near toilets or other facilities in parks that require screening.

Some cluster palms have spikes or spines on them, e.g. *Oncosperma tigillarium*. These palms should not be planted near footpaths or in areas where there is public access.

Due to the dense foliage of some cluster palm species, it is important to eliminate possible blind spots that would be formed by the placement of the palms when designing the planting plan. This is especially important if the palms are planted next to a cycling paths. It is extremely dangerous as cyclists travelling at high speed would not be able to see pedestrians who are around the corner, behind a cluster of dense palms.

It is also important to note that palm roots tend to grow downwards, unlike that of a tree, which tends to grow laterally. This allows palms to be grown in confined spaces like planter boxes or narrow planting verges.

b) *Single stem palms*: Single stem palms are often planted in front of park entrances or around significant areas of the park as accents or features. This is especially true for some of the more majestically looking species like *Roystonea regia*, *Livistonia rotundifolia*, *Phoenix sylvestris* and *Prichardia pacifica*.

Although single stem palms do not provide much shade, they generally require less maintenance as compared to trees. However, it is still necessary to remove any fallen fronds on site as the sheaths of the fronds often collect water and might result in mosquito breeding. It is important to regularly remove dead fronds and fruits as they are often heavy and can cause severe injury to park users if they fall from height. Very often, the palms are so tall that a boom lift or crane is required to access the fronds for maintenance.

Palms require regular maintenance to remove fronds and fruits

1.1.3 Shrubs

Shrubs are commonly used to enhance landmarks, mark boundaries and for screening. Using the correct species for the right purpose is important, for example, to screen a substation or block of toilets, the shrub selected has to be dense, low branching and upright, like a hedge. A commonly selected species for this purpose is *Syzygium myrtifolium (Eugenia oleina).*

Shrubs generally require higher maintenance as compared to trees. However, the correct selection of shrub species for a given location and environment can eliminate many of these maintenance issues. Some shrubs require a high level of maintenance because they need to be fertilised and watered frequently, especially at the establishment stage.

***Syzygium myrtifolium* is an effective hedge due to its dense and colourful foliage**

Some shrubs tend to become 'leggy' if not pruned properly. A few examples of common species that exhibits this characteristic are *Jatropha integerrima, Caesalpinia pulcherrima and Lagerstroemia indica.* To reduce the frequency of pruning, these shrubs should be planted behind shorter, denser shrubs or groundcovers in a planting composition. This way, the shorter shrubs or groundcovers can help screen off the bare lower portions of these 'leggy' shrubs.

'Leggy' shrubs (*Caesalpinia pulcherrima*) with bare lower branches

Species selected for planting in a specific environment should be those that will adapt well to the site conditions. For example, shrub species selected for planting at coastlines need to easily adapt to sandy soils and salt sprays in order to flourish.

Very often, groundcovers and lawns are trampled over by park users causing damage to plants and puddles of mud to be formed on the lawns. This is especially the case when the shrubs are in the way of the shortest route of circulation in the park. This then makes circulation planning in the park during the design and development stages of a park extremely important. Careful consideration should be given to human behaviour while travelling from point A to point B in parks.

1.1.4 Groundcovers

Groundcovers are often planted next to or over hard objects like retaining walls and planter boxes for aesthetic purposes, to help soften the otherwise hard edges. They are also planted on slopes to help stabilise them and prevent soil erosion on slopes. Some species of groundcovers can tolerate shade and can be planted at the foot of shady trees and in the shadows of building structures. Low groundcovers, however, are not suitable to be planted in areas where there are high pedestrian and vehicular traffic, like car parks. Surface material, tall dense shrubs, or hard paving is generally preferred in these situations.

Groundcovers generally require relatively low maintenance. Ferns, for example, can go without pruning for months. During the design and development stages, care must be taken to ensure that the corners of groundcover beds are not at an acute angle as park users would just take a shortcut and trample over the planting beds.

1.1.5 Bamboo

Bamboo is generally not proposed in parks unless it meets certain thematic requirements. For example, at a Chinese or Japanese themed garden. This is because most bamboo species shed massive amounts of leaves and if planted near a water body, can cause maintenance problems. When planted near drains, the shed leaves can cause the drains and other waterways to choke, resulting in mosquito breeding and even flooding.

Some species of bamboo are extremely dense in growth habit and can be difficult to maintain when rubbish is trapped inside the clusters. Rats can nest within the clusters, too, and bring about hygiene and snake problems in parks.

Bamboo shed leaves heavily and require frequent sweeping

Bamboo is known to be a sustainable building material because of its strength and rapid growth rate. However, because of this, bamboo can be extremely aggressive and invasive. Frequent pruning is required to prevent the bamboo cluster from growing sideways too quickly.

1.1.6 Climbers

Climbers are used in situations when plants are required at a higher level where soil cannot be located, for example, on trellises, link ways, pavilion roofs, bridges, pergolas. They only require a small planting space at ground level. Some species of climbers have showy inflorescence (such as *Bauhinia kockiana, Thunbergia grandiflora, Allamanda cathartica* and *Lonicera japonica*) and are popularly used to green up structures.

Dense and heavy climbers require strong structural support

Some common problems faced when using climbers are:

- A lack of water on the ground can often result in the browning of the climber's leaves. This can be mitigated by a careful selection of species as some require less water. For flowering climbers, it is encouraged to add fertiliser every 3 months.
- Some climbers grow into a dense, thick layer and bees and hornets tend to build their nests in such denseness. Frequent pruning is required to avoid this.
- Dense climbers also exert a lot of weight on supporting structures, sometimes resulting in the structural failure of these structures. The design of the structure should have a loading capacity to withstand the eventual weight of the climbers and maintenance crew and equipment.
- The design of the structures that will hold up the climbers should also take into consideration the growth habit of the climbers. Trellis or cables that are used to support the climbers are often spaced too far apart and certain species of climbers are unable to span that kind of gap.

1.1.7 Lawns

Lawns provide green open space in parks. Many parks have large open lawns for occasional events. Although cow grass (*Axonopus compressus*) is commonly used, other grass species may be used to create a fine lawn effect. Please refer to the previous chapter, "Lawns", for more information about lawns and lawn management.

1.2 Mulching

Mulching is performed on planted trees, palms, shrubs and groundcovers to help retain moisture in the soil around the plants and keep weeds out of the planting site. Composted mulch will also break down over time and provide nutrients for the plants.

Wood chips are often used as a material for mulching. However, if the chips are not broken down or decomposed properly, maintenance issues will crop up. Decomposing wood chips in soil causes the soil to become acidic due to nitrogen drawdown during the decomposing process of wood chips, which is not ideal for the growth of most plants. Moreover, the decomposing wood chips can be contaminated with millipede eggs, and when they hatch, the site will be infested with millipedes.

Decomposing wood chips infested with millipedes

When mulching the planting site of a tree, it is important to apply the mulch away from the collar of the tree. This is because the heat generated when the mulch starts to break down, combined with the retention of moisture caused by mulching, will cause the root collar of the tree to decay.

2. Hardscape

2.1 Paving materials

2.1.1 Asphalt

Asphalt is preferred over other materials for use in parks because it is more conducive to jog and cycle on. This is due to the shock absorbing quality that asphalt possesses. The relatively rougher texture also provides friction for both cyclists and joggers. On top of that, asphalt is relatively porous and allows water to percolate through it and into the soil.

Asphalt is naturally black but colour additives can be added. The base must be stable and well compacted to prevent cracks and repair.

Asphalt is most suitable for cycling paths in parks and park connectors

2.1.2 Cast in-situ concrete

Concrete is commonly used as paving finish as it is easy to repair. Concrete paving must be constructed with reinforcement steel bars on well-compacted base and with expansion joints for large surfaces. The surfaces can be slippery when wet or stained with algae and dirt and have to be cleaned by using high-pressure jet wash.

Concrete has to be reinforced with steel bars according to load requirements by Professional Engineers. Concrete benches tend to be hot under the sun, and when used for large surfaces, expansion joints need to be provided to prevent cracks. For large areas or long tracks, laying asphalt would be faster.

2.1.3 Concrete pavers

Concrete or block pavers are often considered to be more aesthetically pleasant when compared to asphalt and cast in-situ concrete. However, pavers protrude out when tree roots spread and grow underneath, or because of soil settlement. This makes the surface uneven and it becomes a tripping hazard. The foundation should thus be prepared well before laying pavers to prevent future problems like soil settlement.

Avoid having grass in crevices to reduce maintenance

Sometimes, pavers are laid in such a way that grass is allowed to grow in the crevices between pavers. This often leads to a maintenance issue as it is difficult to cut grass on such a surface.

2.1.4 Gravel

Loose gravel may be used as an inorganic mulch to prevent weed growth or at locations where there is water ponding to ease surface drainage. However, it is important to keep loose gravel and grass apart for safety during grass cutting. Loose gravel that come in contact with the rotating blades of a cutting machine can hit anyone nearby and cause injury.

Loose gravel beside grass can cause grasscutting hazard

When used as a subsoil drainage, loose gravel may choke with silt over time and cause drainage failure. It is necessary to repair the affected areas by replacing the filter membrane or separator underneath it.

2.2 Park amenities

2.2.1 Lights

One of the major causes of lighting failure in parks is water seepage in light fixtures. Designs should avoid specifying embedded inground lighting in exposed areas. Another common problem is improper routing and overload

caused by multiple lights, possibly from subsequent add-on installations. Regular maintenance checks, repair and servicing are required to ensure light fixtures are in working condition. All lighting and associated electrical cabling works must be carried out by a licensed electrical worker (LEW).

2.2.2 Handrails

Handrails should be provided for safety along ramps and steep steps/ staircases according to the guidelines in BCA Code on Accessibility in the Built Environment. Designs should be elderly friendly and should avoid sharp corners and acute bends for park users with disabilities.

When considering the structural strength of different materials, it is important to note that composite wood can warp depending on the composite materials' exposure to the elements. They are durable but generally expensive to replace. Stainless steel handrails are also durable but can be slippery when wet and uncomfortable to hold when exposed to the heat and glare of sunlight.

Handrails provided for staircase and ramp

2.2.3 Bollards

Bollards are used to control and regulate the access of motorised vehicles into parks. However, poor planning and design often results in the poor location of bollards. This, in return, often results in vehicles accidentally reversing into them and damaging them. A constant need to replace damaged bollards will increase maintenance costs and efforts. As such, placing the bollards away from turning points and blind spots of drivers will reduce the need to replace them. Reflective bands on bollards will improve their visibility at night. In areas where no underground services are located, retractable bollards can be considered.

It is also important to ensure that the material selected for the bollards is durable and of good quality. PVC bollards are good for cyclists as they will not get hurt if they hit them. The bollards are also able to bend back to shape after being mowed over by a vehicle. Stainless steel bollards are often stolen due to the high price of the material. Cast aluminium can also be an alternative.

Reflective band on bollards helps improve visibility

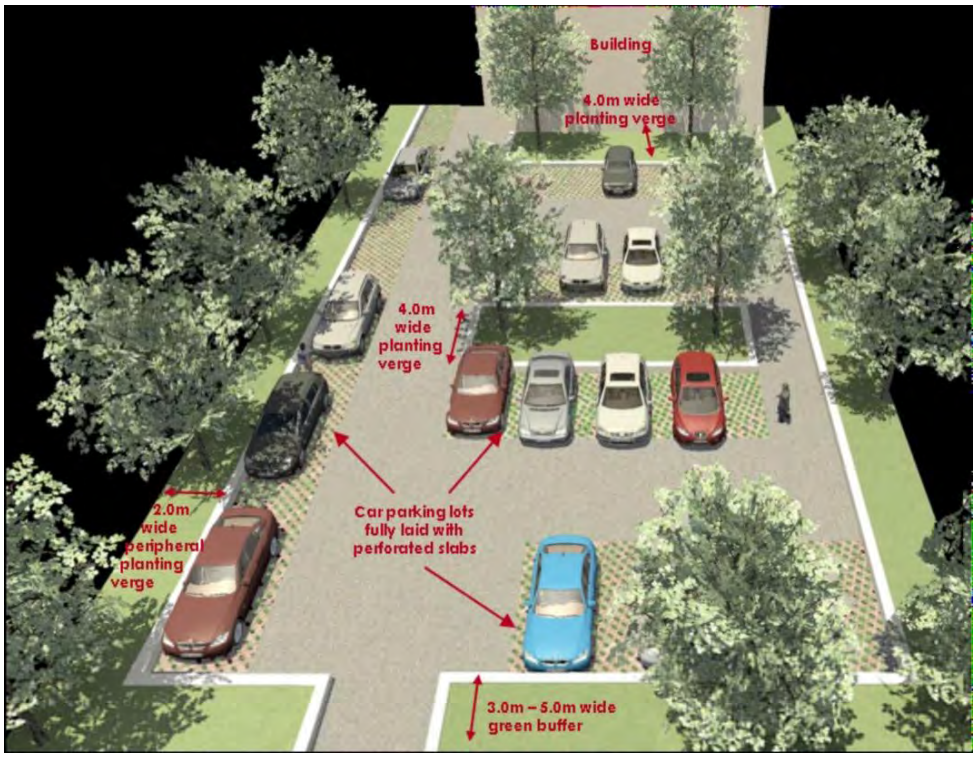
2.2.4 Shelters

The design of park shelters should provide adequate shade cover and protection from rain and lightning. Shelters should have a good location, be well lit and open for visual surveillance to discourage misuse by park users. General maintenance such as cleaning and clearing of leaves and other litter should be performed frequently. Periodic painting and repair works are also required for the upkeep of shelters.

Park shelter in open and safe location, slightly away from footpath

2.2.5 Car parks

For design of car parks, please refer to the *Handbook on Tree Conservation & Tree Planting Provision for Development Projects, PTRS Greenery Guidelines 4.1.10* (https://www.nparks.gov.sg/partner-us/developers-architects-and-engineers/development-plan-submission-requirements). Although it is encouraged to provide planting to reduce the harshness of the car park environment, it is important that the plants are located in areas that will not hinder the movement of people around the parked cars. There should be sufficient space behind cars for drivers to access their boots. There should also be sufficient lighting in car parks to ensure safety and discourage theft and vandalism.



Tree planting provision for open car park

2.2.6 Drains

Drains are often provided to prevent rainwater retention on footpaths and hard surfaces. Regular clearing of fallen leaves or rubbish will help to ensure smooth drainage and reduce potential mosquito breeding in stagnant water.

Drain covers made of precast porous slabs are easily damaged by the heavy weight of service vehicles and weathering after a few years. Galvanised steel plates and gratings make stronger and more durable drain covers. Although stainless steel plates and gratings will require less maintenance, they are vulnerable to theft and not recommended for public parks. For the safety of park users, gratings should be installed perpendicular to footpaths to avoid bicycle wheels from getting wedged in between the gratings.

Galvanised steel plates and gratings over drains

When installing subsoil drainage it is important to consider that drainage of rainwater can be choked by silt over a period of time. Careful detailing and design can help to resolve some of these problems. Alternative forms of drainage such as bioswales, can be used to drain sites. They can also help to create a beautiful and natural setting within the park.

2.3 Other park features

2.3.1 Planter boxes

Planter boxes provide an opportunity to control soil media. The amount of soil in planter boxes is usually limited in volume, as compared to planting in the ground. The water content is also lower as planter boxes are designed to be drained efficiently.

Planter boxes are useful for confining shrubs. However, when trees that have invasive and aggressive root growth are planted inside planter boxes, the roots tend to crack the walls of planter boxes. Another common problem with planter boxes is waterlogging, caused by drainage systems that are not designed properly.

Therefore, during the design process, it is very important that a careful selection of plant species to be planted in planter boxes be made. Equally important is the design of a proper drainage system to prevent ponding in the planter boxes.

2.3.2 Sandpits

A common challenge for managing sandpits is how to effectively contain the sand within the pits. Play activities, heavy trampling, strong winds, etc. often

cause the sand to spill over to nearby footpaths and amenities. One way to mediate this is to place sandpits away from areas where sand is undesirable, such as footpaths, where sand can often cause slipping accidents.

Weeds often grow on sand and they can cause the sandpit to be unsightly and poorly maintained. Regular weed removal has to be factored into the maintenance regime. Racking sand to remove weeds and other debris is a must.

Sand is contained within grass slopes all around and sheltered from strong winds

2.3.3 Wooden decks

Warping is often a problem faced when working with timber. To resolve this, one way is to procure high-quality treated timber, but it would inflate the cost of the project. Alternatively, composite timber or glass fibre reinforced concrete (GFRC) could be used. They can be made to look like real timber and do not have warping tendencies.

Algae often grows on timber decks and become a slipping hazard. Regular jet washing has to be factored into the maintenance programme. One preventive measure is to reduce the shade cover caused by canopies of tree crowns above. This can be done at the design stage by locating timber decks away from shady areas.

Algae on timber deck can be a slipping hazard

2.3.4 Water features

Water features are not recommended in parks due to their requirement for high maintenance. It is necessary to ensure that water features are well aerated, such as using water jets. To ensure water features are well aerated, pumps or sumps are required, but they take up a lot of space. There is also a need for a filtration chamber, depending on the scale of the water feature.

Bio-swales can create a natural park setting

Rain gardens or bioswale/ bioretention ponds may also be created in parks for stormwater management. Bioswales only fill up with water when it rains and the rainwater is able to percolate into the ground slowly. Plants planted in the swales will help to filter the rainwater before they are released into the drainage system.

Water features that are created need to comply with PUB's Code of Practice (COP) on Surface Water Drainage (http://www.pub.gov.sg/general/Documents/ CP2013/COP_Final.pdf).

3. Themed Gardens

3.1 Butterfly gardens

Butterfly gardens are getting more and more popular nowadays. If successfully implemented, butterflies are a good attraction and a good way for visitors to enjoy the garden. However, the eating habits of caterpillars leave unsightly plants. One solution is to plant caterpillar host plants behind nectar plants or other shrubs. This way, the eaten leaves and unsightly plants can be hidden from view while continuing to supply food for the caterpillars.

Nectar and host plants are needed to create a butterfly habitat

Different types of plants will host different species of butterflies. It is important to have a variety of host plants so that the butterfly garden can exhibit various butterfly species. Examples of plants that attract butterflies are:

- *Aristolochia acuminata* (climber)
- *Hoya* spp. (climber)

- *Passiflora foetida* (climber)
- *Asclepias currasavica* (shrub)
- *Caesalpinia pulcherrima* (shrub)
- *Calotropis gigantea* (shrub)
- *Citrus maxima* (shrub)
- Big leaf varieties of *Ixora* spp. (shrub)
- *Lantana camara* (shrub)
- *Lespedeza bicolor* (shrub).

3.2 Dragonfly ponds

Plants in a pond provide a good habitat for dragonflies and its young. A dragonfly nymph needs to climb onto a plant to emerge as a dragonfly, and dragonflies need plants to perch and rest. Besides, dragonflies need water.

Typha, *Papyrus* and *Thalia* are good host plants for dragonflies. Apart from some trimming when the plants are overgrown or drying up, they need minimal care. Remember to leave a lot of space between the plants for dragonflies to fly.

Floating plants that cover about a third of the pond surface provide adequate shade for a balanced ecosystem. Examples of floating plants are:

- *Centella asiatica*
- *Echinodorus cordifolius* 'Marble Queen'
- *Echinodorus palifolius*
- *Hydrocotyle sibthorpioides*
- *Ludwigia sedioides*
- *Lysimachia nummularia*
- *Nelumbo nucifera* (Lotus)
- *Nymphaea* cultivar (Water Lily)
- *Nymphoides indica*
- *Pontederia cordata.*

Water plants can create habitats for dragonflies

Refer to the NParks Flora & Fauna Web (https://florafaunaweb.nparks.gov.sg) for more information about these plants.

About one-third of the pond's perimeter should be planted with emergent plants. They serve as perching posts for adults as well as places to lay eggs for female dragonflies. Some examples are:

- *Acorus calamus*
- *Acrostichum aureum*
- *Cyperus alternifolius*
- *Eleocharis dulcis*
- *Lepironia articulata*
- *Limnocharis flava*
- *Sagittaria lancifolia*
- *Sagittaria sagittifolia*
- *Thalia dealbata*
- *Thalia geniculata.*

More information about these plants can be obtained at the NParks Flora & Fauna Web (https://florafaunaweb.nparks.gov.sg).

3.3 Fragrant gardens

Fragrant plants can be planted together to create a thematic fragrant garden. Some plants are only fragrant at a certain time of the day whereas others only when they flower. It is important to select the plants carefully to ensure that the garden can be enjoyed throughout the day. Recommended fragrant plants include:

- *Quisqualis indica* (climber)
- *Vallaris glabra* (climber)
- *Plectranthus amboinicus* 'Variegatus' (herb)
- *Buddleja davidii* (shrub)
- *Gardenia jasminoides* (shrub)
- *Volkameria inermis* (shrub)
- *Wrightia religiosa* (shrub)
- *Hopea odorata* (tree)
- *Plumeria rubra* (tree)
- *Tarenna fragrans* (tree).

The NParks Flora & Fauna Web (https://florafaunaweb.nparks.gov.sg/) has more information about fragrant plants.

3.4 Herb gardens

Herbs need well-draining soil as their roots are very susceptible to pests and fungi attacks. Therefore, it is good to have sand, charcoal bits or volcanic sand added into the soil mix when potting these delicate plants. The composition of the potting mix is 1 portion of soil and 1 portion of compost to 0.5 portion of sand, charcoal bits or volcanic sand. A slow-releasing fertiliser may be applied as necessary.

Mint generally need moist and well-drained soil. Basically, all types of mint, be it chocolate, pineapple, apple, etc. need soil that is porous but still has the ability to retain water. Rosemary and thyme are herbs that need well-draining soil at least 75% of the time.

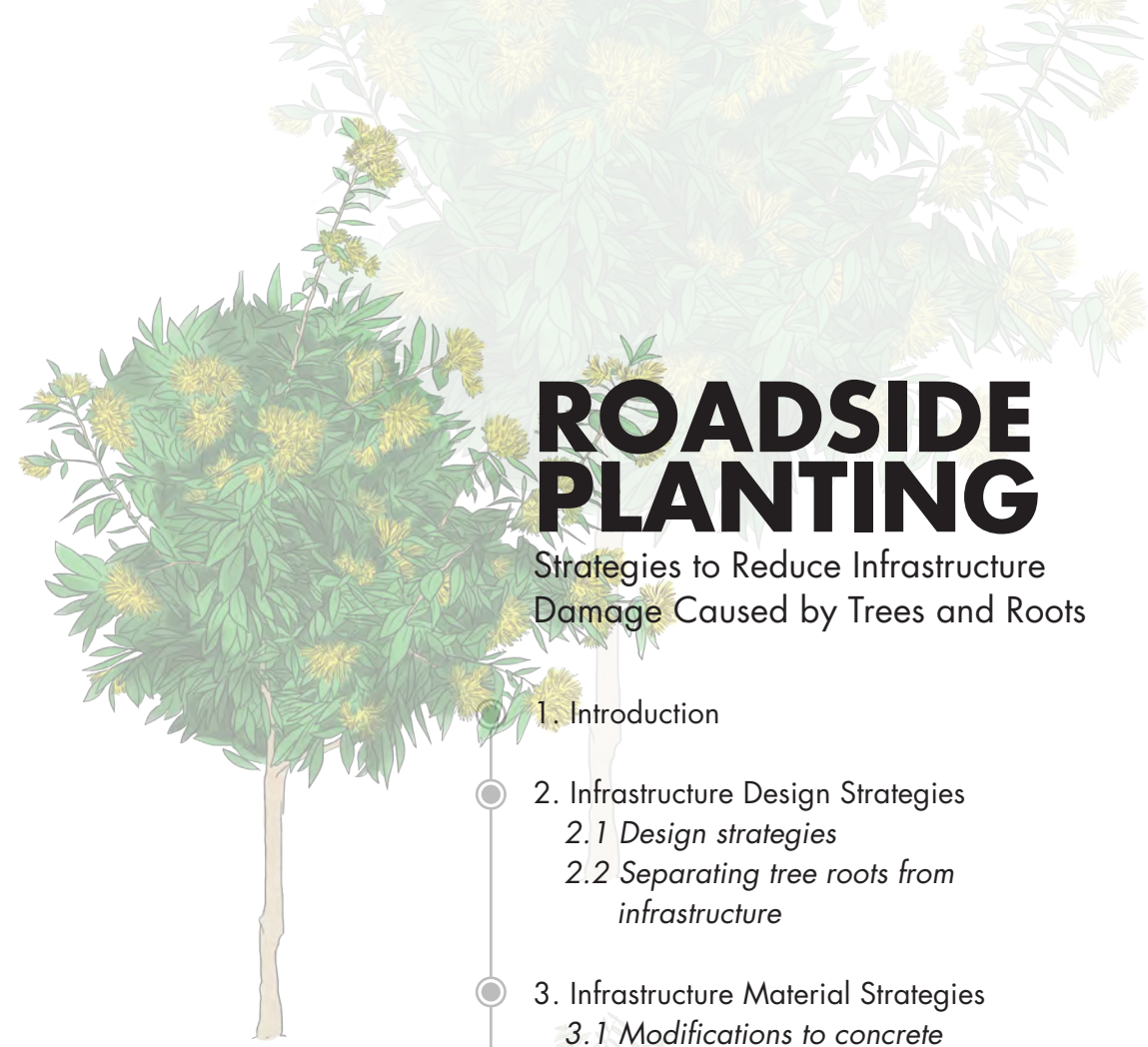
Examples of herbs that can be planted in a herb garden are:

- Basil
- Chili
- Curry leaf
- Hibiscus
- Indian borage
- Lemongrass
- Mint
- Pandan
- Rosemary
- Zinger.

Basil plant is useful as a herb and spice

More information about these herbs can be obtained from the NParks Flora & Fauna Web (https://florafaunaweb.nparks.gov.sg).

Herbs are mostly grown for education purposes and community gardening



ROADSIDE PLANTING

Strategies to Reduce Infrastructure Damage Caused by Trees and Roots

1. Introduction

As land use intensifies, it has become increasingly difficult to plant large trees in urban landscapes. Large trees require adequate planting space to grow healthily and achieve balanced tree form and canopy. The competition for planting space is more acute for roadside tree planting.

Many mature trees along older roads have been severely affected where planting strip is shared with underground services such as electrical cables and water pipes. In order to avoid damaging these services, tree roots have been cut or controlled, resulting in unbalanced and weak tree canopy growth. Over time, this has resulted in a gradual decline of well-formed, mature roadside trees.

Although newer road developments are now installed with service and planting strips side by side within the sidetable, it is important to note that the root growth volume to support large trees is at minimal provision.

In the process of upgrading footpaths, drains and other underground services, it is not uncommon for affected tree roots to be cut as a quick-fix solution, without proper professional advice as to whether the tree's stability and road safety will be endangered. With impending increase of hard infrastructure, roadside trees are faced with greater challenges to provide good shade canopy along roads.

For a sustainable city in a garden, there is a need to continuously develop solutions to ensure the co-existence of infrastructure and trees. The development of solutions and the exploration of technology through research and development are therefore needed to address and overcome these challenges.

Table 1 shows a list of strategies that will be covered in this chapter. It can serve as a summary for the strategies discussed and allow users to make an informed decision on the strategy that will best suit the range of problems that urban municipalities commonly face in maintaining and sustaining an urban city. Certified arborists should be engaged in all instances to advise on the applications of the various strategies.

Preventive strategies in the table on the next page can be defined as the ability to avoid or mitigate incipient problems before they become major defects. **Remedial strategies** can be defined as curative actions required for incipient problems and major defects.

INFRASTRUCTURE DESIGN STRATEGIES	PREVENTIVE	REMEDIAL
Bigger planting space	•	•
Curved footpaths	•	•
Pop-outs	•	•
Non-standard slab size		•
Monolithic footpaths	•	•
Tree islands	•	
Bridges and ramps	•	•
Lowered sites	•	
Modified gravel layer	•	•
INFRASTRUCTURE MATERIAL STRATEGIES	**PREVENTIVE**	**REMEDIAL**
Reinforced concrete slabs	•	•
Expansion joints	•	•
Thicker slabs	•	
Pervious concrete	•	•
Flexible concrete, footpaths and joints	•	•
Asphalt	•	•
Decomposed granite	•	•
Compacted gravel	•	•
Pavers	•	•
Recycled rubber	•	•
Mulch	•	•
Grinding		•
Wedges		•
Mud jacking		•
ROOT ZONE-BASED STRATEGIES	**PREVENTIVE**	**REMEDIAL**
Root barriers	•	•
Continuous trenches	•	
Root paths	•	
Root channels	•	
Steel plates		•
Foam underlay		•
Structural soil	•	
Structural cells	•	
Soil modification	•	

Table 1. Summary of strategies to reduce infrastructure damage caused by trees and roots

2. Infrastructure Design Strategies

2.1 Design strategies

2.1.1 Bigger planting space

Infrastructure damage is often caused by trees that outgrow their planting space. Providing adequate space for new trees by using larger planting sites and tree islands are key preventative strategies to consider.

The larger the planting space, the lower the potential for damage from trunk expansion, buttress development and surface root extension. A distance of 5 m is needed between trees and footpaths for species that grow very large. It is recommended that any planting strip be 3 m wide and cut-outs be 2 by 2 m. Trees with a larger shade should have a minimum planting strip width of 3.5 to 4 m.

Large trees provided with adequate planting spaces (top and above)

Roadside trees with minimal planting provision

2.1.2 Curved footpaths

Additional space can be created for trees in planting strips by replacing existing straight footpaths with curved ones. This can be done by installing a new section or by narrowing the existing footpath to the minimum standard of 1 m.

Curved footpath

Pop-outs

2.1.3 Pop-outs

Similar to curved footpaths, increasing space by removing a section of the kerb and extending the planting space into the street are other options to optimise green spaces. However, care must be taken to not negatively impact drainage. To maximise space, both pop-outs and curved footpaths can be used in the same location.

2.1.4 Non-standard slab size

Concrete slabs that are not of a standard size or shape can help increase space for established trees. Avoid using long, narrow slabs as they are more likely to crack. When using curved or oddly shaped slabs, avoid those with a sharp radius and refrain from placing a joint where cracks are expected to occur.

2.1.5 Monolithic footpaths

These are footpaths that are installed against the kerb with no planting strip on the street side. Trees are planted on the other side of the footpath, still within the public right-of-way but adjacent to infrastructure. Depending on the amount of space available, this approach may increase tree planting space, but will also increase the proximity of trees to the surrounding infrastructure and may cause conflict in the future.

Monolithic footpath

Monolithic footpath

2.1.6 Tree islands

Tree islands can reduce root contact with existing infrastructure. Water and soil conditions can also be managed in tree islands to enhance tree growth and improve tree health.

2.2 Separating tree roots from infrastructure

2.2.1 Alternatives to root pruning

- Remove or realign footpaths
- Provide larger planting spaces from the onset
- Redesign footpaths and kerbs
- Relocate utilities
- Bridging.

2.2.2 Bridges and ramps

Pier and beam bridges, cantilevered sections, and boardwalks create a spatial separation between infrastructural elements (typically footpaths) and the root zone. Ramps can be installed over unpruned or minimally pruned surface roots to alleviate the conflict. Alternatively, soil can be placed over the offending roots and pavement installed over it.

Bridges can be an alternative to root pruning — instead of removing roots, a pier-and-beam design can provide pedestrian access over the offending roots

2.2.3 Lowered sites

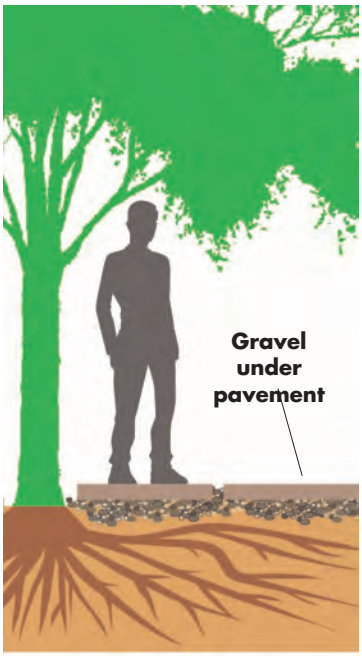
Lowered planting sites reduce damage potential by establishing a spatial separation between the soil surface and infrastructure. Planting pits are excavated so that the top of the root ball and finished soil grade are beneath the infrastructure grade by some 40 to 50 cm. Potential for root contact is reduced when the root ball is positioned lower than new or existing infrastructure.

2.2.4 Modified gravel layer

Attempts may be made to modify the gravel layer (base course) between the pavement and the soil to reduce damage and conflict.

a) *Large gravel*: A separation between tree roots and surrounding infrastructure may be established by depositing large diameter gravel (>2 cm) on the soil surface, before pavement is placed over it. This strategy will enable big air or pore spaces to exist within the gravel layer, thus reducing water retention to the point where root development is impaired.

b) *Thick layer of gravel*: A well-graded aggregate base with a mixture of large and small rocks would reduce the void space and increase the bulk density of the gravel.



Gravel can improve aeration under footpaths

This may help reduce damages caused by roots by making it harder for roots to grow into the gravel.

c) *An alternative to gravel*: Recycled concrete can be used to repair footpaths around trees. Old concrete from footpaths can be crushed and the concrete aggregate used in place of gravel.

3. Infrastructure Material Strategies

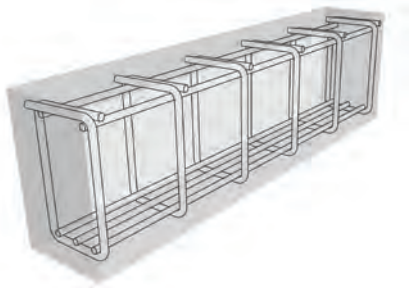
3.1 Modifications to concrete

3.1.1 Concrete reinforcement with rebar, polymeric mesh or fibreglass (plastic)

Rebar has long been used inside concrete to reduce the potential for cracking. For rebar to be effective, it must be correctly sized and placed within the concrete slab.

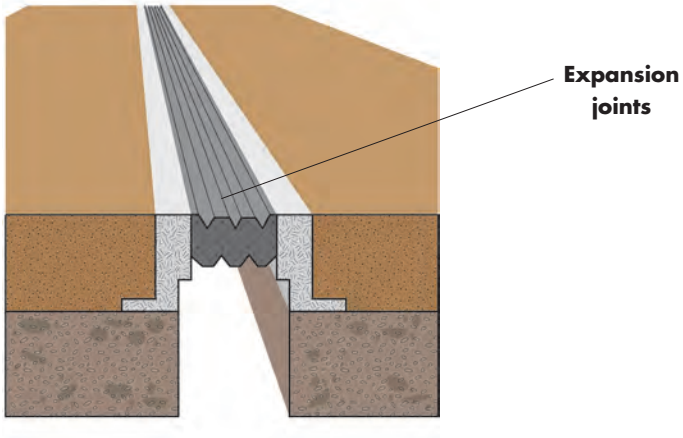
If rebar is used, it should be terminated at the slab joint so that cracking is controlled. Fibreglass reinforced plastic rebar has also been used to reinforce concrete. It is light and will not corrode but costs more than steel.

Polymeric mesh fibres are another type of strengthening agent that inhibits random cracking over the life of the slab. The fibres are to be mixed with concrete at a rate of 0.5 to 2 kg/m^3.



3.1.2 Expansion joints

These can be placed close to trees located near footpaths to reduce damage to the infrastructure. They will limit possible footpath replacements to just a few sections rather than large sections. Expansion joints are a pre-moulded strip made of tar-impregnated, black felt-like material.



3.1.3 Thicker slabs of concrete

Thicker concrete slabs (>15 cm) have been used to reduce the damage caused to infrastructure.

3.1.4 Pervious concrete

To prevent water from accumulating under the footpath, pervious concrete is best used over sandy or well-drained soil. With the absence of water close to the surface, the presence of surface roots will potentially be eliminated.

3.1.5 Flexible concrete footpaths and joints

The use of flexible materials and expansion joints for footpaths will accommodate the growth of tree roots and help to avoid the development of uneven slabs. Alternatively, slabs can be tied together with reinforcing bars and have a compressible foam wedge between the joints for increased flexibility.

3.2 Alternatives to concrete

3.2.1 Asphalt

This material is used as a finishing surface or for patching up cracks in pavement.

Asphalt

3.2.2 Decomposed granite and compacted gravel

Used as a temporary surface when concrete surface is yet to be installed or has been removed. They can be installed at depths of 7.5 to 10 cm.

Decomposed granite

Compacted gravel

3.2.3 Pavers

Paving blocks and slabs laid on sand base can be easily and individually lifted to replace areas where aggressive root systems have caused unevenness.

Pavers affected by tree roots are easily relaid

3.2.4 Recycled rubber and EPDM tiles
Recycled rubber tiles as well as EPDM synthetic rubber materials can be easily replaced to create a uniform surface.

3.2.5 Mulch
To minimise injury to trees along the edge of a road, bark mulch, dried leaves, or compost can be used as a substitute to concrete.

3.3 Remedial treatment for damaged footpaths

3.3.1 Grinding
Lifted footpaths can be ground down to remove the lifted edge and establish a smooth, continuous surface between adjacent concrete slabs. This is done if the lift is not more than 2.5 cm and is located at an expansion joint.

3.3.2 Wedges
Wedges are used to create a temporary sloped transition from the edge of a lifted section to the original grade of the footpath. Either asphalt or concrete may be used.

3.3.3 Mud jacking (slab jacking)
Cement grout is pumped underneath sunken sections. Due to the pressure, the grout depresses and stabilises the sub soil, filling the void and raising the slabs to the original grade. All civil and structural works have to be endorsed by a Professional Engineer.

4. Root Zone-based Strategies

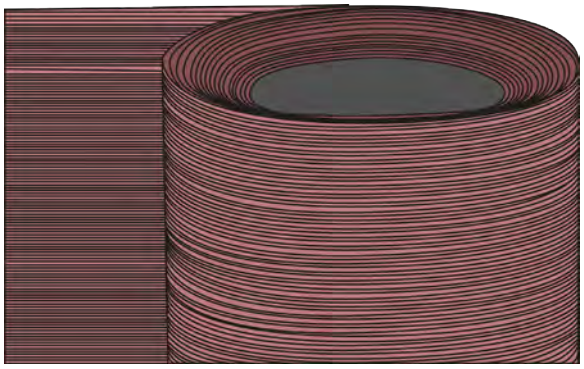
4.1 Root guidance systems

4.1.1 Root barriers
There are three types of root barriers: deflectors, inhibitors and traps.

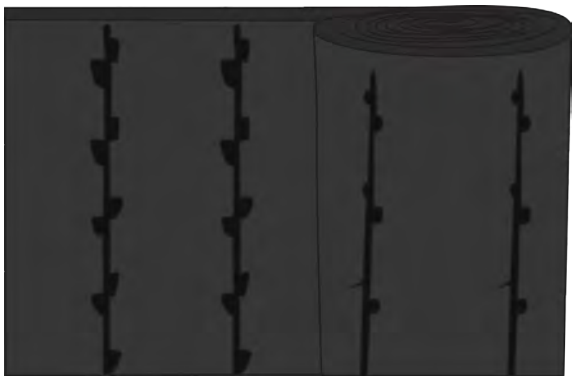
- Deflectors are used to block lateral root development and avoid conflict with infrastructure.
- Inhibitors are landscape fabrics or screens impregnated with chemical compounds to inhibit root development.
- Traps have small holes in the material to allow only small roots or root tips to penetrate while larger roots are kept at bay.

Certified arborists should be consulted for the most appropriate type of root barrier for each individual project.

Deflector barriers



Copper screens can be used as inhibitors and/or traps



Traps

a) *Barrier configurations*: All three types of barriers can be used in either a linear or circular configuration.

- Linear: Barriers should be installed along a section or the entire length of the infrastructure prior to planting. It is recommended that linear barriers along infrastructure are installed after root pruning to prevent regrowth of roots.
- Circular: The barrier encircles the root ball of a newly planted tree, allowing roots to grow downwards instead of laterally.

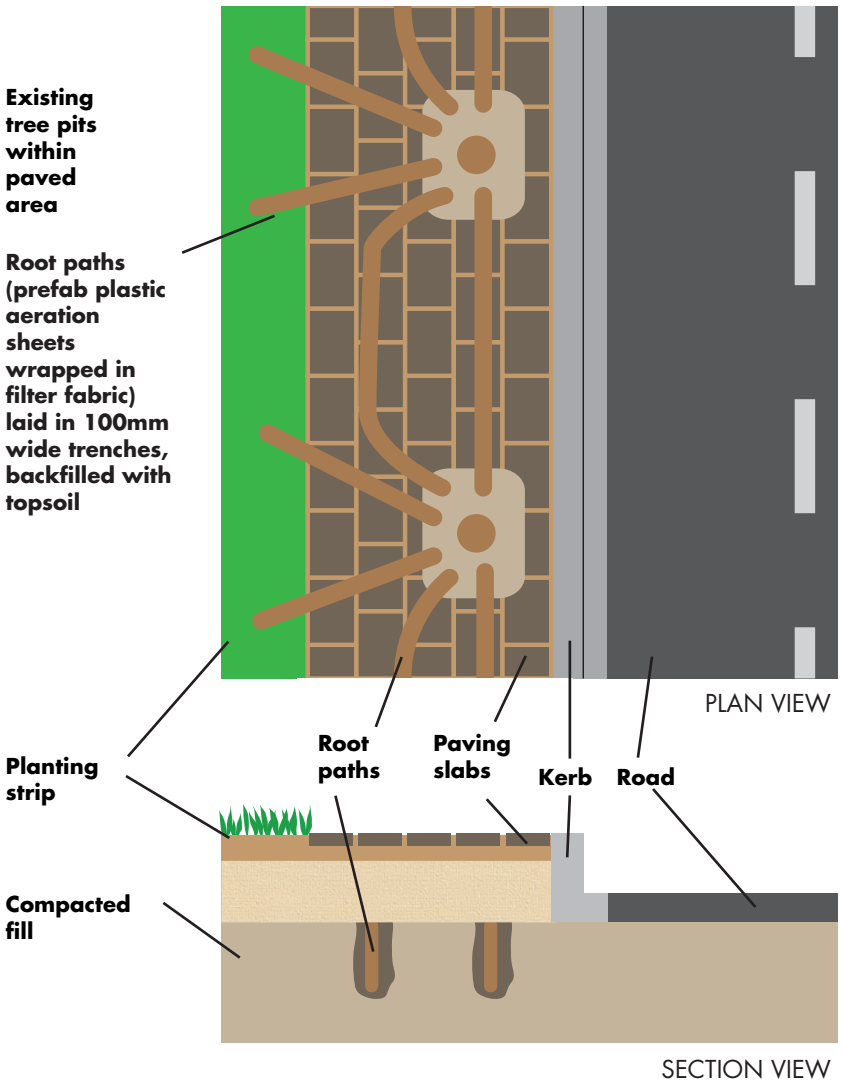
b) *Root barrier research*: Roots that grow through fabric or screens are constricted, stunted and unlikely to have much impact on infrastructure damage. The smaller the holes in the barrier, the more stunted the roots will be.

4.1.2 Continuous trenches

Trenches constructed under pavement provide extra soil volume for root growth while maintaining sufficient stability for the pavement. An open gravel layer above the soil can help reduce root and pavement conflict.

4.1.3 Root paths

Tree root paths are narrow soil-filled trenches (10 cm wide by 30 cm deep) that hold a modular strip drain to allow air and water for the roots. These are useful to guide roots out from confined trapped spaces. They are installed within compacted sub-grade material before a gravel base is added.



4.1.4 Root channels

Root channels direct roots towards remote rooting areas. This helps to expand the rooting zone for a tree while keeping the roots away from infrastructure.

Pipes may be used as a channel for root development by installing 25 cm (diameter) pipes about 25 cm from the surface.

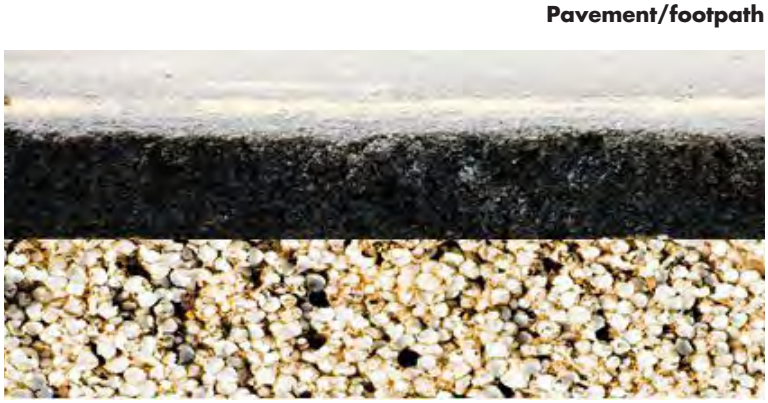
4.1.5 Steel plates

To avoid pruning large diameter roots, steel plates are used to restrict the radial growth of roots. The plates are held in place by anchor bolts set on top or placed on opposite sides of a root and bolted together, sandwiching it. Future root growth cannot push the steel apart and the root will be flattened between the plates.

The plates are placed under or adjacent to the footpath to strategically limit future radial root growth. This technique is more expensive than root pruning and it takes time to perform the plate work. This option is considered extreme as the effect on the roots is long lasting. As such, it should be used as a last resort.

4.1.6 Foam underlay

Foam has long been used as a backing material between new concrete and offending roots. It protects the replaced slab and reduces the potential for damage. As the roots increase in diameter (radial expansion) the foam will be compressed, reducing the likelihood of slab displacement.



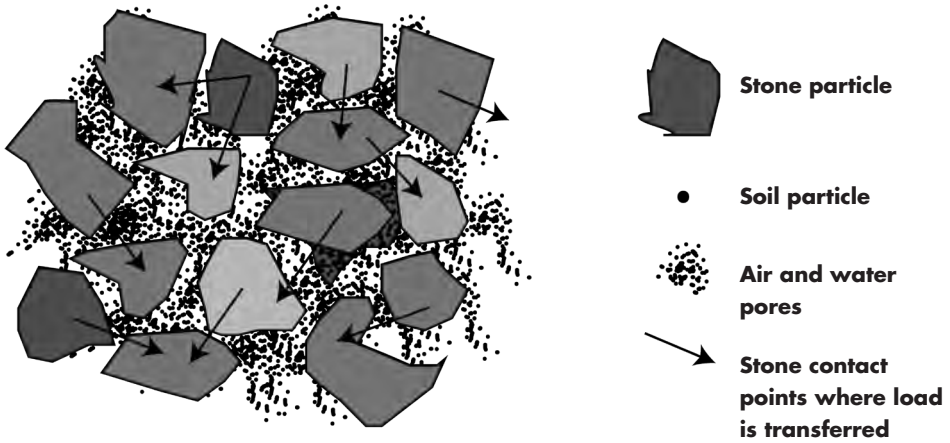
Foam underlay

4.2 Soil replacement, modification and management

4.2.1 Soil replacement with structural soil

This is a medium that can be compacted for pavement design and installation requirements while permitting root growth. It comprises gap-graded gravel and clay- loam soil in variable proportions according to the load-bearing requirement of a site. In order to have sufficient nutrient and water holding capacity for soil, the mixture must contain some clay.

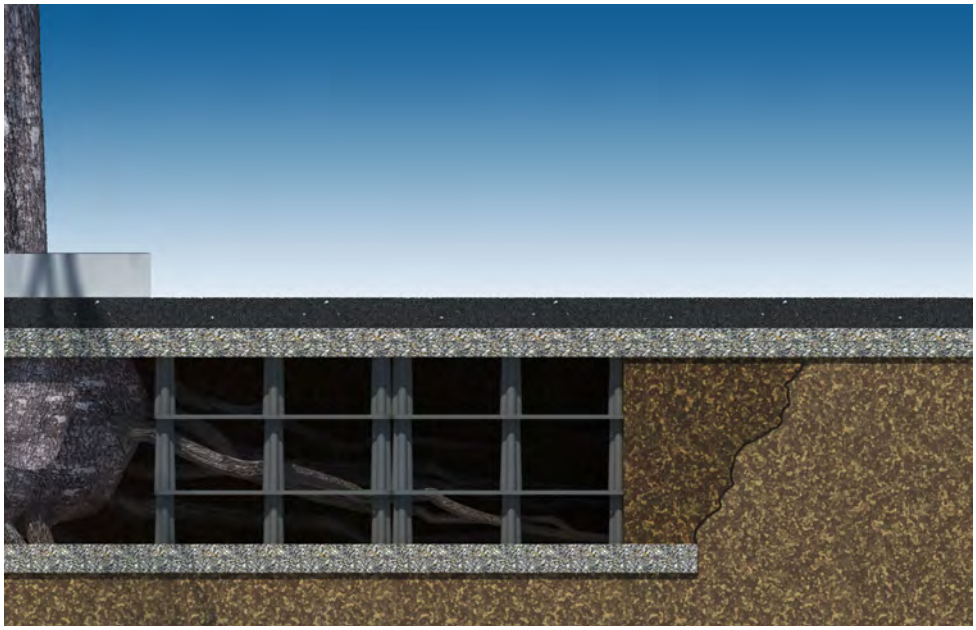
The planting space should be as large as possible to allow for trunk flare and buttress development. The pavement should be no closer than the expected size of the flare or buttress when the tree is mature. This can be determined by measuring the flare/buttress diameter of mature specimens for the species to be planted. Several studies have reported favourable trunk diameter growth and root distribution in structural soil.



4.2.2 Structural cells

Structural cells are a modular building block for containing unlimited amounts of healthy soil beneath paving while supporting traffic loads and accommodating surrounding utilities. They are filled with high-quality, uncompacted soil to grow trees and manage the rate, quality and volume of storm water. The modular system can be easily sized to accommodate the needs of any site without compromising its effectiveness or the site design. More information on structural cells can be found at www.citygreen.com and www.deeproot.com.

3D view of modular structural cell
Photo courtesy of Citygreen Systems Ltd
(www.citygreen.com)



Section view of modular structural cell
Photo courtesy of DeepRoot
(www.deeproot.com)

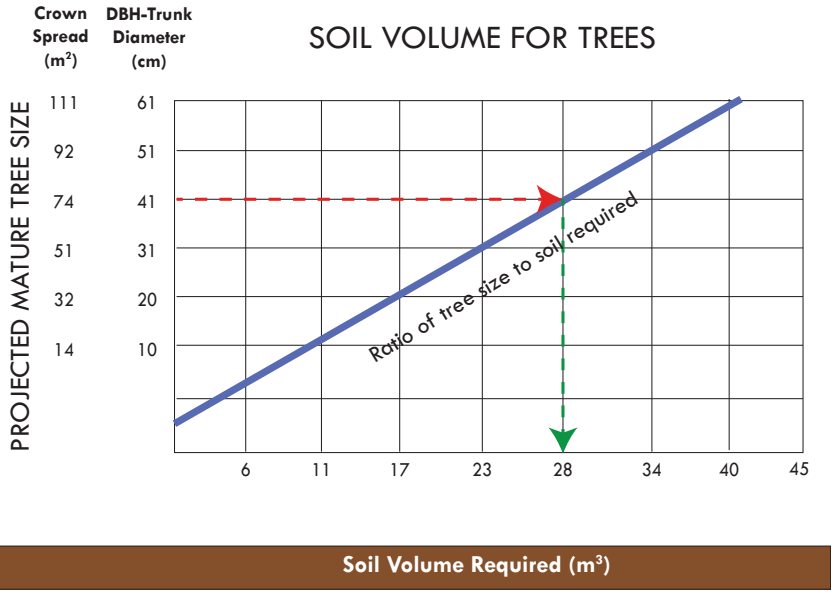
The more healthy soil is available to trees, the bigger they can grow. The larger a tree grows to be, the more significant the environmental and social benefit it provides.

Typically, urban tree growth is stunted by limited access to soil, the lack of space and poor soil quality. Buckling footpaths resulting from surface roots are hazardous and an additional cost to repair. Structural cells overcome these challenges by providing unlimited soil volumes without compromising above ground surface areas, which can be used for urban infrastructure, thus optimising space. At the same time, structural cells encourage roots to penetrate deeper, which is beneficial for anchorage and avoids potential damages caused to pavement by aggressive roots.

4.2.3 Soil modification: Increasing soil volume

a) *Soil volume:* The volume of soil needed to retain sufficient water to meet transpiration losses is calculated using assessments of soil water holding capacity and recharge potential.

The graph below shows the relationship of soil volume and tree size as measured by the crown area and trunk diameter of mature trees. However, the graph is only indicative of the approximate volume of soil needed for trees of various sizes. The required soil volume is likely to vary with different site and climatic conditions.



Source: James Urban (1992)

b) *Assessing soil quality* (soil functional state): A soil assessment gives information on how well the soil functions. The indicators may be quantitative or qualitative.

CATEGORIES	RELATED SOIL FUNCTION
Chemical	Nutrient cycling, water relations, buffering
Physical	Aggregate stability and support, water relations, habitat for insects, microorganisms, etc.
Biological	Biodiversity, nutrient cycling, filtering

CHEMICAL	PHYSICAL	BIOLOGICAL
▪ pH ▪ Nitrate levels ▪ Electrical conductivity	▪ Bulk density ▪ Soil structure and macropores ▪ Available water capacity	▪ Soil microorganism activity and/or population ▪ Particulate organic matter content ▪ Soil enzyme activity ▪ Soil respiration ▪ Total organic carbon

c) *Improving soil condition:* Vertical holes can be augured through a compact zone to improve drainage and reduce soil resistance to root penetration.

The categories above are major functions of any soil. Having this knowledge is important as it opens up options for soil improvement.

Soil samples may be collected and submitted to a laboratory for testing to derive some of the information detailed above.

d) *Soil conditioners*: Soil conditioners can be applied to improve and sustain good soil conditions. Examples of soil conditioners are peat, compost, vermiculite, expanded clay and charcoal.

Compost

Charcoal

Vermiculite

Expanded clay

WATERWAY PLANTING

1. ABC Waters Programme and Definition of a Waterway

1.1 ABC Waters Programme

Driven by the vision of beautiful and clean rivers and streams with landscaped banks and kayakers paddling leisurely in picturesque lakes, Singapore has undertaken the challenge of transforming itself into a City of Gardens and Water.

Over the years, Singapore has gradually developed a pervasive network of about 8,000km of waterways and 17 reservoirs for our water supply. To realise the full potential of this water infrastructure, PUB launched the Active, Beautiful, Clean Waters (ABC Waters) Programme in 2006. It is a long term initiative to enhance our water and bring Singaporeans closer to water so that they can better appreciate and cherish this precious resource.

By turning the network of utilitarian drains, canals and reservoirs into beautiful and clean streams, rivers and lakes and integrating them with the surrounding environment in a holistic way, new community and recreational spaces are created, bringing the community closer to water so that they can better enjoy our waters.

1.2 The definition of waterways

In the Sewerage and Drainage Act, "waterways" refers to drains which include canals, culverts, conduits, rivers or watercourses. For the purpose of this Chapter, 'waterways' will be confined to rivers, canals and drains with a width of 600mm or more.

2. Plant Considerations for Waterway Planting

2.1 Considerations

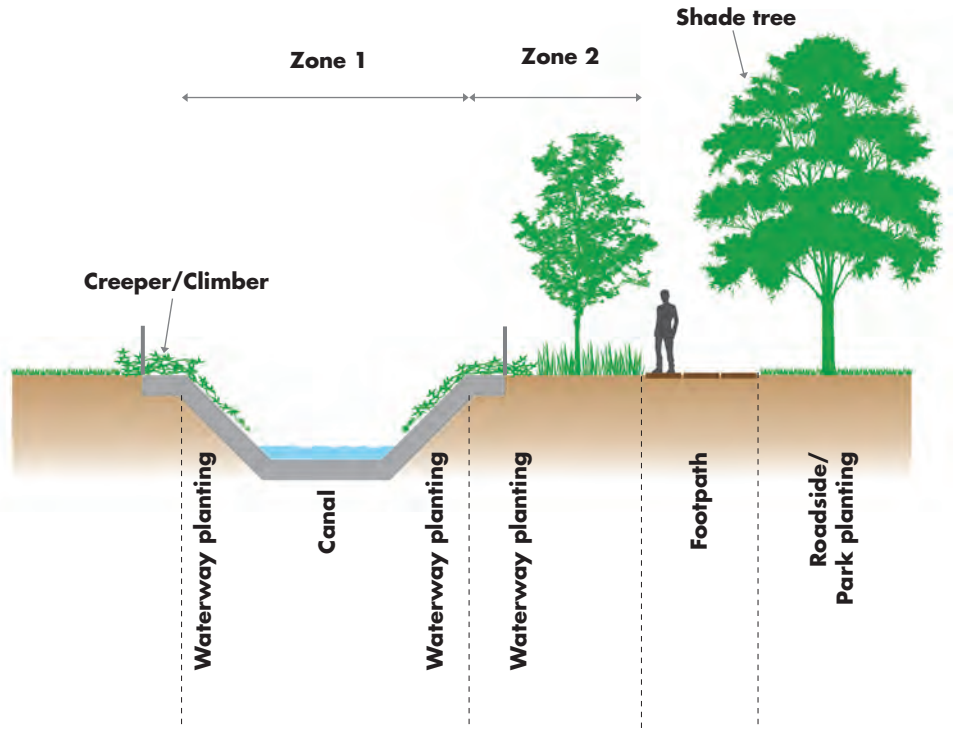
Ease of maintenance and that the plants do not affect the structural integrity of the concrete walls of the waterways are the primary considerations for planting alongside waterways. No crane or boat should be required for plant pruning. There should also be minimum shedding of leaves, no mass flowering and fruiting from plants. This ensures that waterways will not be clogged by leaves, flowers, and fruits. Concrete walls of the waterways should not be damaged or uplifted by aggressive roots of plants.

2.2 Key plant characteristics

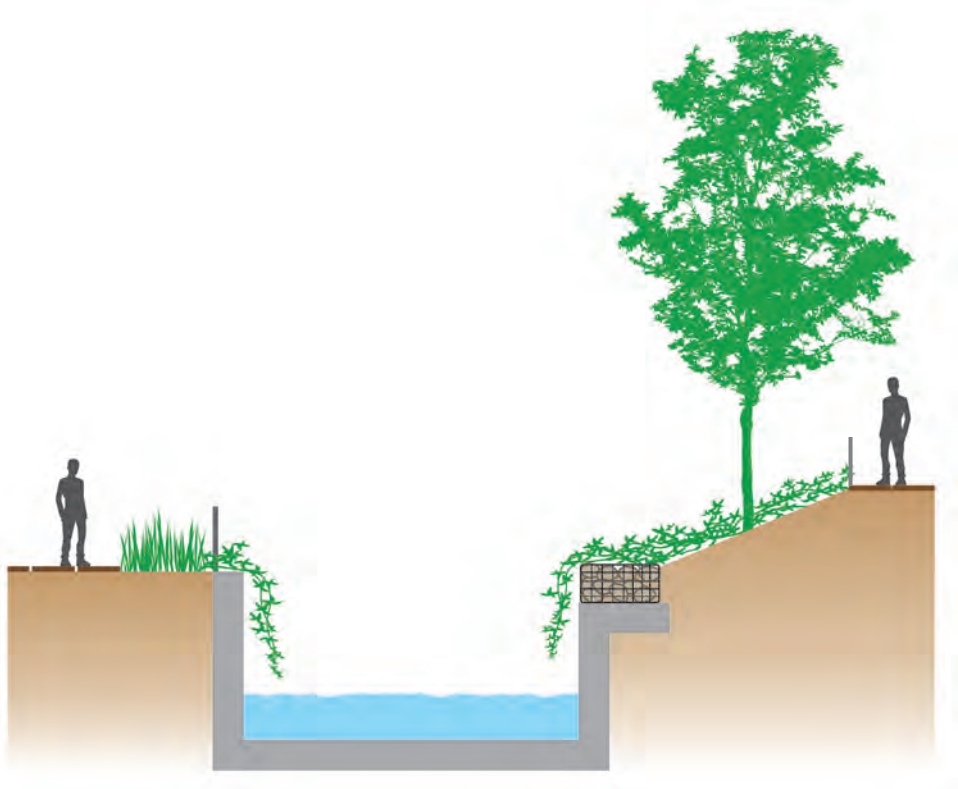
- Mature plant height less than 20 m.
- No seasonal mass leaf, flower and fruit shedding.
- Non-aggressive root system.

3. Waterway Planting Zones and Examples

There are two types of planting zones:
- *Zone 1* – Creepers/climbers for greening of the canal walls.
- *Zone 2* – Plants for planting between waterways and paths, e.g. roads, footpaths, park connector networks.

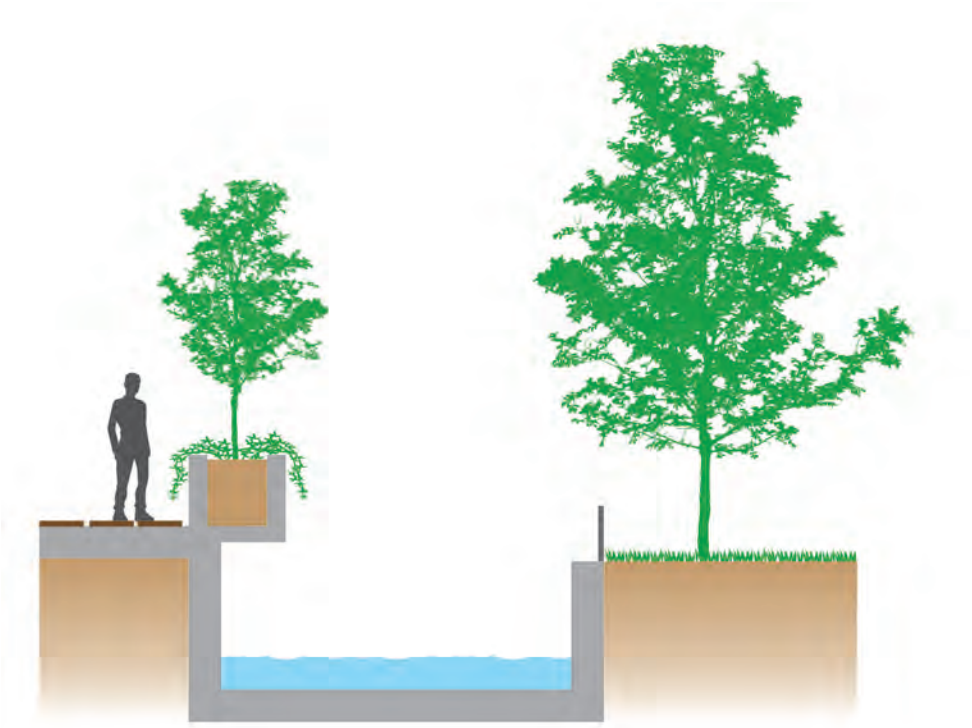


Two kinds of planting are done along waterways:
- True ground planting



True ground planting is preferred if there is the luxury of space at site

▪ Cantilever planting



Cantilever planters can be considered if there are space limitations

3.1 Zone 1: Creepers and climbers for greening of the canal walls

3.1.1 True ground planting

3.1.1.1 Alexandra Canal

▪ Figure 1 & Figure 2

▪ *Bauhinia kockiana* and *Vernonia elliptica* are planted along the railing. (Figure 1)

▪ Planting can be improved with an additional layer of dense shrub (*Murraya paniculata*) planting beside the footpath. (Figure 2)

▪ Effective in terms of maintenance and overall aesthetics.

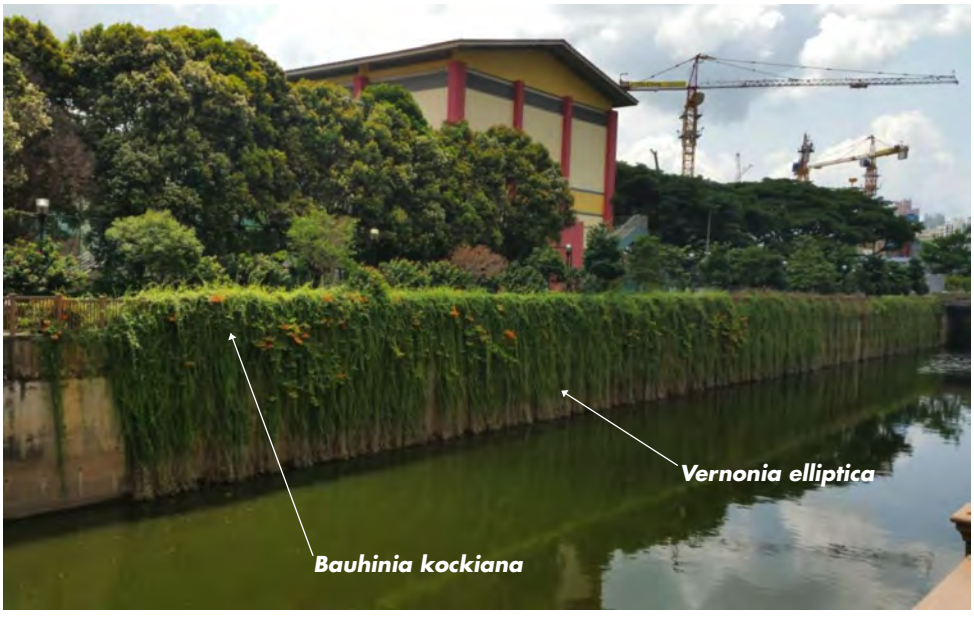


Figure 1

Figure 2

3.1.1.2 Sungei Whampoa-St. George's Lane

- Figure 3
- *Tristellateia australasiae* is effective in terms of maintenance and overall aesthetics.

Figure 3

3.1.1.3 Sungei Ulu Pandan

- Figure 4
- *Sphagneticola trilobata* is planted with room to spread.

Figure 4

3.1.1.4 Geylang River

- Figure 5
- *Thunbergia laurifolia* and *Ipomea batatas* are planted beyond the railing.
- When species are planted side-by-side, maintenance needs to be carried out to ensure that the planting design is preserved. More aggressive species may take over others.

Figure 5

3.2 Zone 2: Plants for planting between waterways and paths

3.2.1 True ground planting

3.2.1.1 Alexandra Canal

- Figure 6 & Figure 7
- *Pennisetum advena* 'Rubrum' provides a good buffer between the footpath and the canal.
- Planting can be improved by setting back *Pennisetum* with a 500 mm mulched area from the footpath as grasses tend to spill over and obstruct the footpath. (Figure 6)

Figure 6

- *Murraya paniculata* provides a dense buffer between the canal edge and the walkway.
- The tree species selected for planting along the footpath provide shade and interest along this stretch of the waterway. (Figure 7)

Figure 7

3.2.1.2 Sungei Whampoa-St George's Lane

- Figure 8
- *Dalbergia oliveri* provides shade along the footpath.

Figure 8

3.2.1.3 Sungei Ulu Pandan

- Figure 9
- *Melaleuca cajuputi* located in this location is optimal as it is farther away from footpath, allowing for less maintenance.
- The tree species selected are commonly used for waterway planting.

Figure 9

3.2.1.4 Geylang River

- Figure 10 & Figure 11
- *Garcinia subelliptica* in this location is optimal as it is beyond the safety railing and requires minimal maintenance.
- *Ipomea batatas* doubles as a groundcover and greens the canal wall.
- *Garcinia subelliptica* and *Syzygium myrtifolium* will also provide good screening from the army camp site as the plants mature. (Figure 10)

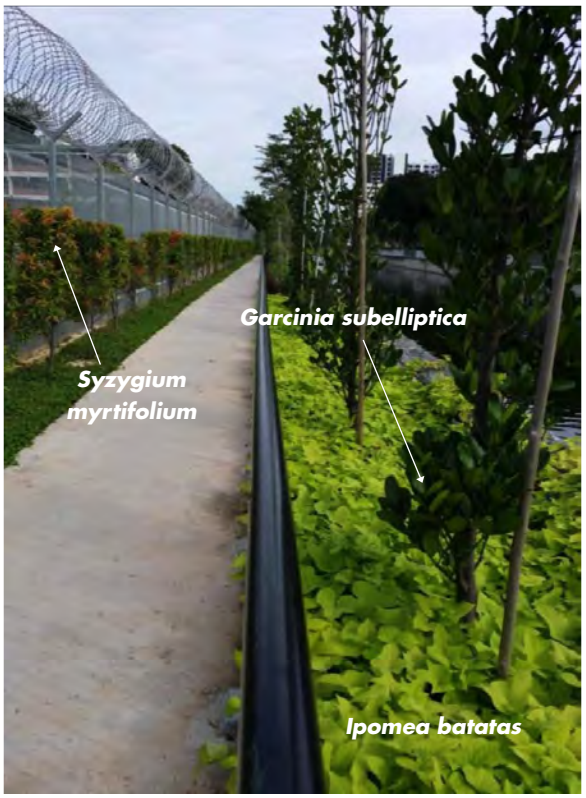


Figure 10

- The tree species are associated with water edge planting.
- *Leptospermum madidum* is an alternative 'weeping' species that is slow growing and requires less maintenance. (Figure 11)

Figure 11

3.2.2 Cantilever planting

3.2.2.1 Geylang River

- Figure 12
- Tree planting provides shade along the footpath.
- A cantilever planter is used as there is limited space along the waterway.

Figure 12

4. Plant Palettes for Waterway Planting

4.1 Trees planting palette

SUITABLE TREE SPECIES FOR PLANTING ALONG WATERWAYS

PLANT SPECIES	MATURE TREE HEIGHT (M)	OTHER CONSIDERATIONS								
		SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Asteromyrtus symphyocarpa	10	Non-native	Full sun	N	N	N	N	Y	General/ Riverine/ Swampy coast/ Small gardens/ Parks & Gardens	Moderate to lots of water
Baccaurea parviflora	19	Native	Full sun	Y (But fruits are restricted at the base only)	N	N	N	Y	General/ Riverine/ Small gardens/ Parks & Gardens	Moderate to lots of water
Barringtonia acutangula	15	Non-native	Full sun	N	N	Y	N	Y	General/ Riverine	Moderate to lots of water
Dillenia alata	12	Non-native	Full sun to semi-shade	N	N	N	N	Y	Roadside/ Riverine/ Small gardens/ Parks & Gardens	Moderate to lots of water
Fagraea racemosa	16	Native	Full sun to shade	N	N	N	N	Y	General/ Roadside/ Riverine/ Parks & Gardens	Moderate to lots of water
Kopsia singapurensis	12	Native	Full sun to semi-shade	N	N	N	N	Y	General/ Roadside/ Riverine/ Parks & Gardens	Moderate to lots of water
Leptospermum madidum	4	Non-native	Full sun	N	N	N	N	Y	General/ Riverine/ Roadside/ Parks & Gardens	Moderate to lots of water

PLANT SPECIES	MATURE TREE HEIGHT (M)	OTHER CONSIDERATIONS								
		SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Lumnitzera littorea	25	Native	Full Sun	N	N	N	Y	Y	Riverine/ Marsh/ Bog/ Coastal/ General/ Parks & Gardens/ Ponds & Lakes	Lots of water
Lumnitzera racemosa	8	Native	Full sun	N	N	N	Y	Y	Riverine/ Marsh/ Bog/ Coastal	Lots of water
Melaleuca cajuputi	18	Native	Full sun	N	N	N	Y	Y	General/ Roadside/ Riverine/ Parks & Gardens	Little to lots of water
Murraya paniculata	20	Non-native	Full sun to semi-shade	N	N	N			Parks & Garden/ Tall Hedge/ Roadside/ Screening	Moderate water to lots of water
Neonauclea pallida ssp. *pallida*	7	Non-native	Full sun	N	N	N	N	YES	General/ Riverine/ Parks & Gardens	moderate water
Ploiarium alternifolium	15	Native	Full sun	N	N	N	N	Y	General/ Marsh/ Bog	Moderate to lots of water
Saraca thaipingensis	20	Non-native	Full sun	N	N	N	Y	Y	General/ Roadside/ Riverine/ Parks & Gardens	Moderate to lots of water
Syzygium pachyphyllum	15	Native	Full sun to semi-shade	N	N	N	N	Y	General/ Roadside/ Riverine/ Parks & Gardens	Moderate to lots of water

PLANT SPECIES	MATURE TREE HEIGHT (M)	OTHER CONSIDERATIONS								
		SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Syzygium myrtifolium	8	Native	Full sun	N	N	N			General/ Roadside/ Coastal/ Riverine/ Hedge/ Screening/ Topiary/ Bonsai/ Container	Moderate water
Taliparitii tiliaceum	8	Non-native	Full sun	N	N	N	N	Y	General/ Roadside/ Riverine/ Parks & Gardens	Moderate to lots of water
Taliparitii tiliaceum 'Tricolor'	8	Non-native	Full sun	N	N	N	N	Y	General/ Roadside/ Riverine/ Parks & Gardens	Moderate to lots of water
Taliparitii tiliaceum var. *purpurascens*	8	Non-native	Full sun	N	N	N	N	Y	General/ Roadside/ Riverine/ Parks & Gardens	Moderate to lots of water
Xanthostemon verticillatus	6	Non-native	Full sun	N	N	N	N	YES	General/ Roadside	Moderate to lots of water

4.2 Shrubs, creepers and climbers planting palette

SUITABLE SHRUBS, CREEPERS AND CLIMBERS FOR PLANTING ALONG WATERWAYS

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Acorus gramineus 'Variegatus'	Herb	30	Non-native	Full sun	N	N	N	Y	Y	Pond/ Lake/ River/ Marsh/ Bog	Lots of water
Acorus gramineus	Herb	30	Non-native	Full sun	N	N	N	Y	Y	Pond/ Lake/ River/ Marsh/ Bog	Lots of water
Acrostichum aureum	Fern	300	Native	Full sun to semi-shade	N	N	N	Y	Y	Coastal/ Pond/ Lake/ River/ Marsh/ Bog/ Screening	Moderate to lots of water
Acrostichum speciosum	Fern	200	Native	Full sun to shade	N	N	N	Y	Y	Coastal/ Pond/ Lake/ River/ Marsh/ Bog/ Screening	Moderate to lots of water
Aglaonema nitidum	Herb	100	Native	Semi-shade to shade	N	N	N		Y	General/ Parks & Gardens/ Small Gardens/ Interiorscape/ Indoor Planting	Moderate to lots of water
Aglaonema simplex	Herb	120	Native	Semi-shade to shade	N	N	N		Y	General/ Parks & Gardens/ Small Gardens/ Interiorscape	Moderate to lots of water
Alpinia aquatica	Herb	200	Native	Full sun to semi-shade	N	N	N	Y	Y	Riverine/ Marsh/ Bog	Lots of water
Angelonia angustifolia 'Purple Stripe'	Herb	60	Non-native	Full sun	N	N	N		Y	Parks/ Gardens/ Small Gardens/ Riverine/ Container	Moderate water
Angelonia angustifolia 'Alba'	Herb	60	Non-native	Full sun	N	N	N		Y	Parks & Gardens/ Small Gardens/ Riverine/ Container	Moderate water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Angelonia angustifolia 'Balangdaros'	Herb	60	Non-native	Full sun	N	N	N		Y	Parks & Gardens/ Small Gardens/ Riverine/ Container	Moderate water
Angelonia angustifolia	Herb	60	Non-native	Full sun	N	N	N		Y	Parks & Gardens/ Small Gardens/ Riverine/ Container	Moderate water
Arundina graminifolia	Orchid	150	Native	Full sun	N	N	N	Y	Y	Coastal/ Riverine/ Pond/ Lake/ Marsh/ Bog	Lots of water
Asclepias curassavica	Herb	100	Non-native	Full sun	N	N	N		Y	Parks & Gardens/ Small Gardens/ Riverine/ Container	Moderate water
Callicarpa longifolia	Shrub (woody)	500	Native	Full sun	N	N	N	Y	Y	General/ Parks & Gardens/ Small Gardens/ Roadside	Moderate water
Canna indica	Herb	150	Non-native	Full sun	N	N	N		Y	General/ Flowerbed/ Border/ Container/ Parks & Gardens	Lots of water
Canna x *generalis* 'Red King Humbert'	Herb	240	Non-native	Full sun	N	N	N		Y	General/ Flowerbed/ Border/ Container/ Parks & Gardens	Lots of water
Cheilocostus speciosus	Herb	400	Native	Full sun	N	N	N		Y	General/ Parks & Gardens/ Small Gardens/ Roadside	Lots of water
Costus guanaiensis var. *tarmicus*	Herb	600	Non-native	Semi-shade	N	N	N		Y	Parks & Gardens/ Small Gardens/ Riverine/ Container	Moderate water
Costus woodsonii	Herb	370	Non-native	Full sun to semi-shade	N	N	N		Y	Parks & Gardens/ Small Gardens/ Flowerbed/ Border/ Container Planting	Lots of water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Crinum 'Menehune'	Herb	100	Non-native	Full sun to semi-shade	N	N	N		Y	Parks & Gardens/ Small Gardens/ Flowerbed/ Border/ Container Planting	Lots of water
Crinum asiaticum 'Variegatum'	Herb	150	Non-native	Full sun to semi-shade	N	N	N		Y	Parks & Gardens/ Small Gardens/ Flowerbed/ Border/ Container	Lots of water
Cyclanthus bipartitus	Herb	200	Non-native	Semi-shade	N	N	N		Y	Parks & Gardens/ Small Gardens/ Interiorscape/ Container	Moderate water
Cyperus papyrus	Herb	300	Non-native	Full sun to semi-shade	N	N	N	Y	Y	Riverine/ Swimming Poolside/ Focal Plant/ Container	Lots of water
Dillenia suffruticosa	Shrub (woody)	1000	Native	Full sun to semi-shade	N	N	N		Y	General/ Parks & Gardens/ Small Gardens/ Riverine/ Coastal/ Marsh/ Bog/ Reforestation	Modrate to lots of water
Equisetum hyemale	Herb	200	Non-native	Full sun to semi-shade	N	N	N	Y	Y	Pond/ Lake/ River/ Aquarium/ Aquascape/ Phytoremediation	Lots of water
Hanguana malayana	Herb	200	Native	Full sun	N	N	N	Y		Riverine/ Pond/ Lake/ Marsh/ Bog	Lots of water
Hedychium coronarium	Herb	300	Non-native	Full sun to semi-shade					Y	Parks & Gardens/ Small Gardens/ Riverine/ Container	Lots of water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Isolepis cernua	Herb	50	unknown	Full sun to semi-shade	N	N	N		Y	Coastal/ Riverine/ Focal Plant/ Container/ Terrarium/ Aquascape	Lots of water
Leea angulata	Shrub (woody)	1500	Native	Full sun to shade	N	N	N		Y	General/ Roadside/ Parks & Gardens/ Small Gardens/ Hedge/ Screening/ Riverine	Moderate to lots of water
Leea rubra	Shrub (woody)	300	Native	Full sun to semi-shade	N	N	N		Y	General/ Roadside Tree/ Parks & Gardens/ Small Gardens/ Hedge/ Screening/ Flowerbed/ Border	Moderate to lots of water
Lepironia auriculata	Herb	150	Native	Full sun	N	N	N	Y		Riverine/ Pond/ Lake/ Marsh/ Bog	Lots of water
Marantochloa filipes	Herb	200	Non-native	Semi-shade	N	N	N		Y	Parks & Gardens/ Small Gardens/ Hedge/ Screening/ Marsh/ Bog/ Interiorscape/ Container	Moderate to lots of water
Marantochloa purpurea	Herb	250	Non-native	Semi-shade	N	N	N		Y	Parks & Gardens/ Small Gardens/ Marsh/ Bog	Moderate to lots of water
Mussaenda 'Calcutta'	Shrub (woody)	400	Non-native	Full sun to semi-shade	N	N	N			Parks/ Gardens/ Small Gardens/ Riverine	Moderate water
Osmoxylon lineare	Shrub (woody)	300	Non-native	Full sun	N	N	N	N	Y	Riverine/ Parks & Gardens	Modearte to lots of water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Pandanus amaryllifolius	Herb	160 (small growth form) 450 (large growth form)	Non-native	Full sun	N	N	N	Y	Y	Parks & Gardens/ Coastal/ Beachfront/ Shoreline/ Riverine/ Pond/ Lake/ Marsh/ Bog/ Hedge/ Screening/ Roadside	Lots of water
Pennisetum alopecuroides	Herb	150	Non-native	Full sun	N	N	N			General/ Coastal, Flowerbed/ Border/ Container	Moderate to lots of water
Pennisetum advena 'Rubrum'	Herb	150	Non-native	Full sun	N	N	N			General/ Coastal/ Green Roof/ Vertical Greenery/ Green Wall/ Flowerbed/ Border/ Focal Plant/ Container Planting	Moderate water
Pluchea indica	Shrub (woody)	300	Native	Full sun to semi-shade	N	N	N		Y	Parks & Gardens/ Coastal, Beachfront/ Shoreline/ Riverine/ Pond/ Lake/ River/ Marsh/ Bog/ Hedge/ Screening	Lots of water
Schismatoglottis wallichii	Herb	50	Native	Semi-shade to shade	N	N	N		Y	General/ Parks & Gardens/ Small Gardens/ Indoor	Moderate to lots of water
Schumannianthus dichotomus	Herb	500	Native	Full sun to semi-shade	N	N	N	Y	Y	Riverine/ General/ Pond/ Lake/ River/ Marsh/ Bog	Moderate to lots of water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Tarenna fragrans	Shrub (woody)	250	Native	Full sun to semi-shade	N	N	N		Y	General/ Roadside/ Parks & Gardens/ Coastal/ Hedge/ Screening/ Riverine/ Skyrise/ Balcony/ Container	Moderate to lots of water
Thalia dealbata	Herb	150	Non-native	Full sun	N	N	N	Y	Y	Riverine/ Swimming Poolside/ Container/ Phytoremediation	Lots of water
Thalia geniculata f. *ruminoides*	Herb	300	Non-native	Full sun to semi-shade	N	N	N	Y	Y	Riverine/ Flowerbed/ Border/ Swimming Poolside/ Focal Plant/ Container/ Marsh/ Bog	Lots of water
Thalia geniculata	Herb	300	Non-native	Full sun	N	N	N	Y	Y	Riverine/ Flowerbed/ Border/ Swimming Poolside/ Focal Plant/ Container/ Marsh/ Bog	Lots of water
Typha angustifolia	Herb	300	Non-native	Full sun	N	N	N		Y	Riverine/ Pond/ Lake/ Marsh/ Bog/ Container/ Phytoremediation	Lots of water
Typhonodorum lindleyanum	Herb	200	Non-native	Full sun to semi-shade	N	N	N	Y		Pond/ Lake/ River	Lots of water
Anemopaegma chamberlaynii	Climber (woody)		Non-native	Full sun	N	N	N			Parks & Gardens/ Hedge/ Pergola/ Trellis/ Groundcover/ Fence	Moderate to lots of water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Argyreia nervosa	Climber (woody)		Non-native	Full sun to semi-shade	N	N	N			Parks & Gardens/ Hedge/ Pergola/ Trellis/ Groundcover/ Fence	Moderate water
Bauhinia kockiana	Climber (woody)		Non-native	Full sun	N	N	N			Parks & Gardens/ Hedge/ Pergola/ Trellis/ Groundcover/ Fence	Moderate to lots of water
Bauhinia galpinii	Climber (woody)		Non-native	Full sun to semi-shade	N	N	N			Parks & Gardens/ Hedge/ Pergola/ Trellis/ Groundcovers/ Fence	Moderate water
Clerodendrum thomsoniae	Climber (woody)		Non-native	Full sun to semi-shade	N	N	N			Parks & Gardens/ Pergola/ Trellis/ Groundcover/ Fence	Moderate water
Clerodendrum x *speciosum*	Climber (woody)		Non-native	Full sun	N	N	N			Parks & Gardens/ Pergola/ Trellis/ Groundcover/ Fence	Moderate water
Ipomoea batatas 'Blackie'	Climber		Non-native	Full sun	N	N	N			Parks & Gardens/ Groundcover/ Container/ Bed/ Border	Moderate water
Ipomoea batatas 'Marguerite'	Climber		Non-native	Full sun to semi-shade	N	N	N			Parks & Gardens/ Groundcover/ Container/ Bed/ Border	Moderate water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Ipomoea aquatica	creeper		Non-native	Full sun to semi-shade	N	N	N	Y	Y	Parks & Gardens/ Small Gardens/ Riverine/ Pond/ Lake/ Marsh/ Bog	Moderate to lots of water
Murdannia nudiflora	creeper (herbaceous)		Non-native	Full sun to semi-shade	N	N	N		Y	Riverine/ Marsh/Bog/ General/ Groundcover	Moderate to lots of water
Phryganocydia corymbosa	Climber (woody)		Non-native	Full sun	N	N	N			Parks & Gardens/ Pergola/ Trellis	Moderate water
Quisqualis indica	Climber (woody)		Non-native	Full sun to semi-shade	N	N	N			Parks & Gardens/ Groundcover/ Container/ Bed/ Border/ Slope/ Lake margin/ Wetland/ Roadside/ Coastal sand dune/ Fence	Moderate water
Sphagneticola trilobata Syn: *Wedelia trilobata*	Creeper / Climber (herbaceous)		Non-native	Full sun to semi-shade	N	N	N			Parks & Gardens/ Groundcover/ Container/ Bed/ Slope/ Lake Margin/ Wetland/ Roadside/ Coastal sand dune	Moderate water
Thunbergia grandiflora	Climber (woody)		Non-native	Full sun to semi-shade	N	N	N			Parks & Gardens/ Pergola/ Trellis/ Fence	Moderate to lots of water

PLANT SPECIES	PLANT GROWTH FORM (HABIT)	MATURE PLANT HEIGHT (CM)	OTHER CONSIDERATIONS								
			SPECIES ORIGIN	MAXIMUM LIGHT TOLERANCE	HEAVY FRUITING	SEASONAL LEAF SHEDDING	MASS FLOWER SHEDDING	CAN BE GROWN IN WATER	WATERLOGGED SOIL ONLY	LANDSCAPE USES	MOISTURE REQUIREMENT
Tristellateia australasiae	Climber (woody)		Non-native	Full sun	N	N	N		Y	General/ Roadside/ Parks & Gardens/ Small Gardens/ Coastal/ Beachfront/ Shoreline/ Vertical Greenery/ Green Wall/ Trellis/ Pergola	Moderate water
Volkameria inermis Syn: *Clerodendrum inerme*	Climber (woody)		Native	Full sun to semi-shade	N	N	N		Y	General/ Parks & Gardens/ Small Gardens/ Roadside/ Coastal	Moderate to lots of water
Vernonia elliptica	Climber (woody)		Non-native	Full sun to semi-shade	N	N	N			Parks/ Hedge/ Fence	Moderate water

SKYRISE GREENERY

Vertical Greenery and Rooftop Greenery

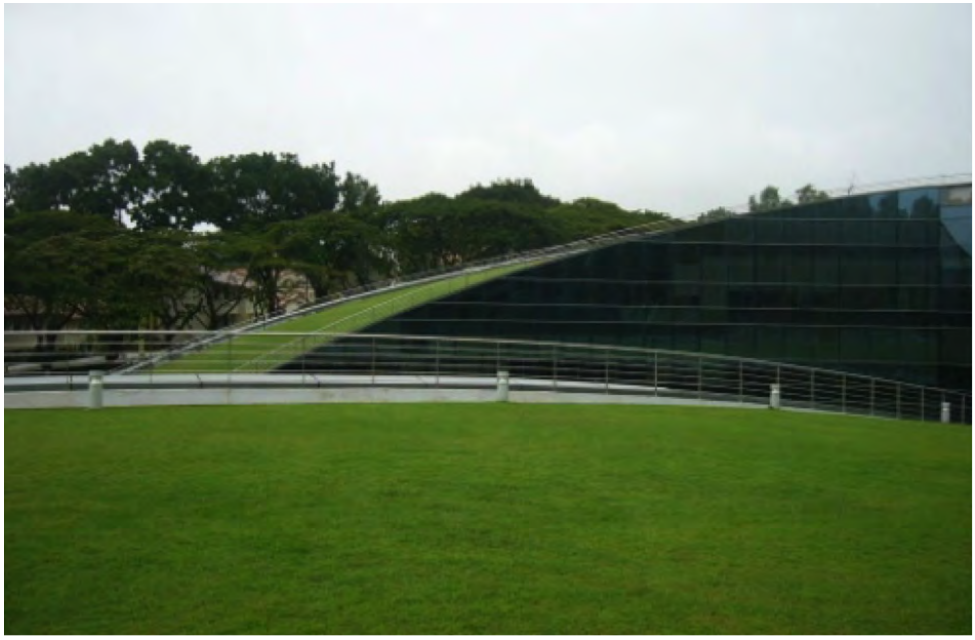
1. Definitions of Skyrise and Rooftop Greenery

"Skyrise greenery" is the collective term commonly used for rooftop and vertical greenery.

"Rooftop greenery" is the collective term used to describe green roofs (both flat and pitched types) and roof gardens (including ledge greening).

1.1 Typical characteristics of green roof

1.1.1 Extensive green roof



Inclined green roof at the Art, Design & Media (ADM) building, Nanyang Technological University of Singapore

These refer to the extensive growing of low cover plants on rooftops using shallow modular roof systems. The modular system (about 10 cm deep) comprises a drainage cum irrigation sheet sandwiched between the roof's waterproofing membrane beneath and soilless or mineral substrate media above for growing creepers, covering plants and turfgrass. Extensive green roofs are traditionally developed for aesthetic and ecological benefits.

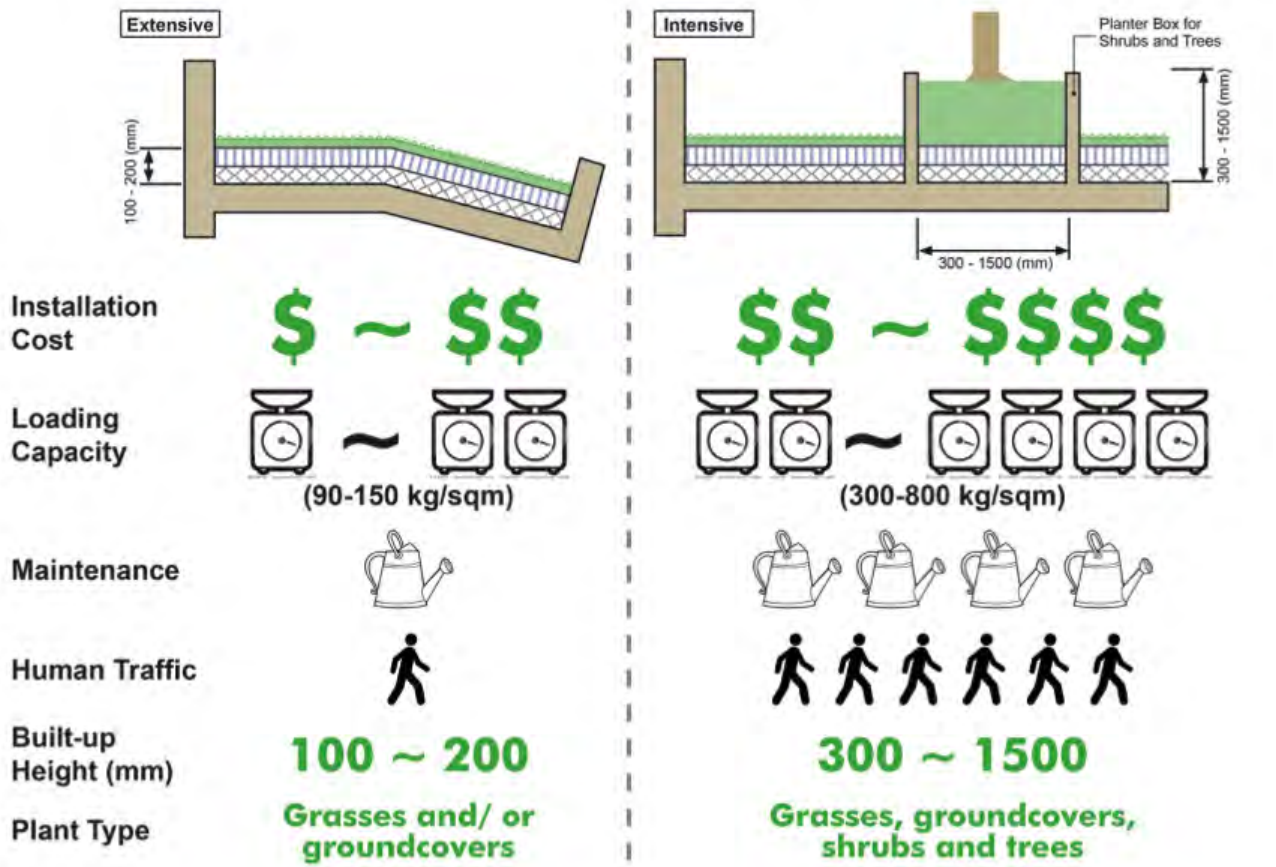
Generally, extensive green roofs are low in installation cost and lightweight (90–150 kg/m^2).They can also be placed on pitched roofs up to an inclination of 30 degrees. Minimal maintenance is required. Inspection should be performed at least once or twice a year. Plants selected are usually of low maintenance and are self-generative. Extensive systems are common in European countries, especially Germany, and increasingly being installed in North American cities and locally as well.

1.1.2 Intensive green roof (roof garden)

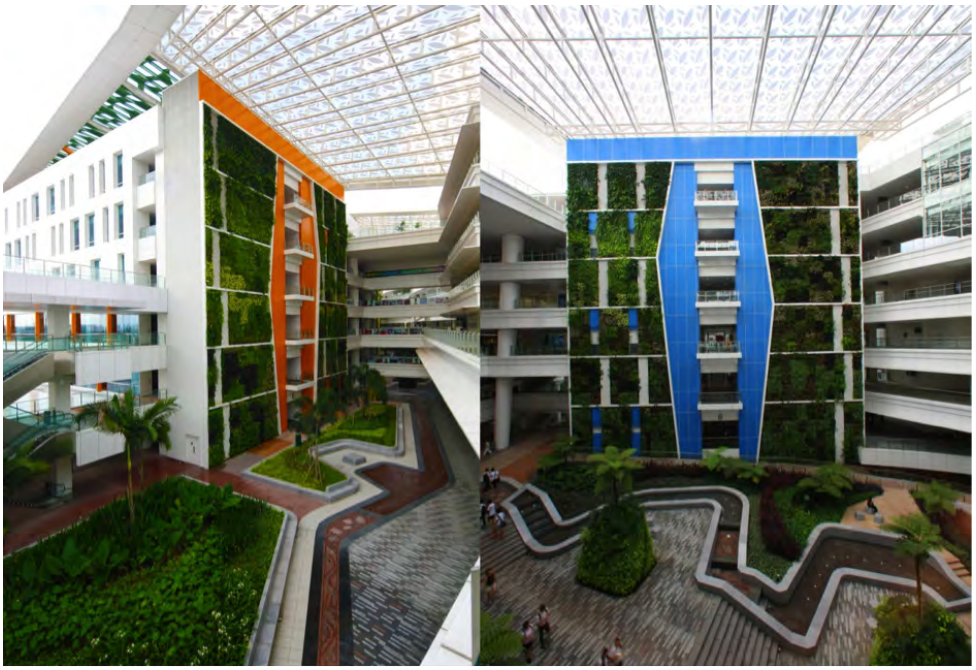
Roof garden at Central Horizon, an HDB project at Toa Payoh Central

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

1.1.3 Diagram comparison and representation of green roof



1.2 Typical characteristics of green wall (vertical greenery)



Green wall at ITE College Central, Ang Mo Kio

Vegetated walls are built mainly for aesthetic and ecological benefits. The level of maintenance is often dependent on the design and safe accessibility of these vegetated vertical surfaces. Vertical vegetated wall surfaces are often more exposed to the drying effects of the wind, especially stronger winds at an increased altitude. Growing plants in such a harsh environment requires more care and frequent inspection of the plants and systems.

The plant selection ranges from ornamental groundcovers and 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 the cost getting more competitive and affordable in recent years.

1.2.1 Types of vertical greenery systems

Currently there are broadly four types of vertical greenery systems in the market, namely the support type, carrier type, fabric type, and planter type systems.

Each system has its own unique set of maintenance requirements, advantages, and limitations. These characteristics have spatial implications for a system's eventual maintainability. Diagram 1 shows the typical profile of all four system types.

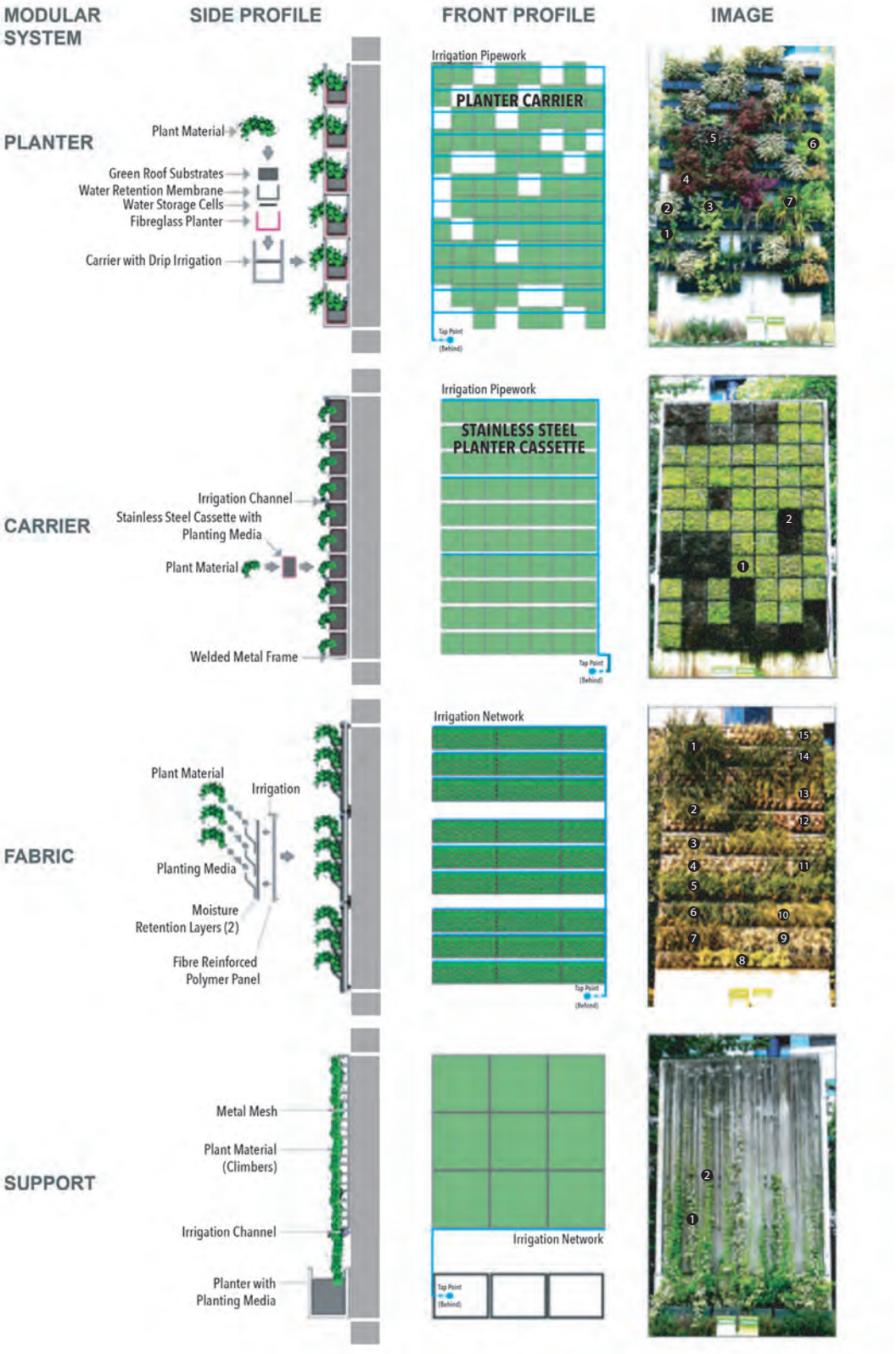


Diagram 1. Different types of green wall systems

2. Designs for Sustainability — Maintenance

The term "sustainability" broadly encompasses the following aspects:
- Economics
- Environment
- Society
- Resource efficacy
- Maintainability (includes safety).

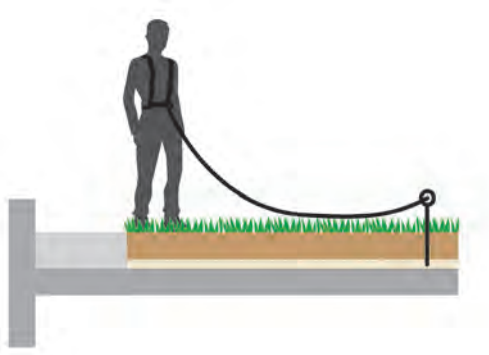
This chapter focuses on the maintainability of vertical greenery and rooftop greenery.

2.1 Maintenance — Extensive green roof

Green roofs are usually installed on non-accessible roof space, functioning as a thermal barrier for the roof surface and/or as an aesthetic vegetated roof surface. Such non-accessible roofs may have a low or no parapet.

Maintenance along such unprotected elevated roof edges is risky. Unless edge protection (such as guardrails, installed to a registered PE's specifications) is in place, such locations are high-risk spaces and not conducive for effective maintenance work.

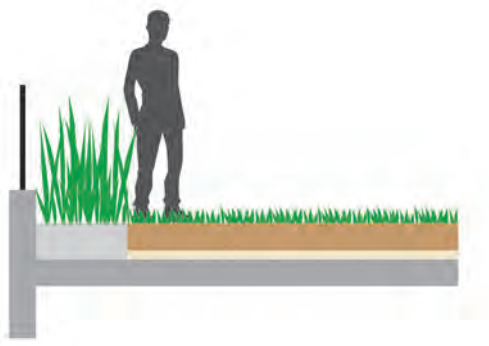
2.1.1 Unprotected green roof edge



Safety line/rail must be no less than 3m from the unprotected roof edge

- **Workers must be competent, following safe work procedures, with site supervision on the roof.**
- **This is an example of an active-edge-protection.**

Suitable for:
- **Inaccessible roof space**



- **Minimum 1 m height roof parapet as passive-edge-protection.**
- **Workers must be competent, following safe work procedures, with site supervision on the roof.**

Suitable for:
- **Accessible roof space**
- **Inaccessible roof space**

Diagram 2. Maintenance works on extensive green roof

Lifelines or rails (active edge protection) should be in place. Informed, trained workers and supervision will be necessary to ensure safety throughout maintenance operation. Please refer to CUGE Standards CS *E11:2014 — Guidelines on Design for Safety of Skyrise Greenery* for further information.

Passive edge protection is preferred and possible through holistic design during project design phase. Please refer to Diagram 2 for examples of passive edge protection and active edge protection for an extensive green roof.

2.2 Maintenance — Intensive green roof (roof garden)

Roof gardens are usually designed as an outdoor communal landscaped roof space. A broad range of plants can usually be found on a roof garden, ranging from turf and groundcovers to small trees and palms.

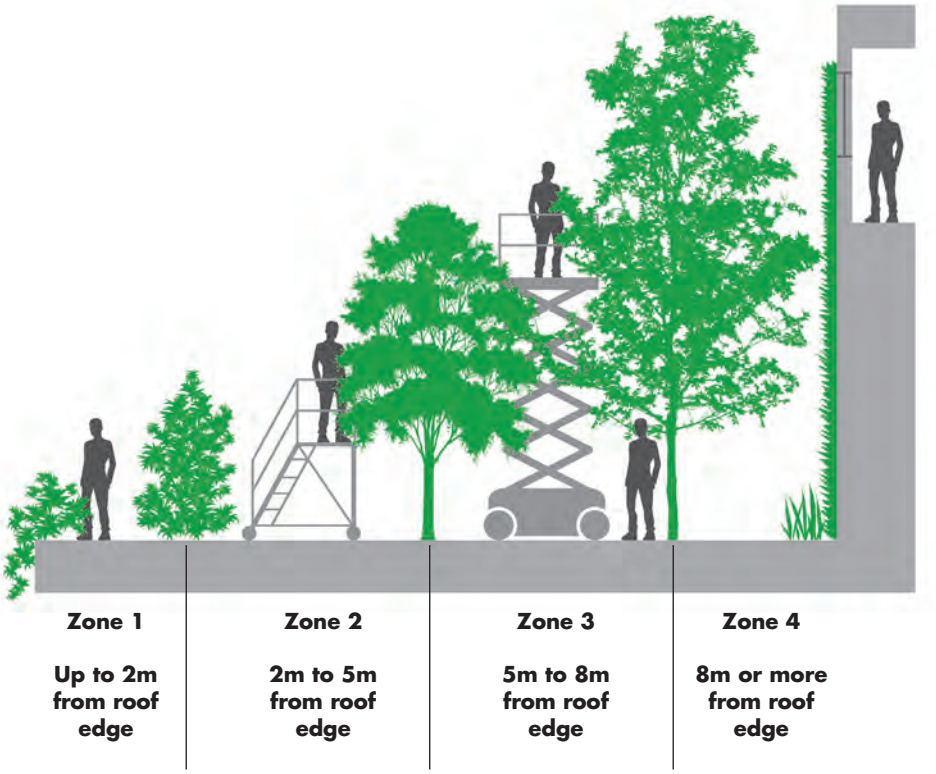


Diagram 3. Graphical illustration on setback distance for rooftop trees

Tall plants planted along roof garden edges are of risk concern. Trees and palms must be set back from the roof edge when planted in a roof garden (Diagram 3).

For more information on suggested setback for rooftop trees, please refer to CUGE Standards *CS E09:2012 — Guidelines on Planting of Trees, Palms and Tall Shrubs on Rooftop*.

2.2.1 Shade

Diagram 4. Graphic representation of expected tree growth due to inadequate direct sunlight

Sky courts are sheltered spaces and can be shady (Diagram 4), with inadequate direct sunlight. In such an environment, plants will grow etiolated over time. Tree canopies may grow lopsided, leaning outwards towards the direction with more daylight. If planted too close to the edge, this expected leaning of the tree canopy and branches can lead to maintenance problems. Where possible, allow for more space around the tree for maintenance access. Alternatively, use smaller plants.

Courtyard roof garden at Nanyang Polytechnic

In the image above, raised planters allow deeper rooting depth and can be integrated with seats. Deep courtyards can get shady. The above example is planted with shade-tolerant plant species.

2.2.2 Rooftop drainage

Drainage direction and adequate drainage provision are pertinent to avoid flooding, especially during tropical torrential downpours.

The finished level of the rooftop greenery should ideally not be higher than the adjoining indoor floor level. The threshold demarcating the exterior from the interior space must be designed to keep rainwater out (Diagram 5).

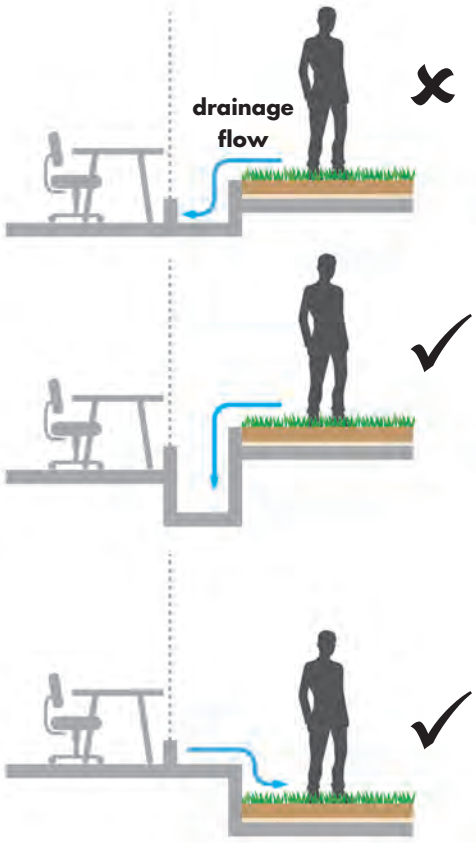


Diagram 5. Graphic representations of rooftop drainage directions

Intensive retrofitted roof garden

In some situations, the rooftop greenery finish level is higher than the indoor finish level due to roof level constraints, as in the case of some retrofitted roof gardens (see image above). An adequate up-stand or a drain of adequate capacity can be appropriately positioned to create an effective threshold in such situations (Diagram 5).

Please refer to CUGE Standards *CS E04:2010 — Guidelines on Filter, Drainage and Root Penetration Barrier Layers for Rooftop Greenery*

2.2.3 Design considerations to facilitate turf mowing

The selection and placement of plants at the ground level as well as on a roof garden can have implications on how subsequent plant maintenance such as turf mowing, etc. is carried out.

The following landscape situations can occur at ground level landscapes as well as on roof gardens, especially larger ones with a large area of softscape.

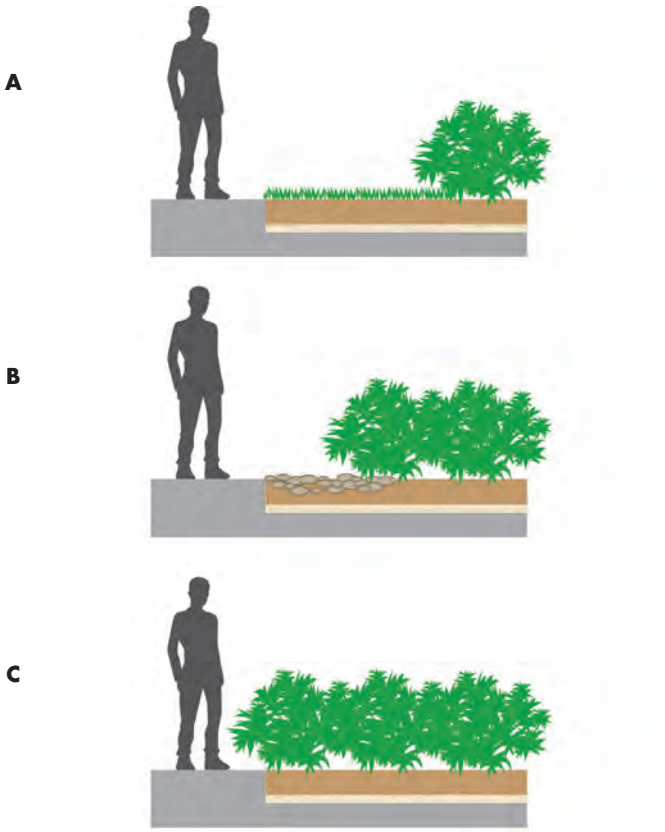


Diagram 6. Graphic representation of turf planting

A thin strip of turf alongside pavement (Diagram 6A) requires frequent mowing and is of little aesthetic value. Diagram 6B and 6C are two examples of softscape treatments that do not require mowing, thereby reducing maintenance.

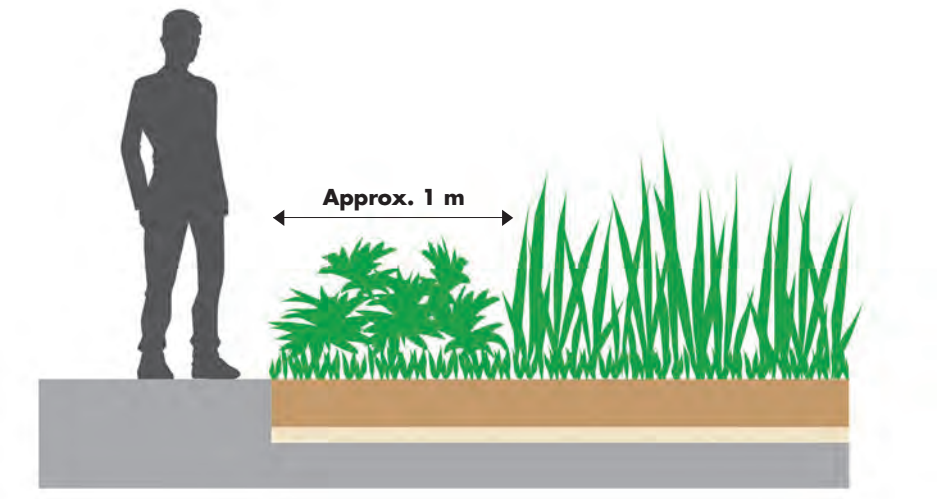


Diagram 7A. Graphic representation of shrub bed width for easy maintenance

For shrub beds planted with shrub species that require frequent pruning along the walkway or pavement, the shrub bed width should have dimensions that allow easy maintenance access. The example in Diagram 7A suggests a width of approximately 1 m so that there is no need to step into the planter bed during maintenance.

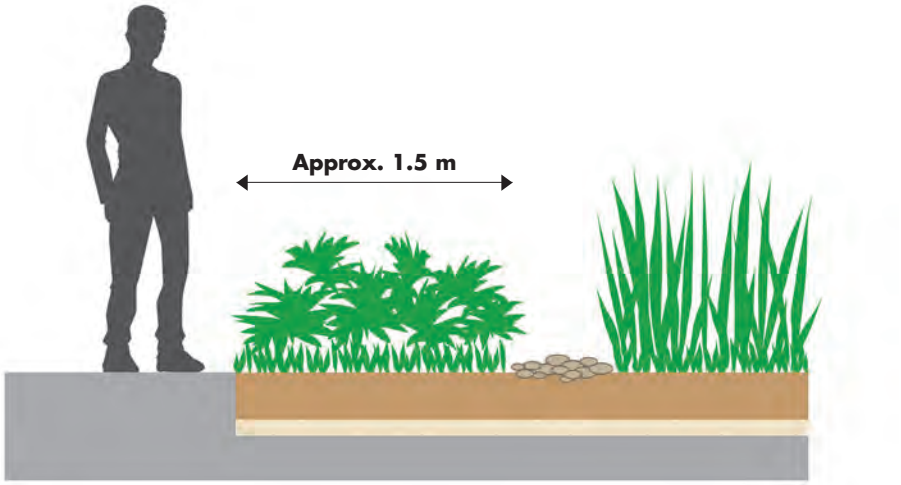


Diagram 7B. Graphic representation of shrub bed width for easy maintenance

For broader shrub beds with a larger area covered by shrub species requiring frequent pruning, intermittent gravel or mulch paths can be considered to allow workers access to the plants during maintenance without the need to step into the established foliage. The above example (Diagram 7B) suggests a gravel path approximately every 1.5 m (or wherever there is a change to vegetation type) to facilitate plant maintenance access.

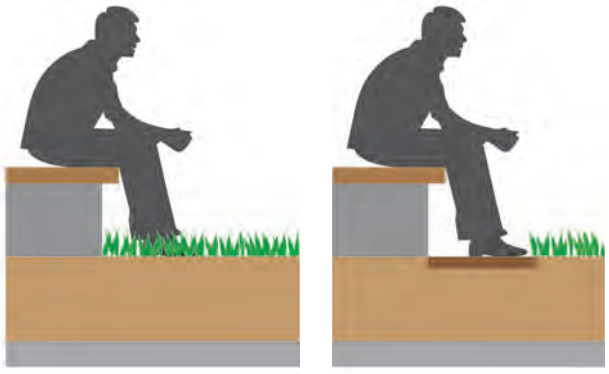


Diagram 8. Graphic representation of design consideration for turf that grows right up to a vertical element

Turf that grows right up to a vertical element, such as a permanent seat, up-stand, wall, step-up and other equivalent, cannot be easily mowed without the mowing blade or strip coming into close contact with the surface's finishing (Diagram 8). This situation makes mowing around corners challenging. This is depicted in the left diagram of a permanent garden seat. In the example on the right, the base of the seat has a paved footrest flushed with the soil level, allowing for easy turf mowing.

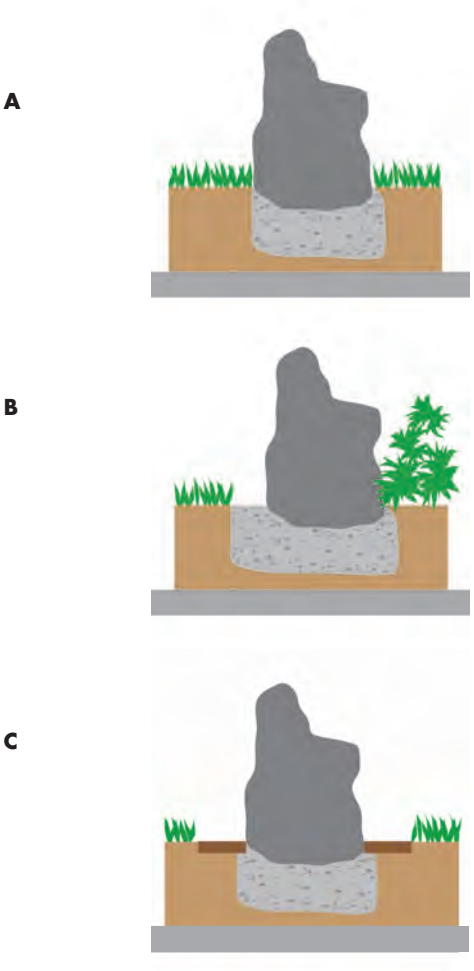


Diagram 9. Graphic representation of design consideration for turf with feature elements

In the example as shown in Diagram 9A, the feature rock (e.g. a sculpture or equivalent) has turf planted right up to its sides, making turf mowing challenging. The example in Diagrams 9B and 9C have shrub (or groundcover) planted instead. Gravel can also create a margin between the turf and the feature rock to allow for easier turf mowing. Alternatively, hard paving can also be used to create the margin.

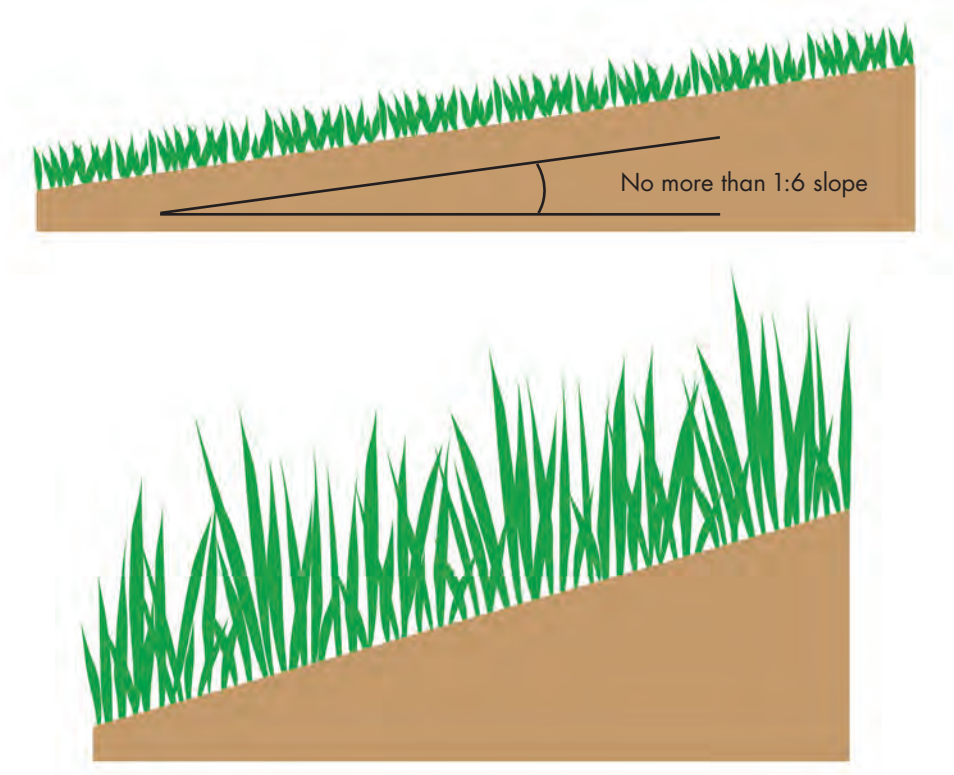


Diagram 10. Graphic representation of design for maintenance of sloping turf

Landscaped slope that has no more than a 1:6 incline is adequately gentle and safe for grass cutting by mowing machines. Such gently sloped surfaces and rooftop greenery can be landscaped with turf grasses.

For slopes that have more than a 1:6 incline, it is advisable to plant with ferns and/or groundcovers. Such vegetation requires less frequent maintenance compared to the maintenance-intensive turf and does not require the use of a mowing machine.

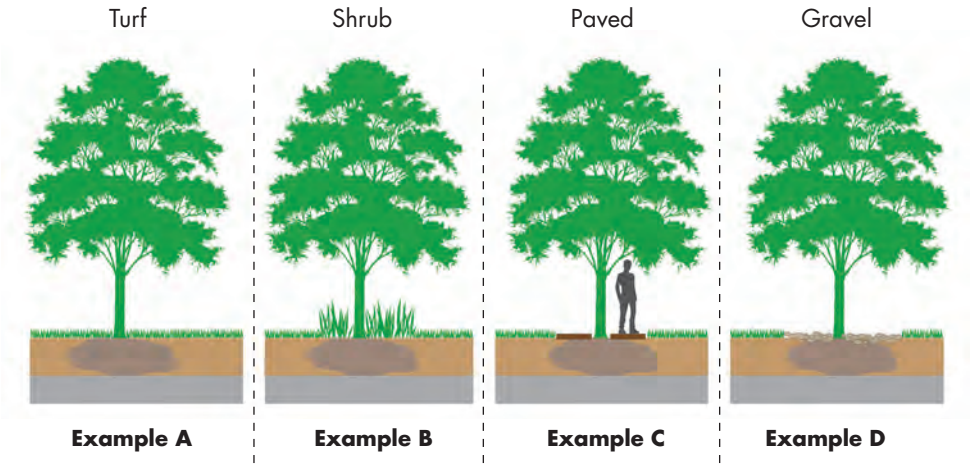


Diagram 11. Graphic representation of design for maintenance of turf around trees

In Example A, the turf is planted right up to the base of the tree, making turf mowing challenging, with risk of damaging the tree bark, which can adversely affect the tree's health.

Examples B, C, and D are suggested alternatives, using landscape design treatments to the tree base to reduce turf-mowing challenges.

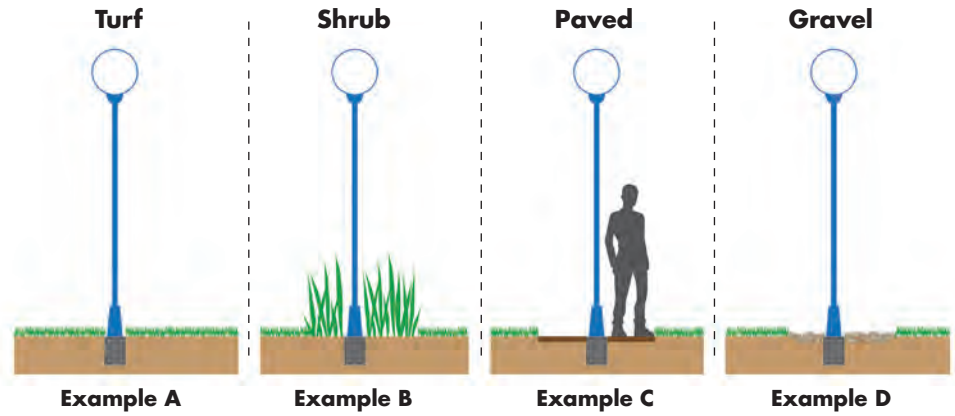


Diagram 12. Graphic representation of design for maintenance of turf around a lamppost

In Example A, the turf is planted right up to the base of the lamppost, making turf mowing challenging. Examples B, C and D are suggested alternatives, with landscape design treatments to the base of the lamppost to reduce turf-mowing challenges.

These design suggestions can also be applied to the base of garden furniture. In general, fixed garden furniture and features should ideally be positioned on paved, hardscape or decked surfaces to reduce turf-mowing challenges.

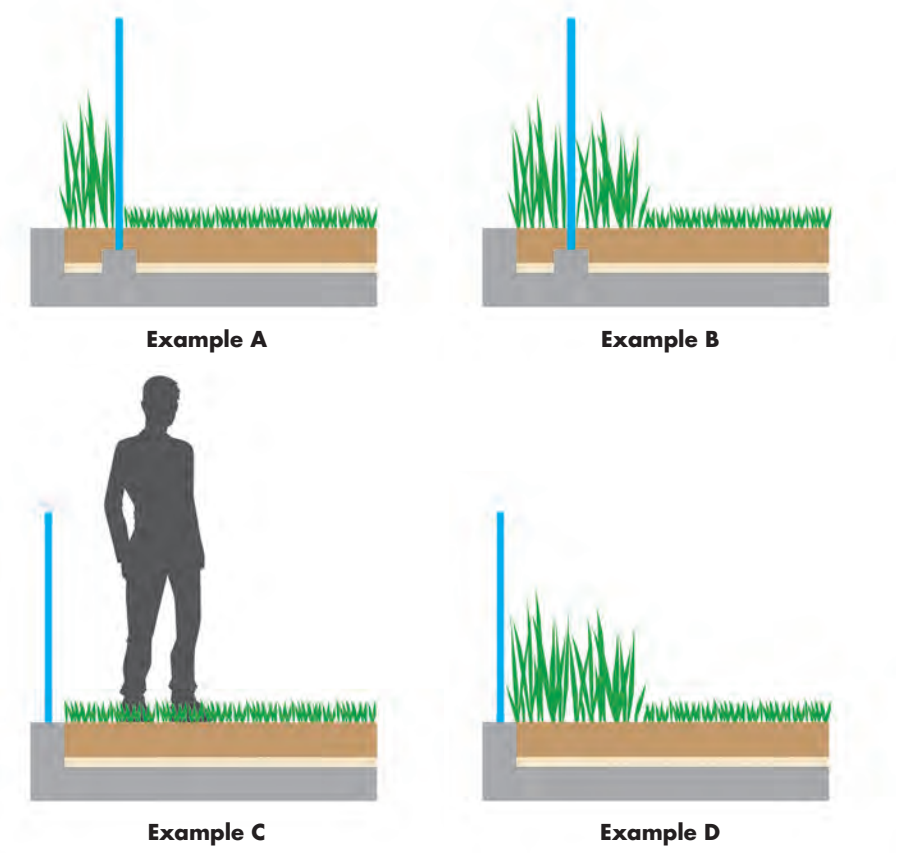
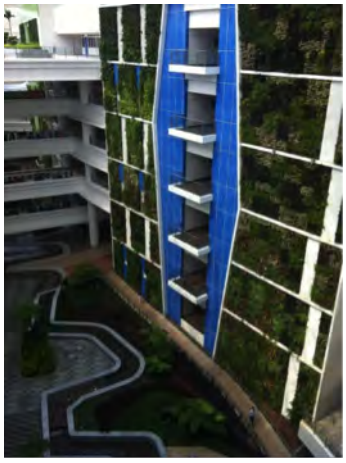


Diagram 13. Graphic representation of turf/shrub placement alongside parapet

In Diagram 13, Examples A and B are not ideal from a maintenance standpoint because the taller shrubs planted beyond the glass parapets are difficult to reach. Workers are very likely going to lean over the parapet in order to reach the foliage to maintain these plants. It is also impossible to reach the roots and soil volumes of these plants along these edges. Instead,

planting should ideally be within the threshold set by the parapets, as shown in Examples C and D.

2.3 Maintenance — Front-accessed green wall



ITE College Central

Wellington Primary School

In general, a green wall (e.g. Wellington Primary School) that is no more than 2 m in height will be relatively easy to access vertically from the front to maintain both the plants and the system. A front-accessed green wall taller than 2 m can be reached with an elevated work platform (a ladder-stand-platform, tower- scaffold, etc.), a pole pruner and/or a combination of these equipment.

For a front-accessed green wall (e.g. ITE College Central) that is more than 2 m in height, have a flat, stable landing surface in front to allow for safe deployment of an elevated work platform and equipment.

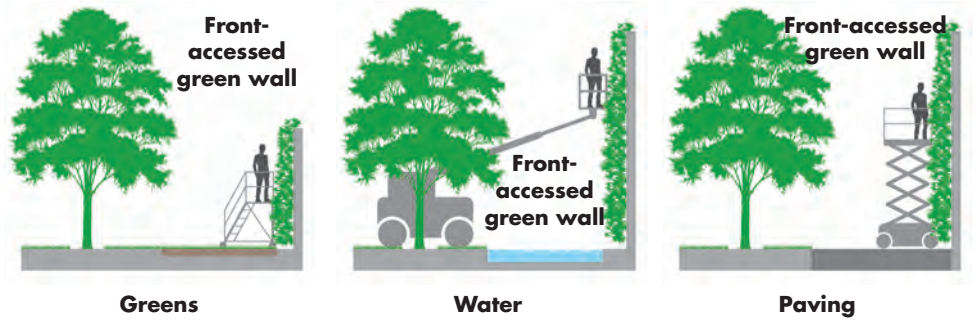


Diagram 14. Graphic representations of how different surface types in front of front-accessed green wall impact maintenance access

The first example above has a vegetated foreground. Turfed surface can be designed and landscaped with suitable supporting underlayers to provide adequate load-bearing capacity for deployment of Mobile Elevating Work Platforms (MEWPs) and/or other elevated work platforms, much like the turfed fire engine access commonly seen in large developments.

The second example has a water body in the foreground, rendering the front vertical access challenging. A more versatile MEWP type, such as the lightweight spider boom lift, will be necessary to effectively access the green wall from the front. In general, an uneven, soft, and/or spatially cluttered foreground is challenging for effective deployment of elevated work platform.

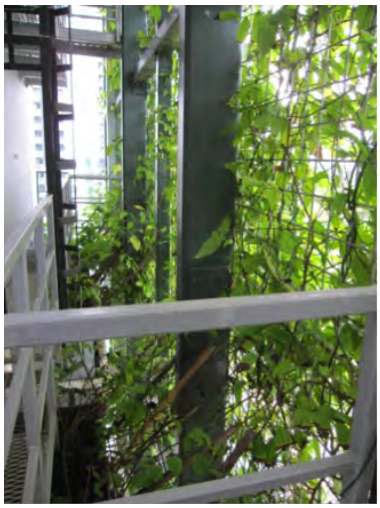
The third example, with a flat, hard-paved foreground, allows for direct and safe deployment of elevated work platforms such as MEWPs. This is especially crucial for front-accessed green walls that are more than 4 m in height. Furniture, if any, should be removable from the foreground for spatial clearance during the deployment of MEWPs and/or other suitable elevated work platforms.

The hard-paved foreground landing must be designed, dimensioned, and built to the specifications of a registered architect and professional engineer (PE). It needs to have an adequate load-bearing capacity for the safe deployment of MEWPs.

Please refer to CUGE Standards *CS E11:2014 — Guidelines on Design for Safety of Skyrise Greenery* for more information.

2.4 Maintenance — Back-accessed green wall

Most green wall systems can be designed to be accessed from the back for maintenance. Access space at the back allows workers a permanent passive workspace access along these elevated greenery surfaces. Back access with "open-able" green wall system must be designed with edge protection to prevent workers from falling out during maintenance.



Tree House Condominium has a façade of vertical greenery, composed of climbing vines, with a back-accessed maintenance walkway. Maintenance from the front is kept to a minimum.

Edge protection for the back access can be in the form of guard rails with mid-rails. They must comply with WSHC requirements and be of suitable height and load-bearing capacity (especially against impact load). The back-accessed maintenance walkway edges must have toe boards or other alternatives to prevent tools from rolling off and dropping from a height.

Ideally, a safety line or rail is to be designed and installed to the back wall along the full length of the maintenance walkway, constructed to a registered PE's specifications. This is especially important when the vertical greenery has full-height "apertures", exposing the maintenance worker to the risk of falling.

If there are cat ladders within the back-accessed maintenance walkway space to connect the different maintenance walkway levels, they must be designed and constructed to a registered PE's specifications.

The vertical greenery at School of the Arts (SOTA), composed of climbing vines, is built against a corridor space, allowing easy and safe access to the planter and the climbing vines. Front access to the climber foliage, using a gondola, is kept to a minimum.

The back-accessed maintenance walkway (see picture on left) should have a minimum 600 mm internal clearance width. The maintenance walkway must be designed and constructed to the specifications of a registered PE.

Each maintenance walkway level should ideally have direct access to the building's permanent stair core with a clear spatial directionality to allow workers to move and escape easily during emergencies. Workers must not work alone in this maintenance walkway. A minimum of two workers per level is required to keep watch of each other.

In general, green walls (see picture above) with a well-designed back-accessed maintenance space provided at every level can be relatively well maintained, and do not require MEWP maintenance access from the front. For such green walls, the foreground base can be landscaped without impeding maintenance.

Please refer to *CS E11:2014 — Guidelines on Design for Safety of Skyrise Greenery* for more information.

Diagram 15 represents a situation in which climbing vines are planted near the edges of a sky court that is a few storeys high. The climber vines are at the edge and have also grown very tall. Maintenance access is very challenging even with the deployment of a gondola. Gondolas may not have adequate reach of the foliage.

Grown dimensions and placement of the selected plants have direct spatial implications on safe maintenance accessibility to the plants. The supporting system parts, such as the substrate, drainage, irrigation pipe lines, supporting sub-frames, grating, etc., need to be safely accessible for periodic inspection and maintenance.

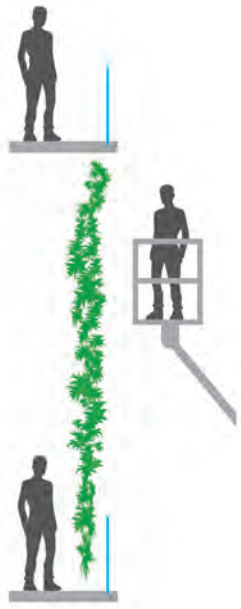


Diagram 15. Graphic representation of maintenance issue with tall climbing vines

2.5 Plant selection for green wall

In both rooftop greenery and vertical greenery, the greenery system is integral to the building envelope design and space making. When the greenery system performs well, the resultant lush healthy foliage benefits the building envelope aesthetically as well as improves the building's external microclimate. On the flipside, poor plant growth with unattractive foliage can be equally apparent.

Skyrise greenery microclimates are diverse and dependent on surrounding urban forms and heights. Where possible, in project phasing, set up plant test plots (with mock-up surfaces, etc.) in consultation with skyrise greenery consultants who have been engaged to ascertain the horticulture performance of selected greenery systems and plant species prior to the greenery installation. Such test plots will serve well to identify suitable plant species as well as manage the building owners' and users' expectations of the relevant greenery systems and subsequent maintenance.

Some plants species, such as *Bromeliad* spp. and *Alocasia* spp., may trap water in their axials. If used, these plants should be regularly monitored every few days for signs of mosquito breeding. Plants that can potentially trap water are not allowed on non-accessible skyrise greenery where inspection is infrequent.

Please refer to section 5 Plant Palette for Skyrise Greenery.

3. Designs for Maintenance — Safety

The term "maintenance" broadly means proper care or upkeep of a certain product or item for a period of time. In order to carry out proper and sustainable maintenance work on green wall and green roof, it is essential to design for safety as contractors need to work at height most of the time.

This chapter will focus on the safety aspect of maintenance on rooftop greenery and vertical greenery.

3.1 Protection from falls

Falls from height (FFH) is the major cause of injury and fatality at workplace. Wherever possible, in the planning, design, construction, and maintenance of rooftop and vertical greenery, the need to work at height must be reduced and managed.

Where it is not possible to avoid work at height, the following passive and active strategies should be considered.

	ACCESS/EGRESS (to elevated work space)	EDGE-PROTECTION (of elevated work space)
PASSIVE	*Example:* Building's permanent stair core	*Example:* Minimum 1m height fixed parapet
ACTIVE	*Example:* MEWPs, ladders, vertical rail, etc.	*Example:* Safety line + PPE

The design, installation, and maintenance of these safety features must comply with industry standards and regulations.

Safety features, when appropriately introduced, can safeguard against workplace accidents. However, when inadequately designed, installed, utilised and/or maintained, they may create more risks and hazards.

Please refer to the Workplace Safety and Health Council's website, www.wshc.sg, for the Code of Practice for Working Safely at Heights. The onus is on the building owner and relevant users to make sure that these safety features are appropriately incorporated, maintained, and correctly utilised.

3.2 Common work-at-height (WAH) situations

SKYRISE GREENERY WAH — COMMON SITUATIONS					
Green roof		**Roof garden**			**Vertical greenery**
Working near green roof edge with low or no parapet	Working on pitched green roof	Reaching out beyond roof edge	Working on narrow planted ledge with low or no parapet	Vertically accessing crown of rooftop tree/ palm	Vertically accessing the top of tall green wall beyond 3M height
					

All work at heights for skyrise greenery must comply with the Workplace

Safety and Health Council (WSHC) Code of Practice for Working Safely at Heights.

Refrain from planting tall plants that are more than 2 m tall along roof edges to avoid:
- Falling plant debris and/or tool(s) during maintenance
- The need to work in such a high-risk, elevated environment.

For rooftop trees and palms setback recommendations, please refer to *CS E09:2012 — Guidelines on Planting of Trees, Palms and Tall Shrubs on Rooftop*.

3.3 Manual tree access (MTA)

Where elevated work platforms cannot be safely deployed to access a rooftop tree canopy for periodic crown maintenance (i.e. crown thinning, crown reduction, etc.), manual tree access (MTA) is the next option.

MTA requires operator skill, fitness, persistent concentration, and alertness. The operators (a minimum of two must be on site to keep watch of each other) must be trained, competent with their equipment, and able to spot potential tree hazards.

The operational task of MTA requires constant commitment from managers, supervisors, operators, and all other team members to ensure personnel safety and that operational objectives are met.

For safety reasons, MTA should never be exercised on rooftop trees planted along rooftop edges and rooftop zone 1. Please refer to section 2.5.

For more information on MTA procedures and requirements, please refer to the Singapore Arboriculture Society website, www.sas.sg, for relevant guidelines on:
- Code of Practice – Tree Pruning
- Tree Inspection Report Guidelines
- SAS Advice on Portable Ladders

4. Relevant CUGE Standards

- CS E01:2010— Guidelines on Design Loads for Rooftop Greenery
- CS E02:2010— Guidelines on Design for Safety on Rooftop Greenery
- CS E03:2010— Guidelines on Substrate Layer for Rooftop Greenery
- CS E04:2010— Guidelines on Filter, Drainage and Root Penetration Barrier Layers for Rooftop Greenery
- CS E05:2012— Guidelines on Waterproofing for Rooftop Greenery
- CS E06:2012— Guidelines on Irrigation for Rooftop Greenery
- CS E07:2012— Guidelines on General Maintenance for Rooftop Greenery
- CS E08:2012— Guidelines on Design and Construction of Pitched Green Roof
- CS E09:2012— Guidelines on Planting Trees, Palms and Tall Shrubs on Rooftop
- CS E10:2014— Guidelines on Design Loads for Skyrise Greenery
- CS E11:2014— Guidelines on Design for Safety of Skyrise Greenery

5. Plant Palette for Skyrise Greenery

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Aeschynanthus spp.	Gesneriaceae	Creeper		•				•			•	
Agave spp. & hybrids	Asparagaceae	Succulent	•					•	•			
Aloe tenuior	Xanthorrhoeaceae	Succulent	•					•	•			
Alternanthera hybrids	Amarantheceae	Shrub	•	•			•		•		•	
Alysicarpus vaginalis	Fabaceae	Creeper	•	•			•		•		•	
Ananas spp. & hybrids	Bromeliaceae	Terrestrial bromeliad	•					•	•			
Antigonon leptopus & hybrids	Polygonaceae	Herbaceous climber	•					•		5 m		
Aptenia cordifolia	Aizoaceae	Succulent	•	•				•	•		•	
Arachis pintoi	Fabaceae	Creeper	•				•				•	
Aristolochia acuminata	Aristolochiaceae	Woody climber	•				•			3 m	•	
Aristolochia gigantea	Aristolochiaceae	Herbaceous climber	•				•			5 m		
Asclepias curassavica	Asclepiadaceae	Herbaceous plant	•				•		•			
Asparagus densiflorus 'Sprengeri'	Asparagaceae	Scrambling Shrub	•	•							•	
Asplenium nidus	Aspleniaceae	Epiphytic fern		•			•		•		•	•
Asystasia gangetica 'Variegata'	Acanthaceae	Creeper	•	•	•		•		•		•	
Bauhinia kockiana	Fabaceae	Woody climber	•				•			3 m		
Bauhinia semibifida	Fabaceae	Woody climber	•				•			3 m		
Begonia spp. & hybrids	Begoniaceae	Rhizomatous herb		•		•	•				•	•

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Bryophyllum x *crenatodaigremontianum*	Crassulaceae	Succulent	•	•				•	•			
Caladium spp. & hybrids	Araceae	Herbaceous plant		•		•					•	
Callisia repens	Commelinaceae	Creeper	•	•			•		•			
Calotropis gigantea	Asclepiadaceae	Herbaceous plant	•				•		•			
Carissa macrocarpa	Apocynaceae	Shrub	•				•		•			
Carpobrotus edulis	Aizoaceae	Creeper	•					•	•			
Ceropegia woodii	Asclepiadaceae	Creeper	•					•	•			
Codiaeum variegatum	Euphorbiaceae	Shrub	•				•		•			
Cordyline spp. & hybrids	Agavaceae	Shrub	•	•			•		•			
Crassula ovata	Crassulaceae	Shrub	•	•				•	•			
Crotalaria pallida	Fabaceae	Herbaceous plant	•				•		•			
Cryptanthus spp. & hybrids	Bromeliaceae	Terrestrial bromeliad	•	•			•		•		•	
Cuphea spp. & hybrids	Lythraceae	Shrub	•				•				•	
Cyanotis cristata	Commelinaceae	Creeper	•				•	•	•		•	
Cyathula prostrata	Amarantheceae	Creeper	•	•			•		•		•	
Davallia denticulata	Davalliaceae	Epiphytic creeping fern	•	•	•		•	•	•		•	•
Desmodium heterophyllum & D. triflorum	Fabaceae	Creeper	•	•				•	•		•	
Dianella ensifolia	Xanthorrhoeaceae	Herbaceous plant		•			•				•	
Dieffenbachia amoena	Araceae	Herbaceous plant		•		•					•	•

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Dischidia spp.	Apocynaceae	Creeper		•				•			•	•
Dracaena reflexa & hybrids	Dracaenaceae	Shrub	•	•			•				•	
Dracaena surculosa & hybrids	Dracaenaceae	Shrub		•			•				•	
Drimiopsis maculata	Asparagaceae	Herbaceous plant		•	•		•		•			
Drynaria quercifolia	Polypodiaceae	Epiphytic fern		•			•				•	•
Duranta erecta & hybrids	Verbenaceae	Shrub	•				•		•			
Echeveria spp.	Crassulaceae	Shrub	•					•	•			
Epiphyllum anguliger	Cactaceae	Succulent		•			•				•	
Epiphyllum hookeri ssp. *Guatemalense*	Cactaceae	Succulent		•			•				•	
Epipremnum pinnatum	Araceae	Herbaceous climber		•		•	•				•	
Episcia spp. & hybrids	Gesneriaceae	Creeper		•		•					•	
Euphorbia milii	Euphorbiaceae	Shrub	•					•	•			
Euphorbia tithymaloides spp. & hybrids	Euphorbiaceae	Succulent	•					•	•			
Excoecaria cochinchinensis	Euphorbiaceae	Shrub	•	•			•				•	
Ficus deltoidea	Moraceae	Shrub	•					•	•		•	
Ficus pumila	Moraceae	Creeper	•	•			•		•		•	
Ficus punctata	Moraceae	Creeper	•	•			•				•	
Ficus vaccinioides	Moraceae	Scrambling Shrub	•	•			•	•	•		•	
Furcraea foetida 'Striata'	Agavaceae	Herbaceous plant		•				•	•			
Geophila repens	Rubiaceae	Creeper		•			•		•		•	

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Grammatophyllum speciosum	Orchidaceae	Epiphytic Orchid	•	•				•	•			
Habranthus gracilifolius	Amaryllidaceae	Herbaceous plant		•			•		•			
Haworthia spp. & hybrids	Xanthorrhoeaceae	Succulent		•				•	•			
Hemigraphis alternata	Acanthaceae	Creeper	•	•			•		•		•	
Hemigraphis alternata 'Exotica'	Acanthaceae	Creeper	•	•			•		•		•	
Hemigraphis repanda	Acanthaceae	Creeper	•	•			•		•		•	
Heterotis rotundifolia	Melastomataceae	Creeper	•	•			•				•	
Homalocladium platycladum	Polygonaceae	Herbaceous plant	•	•			•		•			
Hoya densifolia	Apocynaceae	Herbaceous climber	•	•			•				•	•
Hoya diversifolia	Apocynaceae	Herbaceous climber		•			•	•			•	•
Hoya obovata	Apocynaceae	Herbaceous climber		•			•				•	
Hoya pubicalyx	Apocynaceae	Herbaceous climber		•			•				•	•
Ipomoea mauritiana	Convolvulaceae	Herbaceous climber	•			•				4 m		
Ixora Dwarf hybrids	Rubiaceae	Shrub	•				•		•			
Kalanchoe pinnata	Crassulaceae	Succulent	•	•				•	•			
Kalanchoe tomentosa	Crassulaceae	Succulent	•	•				•	•			
Klanchoe millotii	Crassulaceae	Succulent		•				•	•			
Lantana camara & hybrids	Verbenaceae	Scrambling Shrub	•				•		•		•	
Lespedeza bicolor	Fabaceae	Shrub	•	•			•		•			

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Leucophyllum frutescens	Scrophulariaceae	Shrub	•				•	•	•			
Liriope muscari	Convallariaceae	Herbaceous plant		•			•		•			
Lobelia chinensis	Campanulaceae	Creeper		•			•		•		•	
Lonicera japonica	Caprifoliaceae	Woody climber	•				•			5 m		
Lysimachia procumbens	Primulaceae	Creeper		•			•		•		•	
Mentha cultivar	Lamiaceae	Creeper	•	•		•	•				•	
Microsorum punctatum 'Grandiceps'	Polypodiaceae	Epiphytic creeping fern		•			•		•		•	•
Murdannia nudiflora	Commelinaceae	Creeper	•	•			•		•		•	
Neoregelia spp. & hybrids	Bromeliaceae	Terrestrial bromeliad	•	•			•		•		•	
Nephrolepis spp. & hybrids	Oleandraceae	Epiphytic creeping fern		•			•		•		•	•
Ophiopogon spp. & hybrids	Convallariaceae	Herbaceous Plant	•	•			•		•		•	
Pandanus amaryllifollius	Pandanaceae	Shrub	•	•		•	•				•	
Pandanus pygmaeus	Pandanaceae	Creeper	•				•		•		•	
Pellionia repens	Urticaceae	Creeper		•	•		•		•		•	
Pennisetum alopecuroides & hybrids	Poaceae	Perennial Grass	•				•		•			
Peperomia spp. & hybrids	Piperaceae	Herbaceous plant		•			•				•	
Philodendron spp. & hybrids	Araceae	Herbaceous climber		•			•		•		•	
Phyllanthus cochinchinensis	Phyllanthaceae	Herbaceous Plant	•				•		•		•	
Phyllanthus myrtifolius	Phyllanthaceae	Herbaceous Plant	•				•		•		•	

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Phymatosorus scolopendria	Polypodiaceae	Epiphytic creeping fern		•	•		•	•	•		•	•
Pilea microphylla	Urticaceae	Succulent		•		•					•	
Pilea nummularifolia	Urticaceae	Herbaceous climber	•	•		•					•	
Pityrogramma calomelanos	Pteridaceae	Creeping fern	•	•			•		•		•	•
Platycerium coronarium	Polypodiaceae	Epiphytic fern	•	•			•				•	•
Plectranthus amboinicus	Lamiaceae	Herbaceous plant		•			•		•			
Polyscias fruticosa (Dwarf)	Araliaceae	Shrub	•	•			•		•		•	
Portulaca spp. & hybrids	Portulacaceae	Creeper	•					•	•		•	
Portulacaria afra	Portulacaceae	Herbaceous plant	•	•				•	•		•	
Pseudogynoxys chenopodioides	Asteraceae	Woody climber	•				•			3-6 m		
Pteris ensiformis 'Victoriae'	Pteridaceae	Creeping fern		•			•				•	
Pteris semipinnata	Pteridaceae	Epiphytic fern							•		•	•
Quisqualis indica	Combretaceae	Woody climber	•				•			8 m		
Russelia equisetiformis	Plantaginaceae	Creeper	•					•	•		•	
Ruta graveolens	Rutaceae	Shrub	•	•				•	•			
Sansevieria spp. & hybrids	Asparagaceae	Creeper	•	•				•	•			
Schefflera arboricola	Araliaceae	Shrub	•	•			•		•		•	
Scindapsus pictus 'Argyraeus'	Araceae	Herbaceous climber		•			•				•	
Sedum mexicanum	Crassulaceae	Succulent		•				•	•		•	
Sedum sarmentosum	Crassulaceae	Succulent		•				•	•		•	

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Sedum x *rubrotinctum*	Crassulaceae	Succulent	•					•	•		•	
Selaginella spp.	Selaginellaceae	Creeping fern		•			•				•	•
Serissa japonica & hybrids	Rubiaceae	Shrub	•	•			•		•			
Sesuvium portulacastrum	Aizoaceae	Creeper	•			•	•	•	•			
Spathoglottis spp. & hybrids	Orchidaceae	Terrestrial Orchid	•				•		•		•	
Sphagneticola trilobata	Asteraceae	Creeper	•	•			•		•		•	
Stachytarpheta indica	Verbenaceae	Shrub	•				•		•			
Stachytarpheta 'Red Compacta'	Verbenaceae	Shrub	•	•			•		•			
Syngonium spp. & hybrids	Araceae	Herbaceous climber		•	•	•					•	
Talinum paniculatum	Portulacaceae	Herbaceous plant	•				•	•	•			
Talinum triangulare 'Variegata'	Portulacaceae	Herbaceous plant	•				•		•			
Telosma cordata	Asclepiadaceae	Woody climber	•				•		•	10 m		
Tetracera indica	Dilleniaceae	Woody climber	•				•		•	5 m		
Thunbergia grandiflora	Acanthaceae	Herbaceous climber	•				•			10 m		
Trachelospermum asiaticum 'Tricolor' & 'Ogon Nishiki'	Apocynaceae	Creeper	•	•			•	•	•		•	
Tradescantia pallida	Commelinaceae	Creeper							•		•	
Tradescantia spathacea	Commelinaceae	Semi epiphytic herbaceous plant	•	•			•		•		•	
Tristellateia australasiae	Malpighiaceae	Woody climber	•				•		•	10 m		
Vernonia elliptica	Asteraceae	Herbaceous climber	•				•		•	3 m	•	
Xiphidium caeruleum	Haemodoraceae	Herbaceous plant	•	•			•		•		•	

SCIENTIFIC NAME	FAMILY NAME	GROWTH TYPE	FULL SUN	SEMI SHADE	SHADE	LOTS OF WATER	MODERATE WATER	LITTLE WATER	EXTENSIVE ROOFTOP	GREEN WALL		REQUIRE MIST SYSTEM
										SUPPORT SYSTEM	VERTICAL PANEL & FABRIC SYSTEM	
Zephyranthes candida	Amaryllidaceae	Herbaceous plant	•				•		•		•	
Zephyranthes rosea	Amaryllidaceae	Herbaceous plant	•				•		•		•	

SPONTANEOUS VEGETATION

Transforming Manicured Lawns into Selectively Maintained Biodiverse Gardens

HWANG Yun Hye

1. Introduction

Beyond the perception of spontaneous vegetation as insignificant weeds, the ecological value of such greenery has been highlighted by many ecologists who argue that our categorisation is grounded in value judgments (Davis et al., 2011). Spontaneous vegetation deserves a place in our city given that it functions as part of the wider ecosystem (Del Tredici, 2010), acting as an ecologically critical element in the urban landscapes (Dunnett & Hitchmough, 2004). The novel visual forms offered are also opportunities to be explored as a means to evoke a sense of place (Kühn, 2006) and as a medium to synthesise into urban ecological design (Nassauer, 1995). In fact, considering spontaneous vegetation as a component of manmade landscape is not new. It has been widely applied in Dutch heemparks since the 1920s under the name 'managed naturalism' (Koningen, 2008). Such application extends the role of the landscape manager to become a mediator between the people and nature. Nevertheless, nature-dependent landscape management strategies are still held in low regard and have little influence on the landscape industry in Singapore.

For such a compact island city, Singapore has a superlative contrast — a primitive tropical jungle alongside highly controlled manmade greenery.The land was originally covered by a regionally-specific form of lowland primary rainforest that saw overwhelming growth of countless plant species within an optimum ecosystem (Corlett, 1992; Terborgh, 1992). On the other hand, much of the current manmade landscapes consist of mowed grass areas as well as neatly pruned shrubs and trees that requires continual labour intensive maintenance (Centre for Urban Greenery & Ecology, 2010), further intensified by the local climate which bestows conditions ideal for relatively faster growth in plants as compared to temperate countries. Most importantly, manicured lawns without recreational purposes seem out of place in the tropical setting.

Managed lawns within public parks, park connectors, roadside green, campus green, as well as temporarily-open fields set aside for future development, can act as suitable sites for creating biodiverse gardens with the use of spontaneous vegetation. Besides these distinctive spaces, scattered unnamed grass patches such as fenced-up lawns, park fringes and space underneath elevated infrastructure can also offer prospective platforms to add ecological value. This holds especially true since most of these areas have the potential to attract more fauna when converted into a local habitat. Currently, these sites are typically covered by a single exotic turf species, *Axonopus compressus* (Cowgrass), and maintained with biweekly mowing to retain their neat appearances.

This generic single species standard does not always perform well in all contexts. For example, grassy areas that are shaded under wide tree canopies may turn into bare compacted patches due to lack of sunlight. Grass on steep slopes may also create issues such as soil erosion, with safety implications for operators of knapsack grass-cutters. Open lawns that are clipped short can furthermore decrease the effectiveness of the vegetation in reducing surface temperatures, as compared to taller plants with higher evapotranspiration and shade provision. The proposed transformation into biodiverse gardens can thus be a feasible solution for such problematic

environmental issues, since spontaneous vegetation in general can easily adapt and thrive well in most harsh urban conditions, such as full shade, steep slopes and extremely hot areas.

In summary, the idea of transforming manicured lawns into biodiverse gardens using spontaneous vegetation offers a plausible alternative for five reasons:

- Promoting biodiversity in managed greenery to form local habitats is befitting of a country that was once a tropical jungle, but has only a vestige of the original left.
- Singapore is climatically suitable for this initiative, where vegetation grows and flourishes within a relatively short time in the hot and humid climate.
- Allowing spontaneous vegetation to convert grassy areas into biodiverse gardens can possibly save time and costs against labour-intensive maintenance, as well as being a solution to problematic site conditions.
- Naturalised gardens would provide the potential for aesthetically pleasant and therapeutic environments that facilitate the up-close appreciation of the dynamic processes in nature.
- Beyond the conventional norm of landscape management to keep the original design, maintenance could be extended to an incremental design action in response to landscape processes, towards a more ecologically productive and sustainable greening of Singapore.

2. Application

Images of lawns at 0 months, 8 months and 1.5 years (from above to bottom)

Transforming manicured lawns into biodiverse gardens requires multidisciplinary actions by designers and managers. Most importantly, management strategies have to be customised for maximum biodiversity

and to suit local site contexts. Based on empirical research projects[1] to convert manicured lawns into naturalised gardens in the campus of National University of Singapore (NUS), time-based interventions are suggested in this chapter for application onto existing manicured lawns in a broad context.

2.1 The first stage (0-0.5 years)

Grass cutting is halted and the assigned area is redefined through observations of changes in the landscape. There will be no notable changes of vegetation volume within the first six months, but emerging groundcovers will slowly increase in number of species. In most of cases, no regular maintenance is needed except to keep the area clean. At this stage, the required actions are as follows, with most to be retained in the long term:

- No grass cutting within the assigned area.
- Remove litter on a regular basis.
- Selective grass cutting can be done once in two months, but only if there is any adjacent infrastructure, such as paved footpaths or concrete drainage areas, in order to avoid potential obstruction and flooding due to encroaching by overgrown grass.
- If necessary, a one-time loosening of any compacted bare soil or topping-up of mulch can be done at the beginning, to encourage the emergence of spontaneous vegetation.

2.2 The second stage (0.5-1 year)

The sixth month is a critical chronological corridor, which warrants interceptive actions in order to achieve a better balance of biodiversity. The changes of the plots become more apparent due to the growth in both the volume and the number of spontaneous vegetation, including groundcovers and shrubs, although in general, the original turf will still occupy more space than other emerging vegetation.

- Invasive species, including the creepers *Mikania micrantha, Cissus hastata* and tall grass *Imperata cylindrica*, *Ischaemum muticum* should be removed before they smother other plants, once in three months.
- Ground herbs *Lindernia* spp., *Spermacoce* and *Desmodium* spp. or smaller wild flowers *Asteraceae, Vernonia, Emilia* and slow-growing groundcovers may be found intermixed within the original turf species *Axonopus compressus*. These slow-growing perennials are highly recommended for retention to enhance the biodiversity of the plot.

Plan view of a manicured lawn before (left) and after 1 year (right)

[1] Applications are based on two academic research projects by the author in "Observation of Changing Landscape: Vegetative Changes of an Un-maintained Site (2010–2012)" and "The Implementation Feasibility of Spontaneous Vegetation as Landscape Materials (2012–2014)", supported by NUS and Ministry of Education Tier 1.

- Native shrubs *Melastoma malabathricum*, woody plants *Dillenia suffruticosa* and *Syzygium grande* as well as a few seedlings of *Ficus* and *Acacia auriculiformis* trees may pop up in scattered areas.

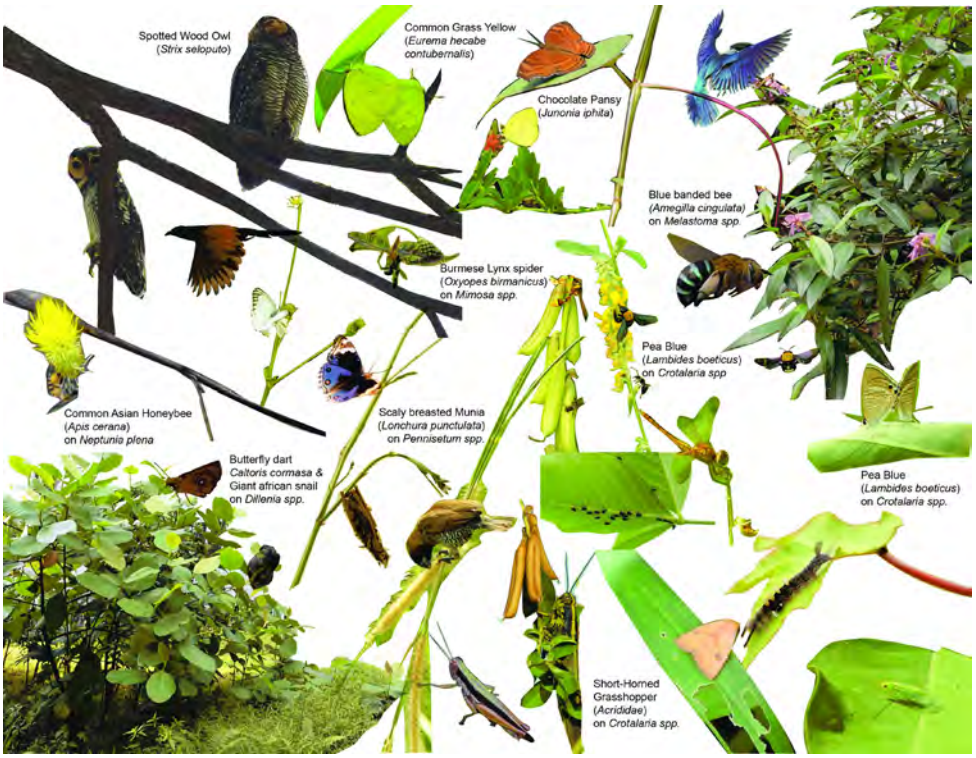
2.3 The third stage (1-1.5 years)

The number of *fauna species will have significantly* increased by this time, and be visible inside the thick understory as well as using the taller shrubs. As the second critical corridor, emerging plants would have exceeded the existing turf species *Axonopus compressus*, while the growth of shrubs have become distinctive and naturally occurring tree saplings have become recognisable. Thin out overpacked groundcovers, such as *Cyrtococcum accrescens*, or trim fast-growing groundcovers that have grown past 0.5 m to increase opportunities for establishment of other slower growing but ecologically desirable plants. This action can be done every six months.

- Retain ecologically desirable plants that are compatible with each other, non-invasive but resilient, stress tolerant and self-sustaining without any external aid, and are able to attract fauna as a food source or a shelter. Long life spans and gradual growth are particularly desirable as well.
- It is recommended to keep a sufficient volume of groundcovers and taller grasses as these are essential in supporting cricket and grasshopper populations.
- It is recommended to keep a fuller variety of shrubs such as *Melastoma malabathricum*, *Murraya koenigii* and *Clidemia hirta* as long as there are no negative effects. For example, some tall shrubs such as *Dillenia suffruticosa* may encourage mosquitoes to breed in the water accumulated on shedded leaves. Monitoring is required once every 3 months.
- Refine edges along the path by pruning encroaching branches of shrubs once a month. This should be done for safety as well as to provide a comfortable walking experience.

2.4 The fourth stage (1.5-3 years)

Various types of management action trimming, mowing, cleaning, removing, pruning, thinning and transplanting (clockwise from top left)

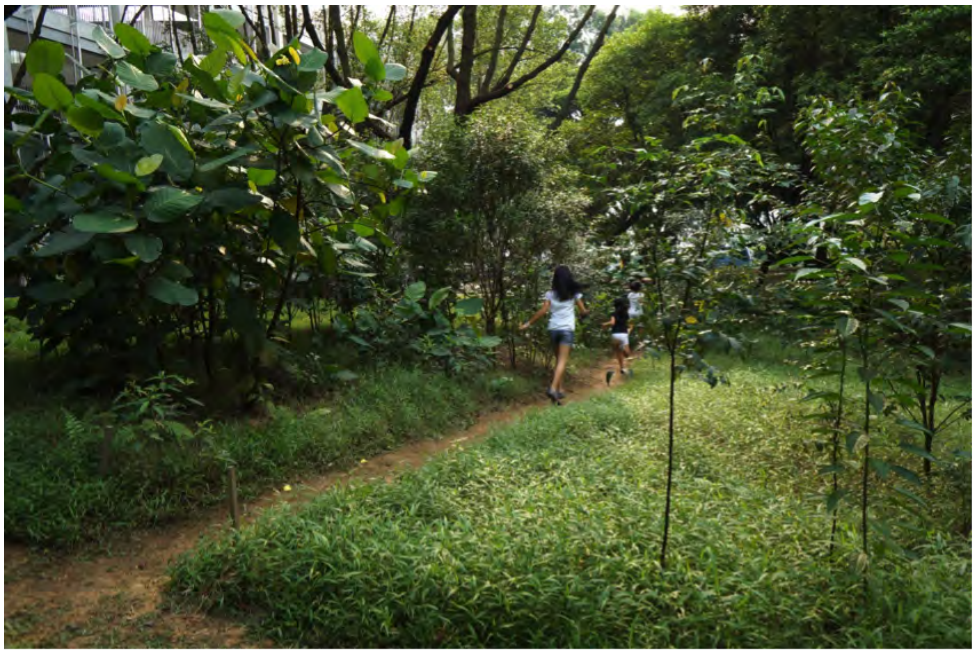


Fauna spotted at NUS plots and associated flora

This is the period when the growth in the total number of species slows down. Garden settings would exhibit fewer changes at this stage as long as the suggested maintenance activities are continued. Most tree saplings become distinctive and some fast-growing trees can grow above 3.0 m if the plot receives enough sunlight. Fauna and flora associations will become clearer as stable niche habitats are formed. Annual plants will regenerate but in a smaller area, and some fast-growing shrubs will attain the full height of their mature stage.

- Preserve flowering shrubs and woody plants as far as possible in order to attract multiple fauna. For example, a fruit tree such as *Morinda citrifolia* can be a local habitat for many types of fauna including a variety of ants, spiders and fruit bats. Annual flowering plants such as *Crotalaria* spp. supply nectar to bees, wasps, butterflies and moths as well as provide shelter for birds with its lower branches.
- Remove species that are susceptible to failure or breakage on sloped areas for safety purposes, such as the self-seeding *Acacia auriculifornis* trees or *Spathodea campanulata*, once in six months.
- Prune the width and height of tree canopies once in six months. The removal of denser and taller trees may eventually be warranted in order to balance their population growth with regards to overshadowing other plants.
- Remove fallen shrubs and branches, if any.
- If the assigned area exhibits the ability to be a tree bank naturally germinated by wind or birds, healthy tree saplings found growing, especially species such as *Syzygium* spp. and *Cinnamomum* spp., can be transferred to and stored in a nursery for use in other plots. Do this once in six months.
- When developing into a walk-through garden, it is encouraged to derive a path based on more dynamic scenery found in the plot so that pedestrians can enjoy the full variety of plants. Mowing of the path can be done once a month. The installation of landscape elements such as boardwalks or a resting bench may be considered.

2.5 The fifth stage (after 3 years)



Perspective of a garden by spontaneous vegetation

This is the period when most suggested management activities become routine. Considering that 5 years is the average time required to convert a grass area into a young pioneer forest within a tropical context, subtraction actions such as removing, cutting, pruning and thinning should continuously be applied on these thicker and denser landscapes to fulfil the preferences of various stakeholders.

3. Further Considerations

Suitable platforms to implement this nature-dependent maintenance strategy include managed greenery that exists as "just green" but does not have active human usage, such as fenced open lawns, unnamed scattered grass patches, park fringes, grassed areas underneath MRT track and non-accessible green roofs (see below). With this vision, managed greenery can springboard a biodiversity boost in the city.

On top of the common actions described above which increase the ecological value of grassed areas, garnering public support is compulsory for the success of the gardens (Kaplan & Kaplan, 1989). Leaving the gardens alone to grow wildly may raise negative concerns in terms of overall tidiness as well as safety. Therefore, it will be necessary to investigate what is perceived as an "acceptable form of nature" in a tropical urban context (Kong & Yeoh, 1996).

It is recommended that the growth and development of native, rare and endangered species be promoted if the site shows the ability to cater for them. Specialised biological knowledge would be required to identify the development potential of the plot. Accumulated data of fauna and flora that emerge on these gardens will contribute to replicate desirable plant palettes for naturalised planting designs. Such a list of plants will also be of value to related professions.

In considering gardens as a living entity that can be sustained for a hundred years, it is too early now to conclude the necessary management activities. Continual monitoring processes over a longer period will certainly provide a more comprehensive management regime.

Perspective of NUS green roof colonized by spontaneous vegetation

References

Centre for Urban Greenery & Ecology, CUGE. (2010). *Guidelines for Tropical Turfgrass Installation and Management* (Vol. CS B01: 2010.). Singapore: Centre for Urban Greenery and Ecology.

Corlett, Richard T. (1992). The Ecological Transformation of Singapore, 1819–1990. *Journal of Biogeography, 19*(4), 411-420.

Davis, M., Chew, M. K., Hobbs, R. J., Lugo, A. E., Ewel, J. J., Vermeij, G. J., . . . Briggs, J. C. (2011). Don't Judge Species on Their Origins. *Nature, 474*(7350), 153-154.
Del Tredici, Peter. (2010). *Wild Urban Plants of the Northeast: A Field Guide*. Ithaca: Cornell University Press.

Dunnett, Nigel, & Hitchmough, James. (2004). *The Dynamic Landscape: Design, Ecology, and Management of Naturalistic Urban Planning*. London; New York: Spon Press.

Hwang, Yun Hye, & Tan, Yit Chuan. (2011, 19–21 January 2011). *Emergent Vegetation on Planned Greenery in Singapore*. Paper presented at the IFLA APR Congress — Hospitality: The Interaction with Land, Bangkok, Thailand.

Kaplan, Rachel, & Kaplan, Stephen. (1989). *The Experience of Nature: A Psychological Perspective*. New York, USA; Melbourne, Australia: Press Syndicate of the University of Cambridge.

Kong, L., & Yeoh, B. S. A. (1996). Social Constructions of Nature in Urban Singapore.

Koningen, Hein. (2008). Creative management. In N. Dunnett & J. Hitchmough (Eds.), *The Dynamic Landscape* (2nd ed.). London: Taylor & Francis.

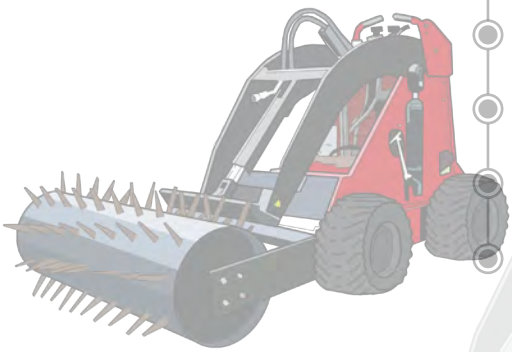
Kühn, Norbert. (2006). Intentions for the Unintentional: Spontaneous Vegetation as the Basis for Innovative Planting Design in Urban Areas. *Journal of Landscape Architecture 1*(2), 46-53. doi: 10.1080/18626033.2006.9723372

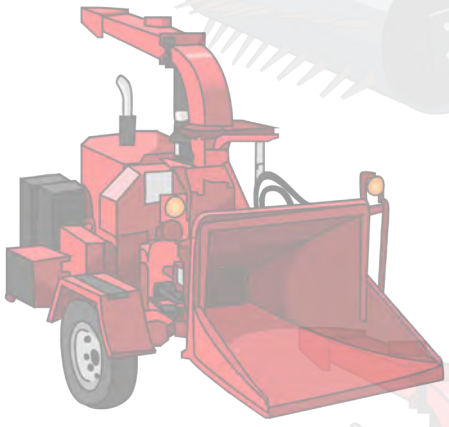
Leong, Kwok Peng. (2011). The Green Corridor: A Proposal to Keep the Railway Lands as a Continuous Green Corridor. Retrieved from Nature Society (Singapore) website: http://nss.org.sg/documents/TheGreenCorridor101103.pdf

Nassauer, Joan Iverson (1995). Messy Ecosystems, Orderly Frames. *Landscape Journal, 14*(2), 161–170.

Terborgh, John. (1992). *Diversity and the Tropical Rain Forest*. New York: Scientific American Library.

INNOVATION IN AUTOMATION & MECHANISATION





1. Introduction

This chapter looks at some recent developments of innovation, technology and creative solutions in the landscape industry. It offers a perspective on the factors that can influence innovation in automation and mechanisation in the local market and a brief update on technology, devices and equipment that could assist sustainable landscape management.

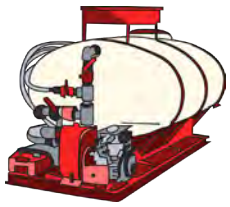
One of the key elements of sustainability is the embracing of new technology and forms of innovation which are relevant, practical and affordable, and that subsequently benefit the local population and the environment. The Singapore government agencies and public bodies have invested much in environmental sustainability through research, financial credit schemes and other development incentives to encourage the development of Green projects, innovation and work productivity in the areas of automation and mechanisation.

2. Productivity Drive for the Landscape Industry

The Landscape Productivity Grant administered by the National Parks Board is a new grant scheme since September 2013 to encourage landscape companies to purchase landscape equipment for the purposes of achieving productivity benefits and gain better operational efficiency when they work on projects (landscape design, construction and maintenance). Companies which are eligible for the grant will be able to defray the costs incurred for the acquisition of new landscape equipment, including associated software and packaged solutions and thus encourage greater adoption of mechanization and automation. The scheme covers five areas of Mechanisation and Innovation, Nursery Innovation, Operations Improvement, Weed Control and Human Resource Applications. More information is available at https://www.cuge.com.sg/landscapeservices/Landscape-Productive-Grant-Scheme.

Examples of equipment that qualify under this scheme are listed below. The table also shows the respective functions and applications.

TYPE OF EQUIPMENT AND ITS APPLICATION		
Management of open lawns, sports fields and golf courses		
Ride-on mower	Four-wheeled ride-on mower for mowing large lawn	
Ride-on aerator	Four-wheeled ride-on mower for performing aeration on large lawn	

Utility loader	Flexible loader that can mount various types of attachments to perform multiple tasks	
Dethatcher/ lawn scarifier	Equipment attached to mower for removing thatch from lawn	
Mechanised lawn sweeper	Equipment attached to vehicle for sweeping leaf and leaf litters	
Hydromulcher/ hydroseeder	Power sprayer for sowing grass sprigs / mulches	
Sod cutter	Equipment for stripping off and rolling up grass sods	
Edger/ lawn edger/ stick edger	Equipment for trimming lawn edges	
Digging works		
Trencher	Equipment attached to vehicle for digging trenches	
Pruning, cutting, spraying and clearing works		
Mechanised leaf shredder/ shredder equipment	Machine for shredding leaves and plant wastes	
Wood chipper	Machine for shredding woody branches and plant wastes	

Stump grinder/ stump cutter	Machine for grinding down or level to grade the remains of tree trunk stump after felling tree	
Sprayer equipment	Chemical spraying set that can be mounted on vehicle or wheeled platform to perform power spray on plants for pest control	
Preparing soil mix and potting in the nursery		
Reversible plate compactor	Flexible compaction plate that can be mounted on vehicle to prepare soil mix in potting yard and/ or soiling works in open landscape	
Soil mixer	Machine with drum for turning and mixing various components of soil mix	
Potting machine	Conveyor belt machine system for potting or placing soil mix into pots in large quantities	

Table 1. Type of equipment and its application

Government subsidies are also available for other automation and mechanisation needs that support landscape works. These include MEPs (Mobile Elevated Platforms) such as scissor lifts, aerial lifts, boom lifts and earthmoving machines (excavators and skid loaders). Contractors may apply for funding under the Mechanisation Credit (Mech C) of the BCA Construction Productivity and Capability Fund (CPCF) which award grant up to 70% depending on eligibility criteria such as the extent of impact the equipment will have on productivity improvement. More information at http://www.bca.gov.sg/mechc_online.

3. Improved Resource Capabilities

In addition, SMEs (Small and Medium Enterprises) can capitalise on various government training grants for horticultural workers. The Skills Development Fund (SDF) administered by the Workforce Development Agency (WDA) awards fee subsidies between 40% and 90% depending on eligibility. More information on SDF and CUGE training programmes can be found at the following websites:

- https://www.skillsconnect.gov.sg/web/guest/applyfortrainginggrant
- https://www.cuge.com.sg/Professional-Certification-Programmes
- https://www.cuge.com.sg/Workforce-Skills-Qualifications-Landscape.

Many SMEs have utilised these training benefits and groomed a well-trained workforce. Coupled with adequate investment in machinery and equipment, their resource capabilities have improved over the years. Moreover, for small businesses on the rise, these types of fundings are windows of opportunity for upgrading business standings despite various mechanisation and operational barriers.

4. Transition to Mechanisation

There is a common assumption that mechanisation would lead to immediate reduced headcount, which in turn translate into cost saving in contract sum, higher productivity and improved service standards.

In reality businesses may need time to adjust to mechanisation in terms of work processes and task redeployment. This is because there will be times and situations when machinery cannot be used and manual labour is required for urgent work. Often, it is not feasible for small businesses to give up workers, especially those who can perform a wide variety of tasks. Productivity savings should also be realistically weighed against operational costs such as fuel, replacement of parts, servicing, and the transportation and mobilisation of heavy machinery and ancillary parts. Generally, the combination of mechanisation with the existing workforce would allow companies to do more with the same headcount and therefore grow their business.

5. Suitability of Site Conditions

The use of the equipment and tools should be considered with a specific site and/or nature of project in mind (Please refer to the approved list of equipment in Table 1). An important consideration is the provision for access and service infrastructure which must be made available by owners and suitable for the appropriate type of machinery such as a ride-on mower or a mechanised sweeper. For example, some existing site access points might not have been constructed to take the weight of heavy machinery for prolonged use, and this can lead on to other site problems. In other cases, the scale and/or the fragmented nature of site and steep landform might hinder continuous work flow and can be counter productive to the overall objectives.

For controlled watercourse and biodiversity sensitive areas, diesel spillage from diesel operated machinery can be a concern. Mechanisation is discouraged as it can disturb birds and wildlife habitats in terms of loud noise, fume pollution, physical disturbance and surface ground compaction.

6. Scheduling of Works

In addition, businesses have to consider practical substitution of working during downtimes such as equipment breakdown and servicing, as well as unfavourable working conditions for machinery. The most common problem in urban and highly sensitive areas is loud noise and dust emission. For example, the use of stump grinders and air spades, which generate loud

noise and dust, restrict work scheduling and locations.

Other than noise restriction, work scheduling can also be affected by working hours, traffic conditions and loading/ unloading restrictions where transportation of heavy machinery is involved. In these scenarios, manual labour may be required to give support to complete task quickly.

7. Innovation in Work Processes

Innovation for productivity and sustainability is not restricted to acquiring new machinery, equipment and tools. Identifying the areas of improvement in work processes and aligning and adopting best industry practices, including automation have helped the landscape industry move forward. Collaboration amongst inter-government agencies is essential for integrated management of public roads, parks and waterways with shared infrastructure and facilities.

8. Adoption of Industry Best Practices

In the last ten years, the landscape industry has adopted many best practices in tree arboriculture and horticultural works, through improved work processes and structured relevant skill training. For example, many safety measures and streamlining of work processes on workplace safety and health matters have been put in place for service providers working on public roads, and this was done essentially through the collaborative efforts of inter-government agencies.

9. Vertical Greenery

For the wider landscape industry, the development of cleaner products and new planning approaches has created spin-off innovative solutions for the urban landscape challenges. Many solutions are found through the integration of landscape and building components.

'Open-able' vertical greenwall panels and service walkway with back access at the National University Hospital

A case in point is the development of vertical greenery in Singapore which until the beginning of the century had only existed as vertical trellis frames with soil filled planters. But today, vertical greenery includes modular structures that now clad building facades and interior spaces as a visual statement of green buildings. It gained wider public interest and acceptance when the substrate media and modular support system were introduced, as people saw the benefits of such lightweight and clean products as being green, and new innovative technology as the way forward.

However, the proper provision of successful maintenance capability often has the last word on the level of success of such installations in development projects. There is a general willingness of owners to take a calculated investment in exchange for government support and incentive schemes and/ or their own organisation's greening policies. Government incentives through co-fund assist schemes, trade off and award schemes to encourage building

owners to collaborate in cooling buildings with skyrise greenery.

What then followed was the search for more friendly automation and mechanisation design, devices, equipment and design solutions to improve high storey vertical planting. Initially, front access methods using boom lifts, scissor lifts and gondolas were generally the accepted standard. Climbing frames may have had back access platforms for plant maintenance. These evolved into building design solutions which provided proper service core back access to green wall panels, so that these panels can be pulled open for trimming plants at high storeys.

The sky trellis at Cleantech Park One is an example of integrated solution for mechanisation. A mobile platform was installed on fixed track at the roof level to allow workers to reach the plants as they move along the trellis path, much like a horizontal gondola.

Sky trellis platform at JTC Cleantech Park One

Very often innovation is associated with developing a new or modified tool or equipment or device for performing a standard task. The first example was an improvised design solution and the second a simple mechanisation solution. Both were conceived at design stage and integrated as part of a building feature. This shows the importance of maintenance considerations and solutions being provided at early design development stage.

10. Automation and Monitoring Devices

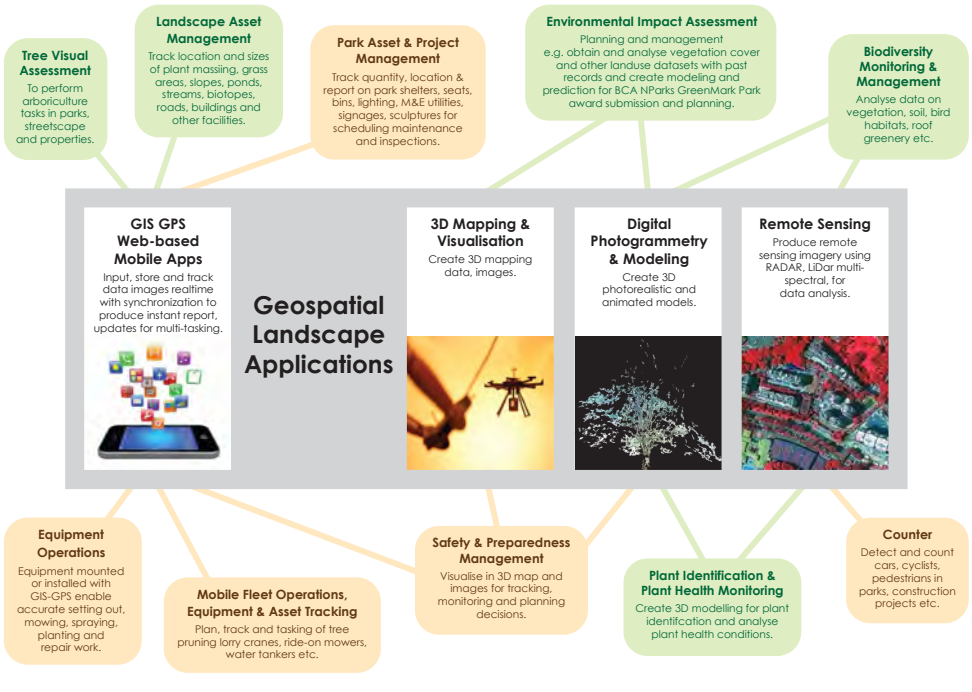
Automated tanker watering can be a one-man operation instead of deploying another worker to hold the hose sprinkler

Electronic and remote sensing devices including PLC (Programmable Logic Controller), thermal and infra lights are now commonly used in landscape and environmental management. These M&E controllers are used to facilitate automatic irrigation systems, water pump and filtration systems for water bodies and interactive water displays, and garden and security lighting. Coupled with a datalogger and CCTV cameras, monitoring work can be analysed and tracked.

For instance, monitoring silty wastewater discharge in sedimentation tanks, as Erosion Control Measures (ECM) for environmental management required in construction works and data can be transmitted via SMS to concerned parties. Data logger is also used for online noise monitoring in construction works.

11. GIS-GPS Technology Applications for Landscape Management

The use of GIS-GPS technology has enabled data communication through mobile phones and data computing via satellite with stronger connectivity and data availability.



The interaction between GIS technology and landscape management

Image courtesy of (www.ApusGeo.com)

Below are some developed areas of applications which are enabled by GIS-GPS technology together with other hardware and software.

- Tree and landscape management database built as mobile application for inspection, tracking data or work output, data updates, web based communication between parties involved at realtime and retrieval via GIS cloud storage.
- The application can be extended to the monitoring and tracking of other landscape elements in parks and facilities. RFID (Radio Frequency Identification) which is transmitted via electro magnetic field has been used in BIM (Building Information Modelling) for storing and retrieving data and can be supplemented for more sheltered environments.

- Mobile tracking of landscape operations and vehicle fleet to manage and deploy working teams, machinery and plant delivery, and planning activities in realtime environment.
- GPS aid in landscape construction and maintenance where a mounted GPS receiver and automation device can facilitate accurate land surveying, trenching, mowing and application of fertilisers, for example in golf courses and large open fields.
- 3D mapping as well as modelling and visualisation have been used to aid planning, management and redevelopment works. It can be applied to study of biodiversity, modelling of ground terrain and building structures, data input and analysis for environmental impact assessment, urban roof greenery, parks and green infrastructure and waterways. It is also useful for security management and emergency response and rescue works. Using 3D photogrammetry, photo images can be translated into 3D objects and models simulated in virtual reality.

Annex A: Case Scenarios for Potential Productivity Savings

1. Introduction

This compilation of common landscape scenarios is derived from an interpretation of the illustrations and data used in *Landscape Design Guidelines for Productive Maintenance & Sustainability* (published in 2012). Findings from the publication are used here to show how more sustainable options can lead to potential productivity savings, in addition to various sustainable landscape solutions already addressed in the preceding chapters of this book.

Common landscape problems have been identified in Scenario A and alternative good practices are shown in Scenario B. Comparisons between the options are further illustrated with photographs.

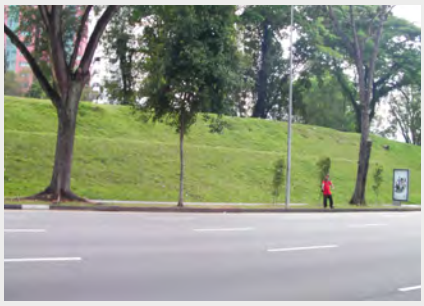
The data and examples taken from the original publication are purely illustrative. The scenario images may not necessarily represent the case studies from which lifecycle investment cost and ratio were calculated. In landscape design, solutions are often site specific; therefore these case scenarios should not be cited for direct site application.

2. Steep Slopes

Maintenance implications of grassed steep slopes

	SCENARIO A	SCENARIO B
Site Description	 Steep slope established with a grass sward	 Steep slope mostly established with native ferns and other soft herbaceous plants
Maintenance Activities	Knapsack cutting with safety harness	Knapsack cutting along drain edges and control of vegetation height
Maintenance Labour	Knapsack cutting crew/ operators	Knapsack cutting crew/ operators
Maintenance Machinery/ Equipment	Knapsack cutter and safety harness	Knapsack cutter for edges and control of vegetation height
Maintenance Cycles Per Year	12	4
Productivity Triggers	▪ Dangerous and difficult to cut on steep slopes ▪ Operators need to use a safety harness	Steep slopes established with native ferns do not require grasscutting
Maintenance Implications	Higher maintenance	Reduced maintenance as grasscutting is not required
Design & Construction Implications	To create the desired effect of an open grassed slope, it may be necessary to stabilise the embankment with cellular confinement system and to minimise the impact of surface drainage and erosion over time	▪ The effect of natural and lush embankment enhances diverse plant species, biodiversity and carbon capture ▪ Over time, ferns, groundcovers and other low growing plants will naturally establish themselves on embankments. ▪ Many grassed slopes can be quickly reverted to this design solution by ceasing grasscutting activities
Life Cycle Investment over 20-year period (site area of 1000 m²)	$17,000	$6,200
Life Cycle Investment Ratio	3	1

Photo illustrations of best practices for maintenance of steep slopes



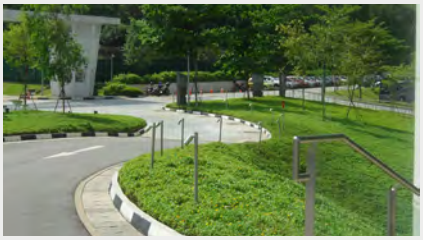
Grassed steep slopes may present an open and tidy appearance but they require labour intensive maintenance.

Vegetated slopes are lush and can significantly reduce maintenance labour.

Grassed steep slopes are vulnerable to soil erosion, and grasscutting is unsafe as safety harness is required for operators using knapsack cutters.

Self-sown/naturally occurring vegetation stabilises and protects steep slopes from erosion. It requires minimal maintenance.

Grassed slope with symptoms of erosion.



Groundcovers can provide surface protection and it requires less maintenance.

3. *Lawns*

Maintenance implications of knapsack cutters and machine mowers

	SCENARIO A	SCENARIO B
		
Site Description	Large open and relatively flat lawn with uneven surfaces and obstacles for mowing grass	Large open and relatively flat lawn with minimal obstructions for mowing grass
Maintenance Activities	▪ Knapsack cutting of grass ▪ Knapsack cutting of grass at base of obstacles ▪ Blowing of debris from paths	▪ Grasscutting using machine mower ▪ Knapsack cutting of edges ▪ Blowing of debris from paths
Maintenance Labour	▪ Knapsack operators ▪ Blower operators	▪ Mower operator ▪ Knapsack operators ▪ Blower operators
Maintenance Machinery/ Equipment	▪ Knapsack cutters operators ▪ Blower	▪ Ride-on mower operators ▪ Knapsack cutters ▪ Blower
Maintenance Cycles per Year	12	12
Productivity Triggers	Uneven bumpy surfaces and obstructions restrict the use of machine mowers, which is more efficient for large lawns.	▪ Smooth and even surfaces and unobstructed access for mowers ▪ Well-compacted soil to facilitate machine mowers
Maintenance Implications	▪ Knapsack cutting is labour intensive for large lawns ▪ Uneven surfaces can cause trip hazards for workers	Provide unobstructed access for machine mowers
Design & Construction Implications	Provide well-graded and well-compacted surfaces and unobstructed access to facilitate machine mowers	Provide well-graded and well-compacted surfaces and unobstructed access to facilitate machine mowers
Life Cycle Investment over 20-year period (site area 1000m²)	$80,000	$43,200
Life Cycle Investment Ratio	1.9	1

Photo illustrations of best practices for lawn maintenance

Exposed and shallow roots have caused uneven surfaces. It restricts continuous machine mowing and a knapsack cutter has to be used.

Planting groundcovers around the tree base protects roots and eases grasscutting.

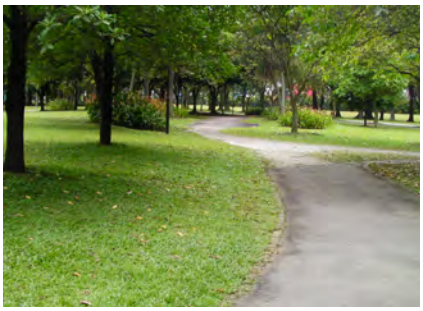
Exposed surface tree roots create obstructions to machine mowers.

Continuous and open lawn allows good movement of machine mowers.

Vehicle damage to a lawn can lead to soil compaction and uneven surfaces. It is necessary to reinstate the lawn to even and well-graded surface.

The grass is being protected to reduce the impact of heavy vehicular path and should be properly reinstated after completion of work.

Long, thin grass strips require significant edge trimming, and require unnecessary maintenance input.



Continuous lawn edges and level pathways allow freer maintenance movement.

Poor reinstatement of grass after trenching creates uneven surfaces for the lawn.

Properly reinstated grass should be lush, evenly graded and compacted and level with path or above it.

4. Plant Selection and Grouping

Maintenance implications of species and layout

	SCENARIO A	SCENARIO B
		
Site Description	▪ Landscaped bed ▪ Little consideration given to growth habits of plants, allowing climbers to grow over groundcovers and with different water requirements	▪ Landscaped bed ▪ As well as aesthetic considerations, plants are selected according to their growth requirements and functionality
Maintenance Activities	Individual species requiring different maintenance regimes within the mixed landscape, e.g. with different water requirements	▪ Occasional pruning of shrubs and covering plants ▪ Both plants require little watering and light level
Maintenance Labour	Experienced gardener appreciative of differing growth and requirements of plants and trimming skills	Gardener capable of performing basic trimming and weeding
Maintenance Machinery/ Equipment	Hand tools for pruning, weeding, fertilising and disease control	Hand tools for pruning, weeding, fertilising and disease control
Maintenance Cycles per Year	12	12
Productivity Triggers	▪ Failure of individual species within garden beds ▪ High labour input to maintain landscaped bed to design intent	▪ Consistently healthy plants ▪ Low labour input to maintain landscaped bed to design intent
Life Cycle Investment Over 10-year period (site area 100m²)	$4,800	$1,300
Life Cycle Investment Ratio	5	1
Maintenance Implications	Higher levels of gardening expertise required for management of individual rather than the grouped plants	Grouped plantings can be managed as a whole for moisture, nutrient, aeration and light requirements
Design & Construction Implications	Plant sourcing and planting investment are likely to be higher due to the higher number of plant variety that requires sourcing	Plant sourcing and planting investment are likely to be lower due to the lower number of plant variety that requires sourcing

Photo illustrations of best practices for plant selection and grouping

Frequent pruning is required to keep plants from pedestrians.

Less frequent pruning is required of taller plants (behind) and covering plants along pathway.

Slow-growing plants under shade will require more care and separation from the fast-growing groundcovers competing for space within the planting bed.

Compatible selection of plants with same growing conditions in bioswale.

Spot planting of shrubs in lawn requires high maintenance weeding and pruning around the single base.

Underplanting of shade-loving shrubs below trees on one side with lawn edge levelled with the plaza allows ease of maintenance.

5. Mulches and Groundcovers

Impact of mulches and groundcovers on landscape maintenance

	SCENARIO A	SCENARIO B
Site Description		
	▪ Groups of trees within lawn ▪ Due to poor soil and shading, tree roots are exposed below the tree canopies	▪ Groups of trees within lawn ▪ Remedial work undertaken — dense, quickly spreading and shade tolerant groundcover established over 6 months
Maintenance Activities	▪ Fortnightly hand cutting of grass ▪ Fortnightly grass edge trimming of grass around base of trees	▪ Preparation of soil, planting of groundcover ▪ Weekly attention during establishment ▪ Fortnightly grass edge trimming around groundcover bed ▪ Quarterly weeding of groundcover
Maintenance Labour	Ground maintenance crew	Ground maintenance crew
Maintenance Machinery/ Equipment	Knapsack cutter	▪ Planting and watering tools/equipment ▪ Knapsack cutter ▪ Machine mower (if bed/ grass edge suitable)
Maintenance Cycles per Year	24	4
Productivity Triggers	▪ Bare areas under trees ▪ Poor soil, exposed tree roots, but some grass patches in the area require regular cutting ▪ Unhealthy trees ▪ Tree trunks damaged from grass cutting ▪ Shallow tree roots damaged from grass cutting	▪ Dense and healthy coverage ▪ Healthy trees ▪ Undamaged tree trunks and roots
Maintenance Implications	Regular weeding around individual tree base is time consuming	▪ Once remedial treatment is completed, maintenance frequency is substantially reduced ▪ Less weeding
Design & Construction Implications	Provide underplanting or mulch to protect bare areas after trees are established	
Life Cycle Investment over 10-year period (site area 200 m²)	$1,024	$807
Life Cycle Investment Ratio	1.3	1

Photo illustration of best practices for using mulches and groundcovers

Avoid knapsack cutting too close to tree collar by mulching and reducing weeding maintenance.

Sweeps of mulches in tree clusters can ease mowing maintenance.

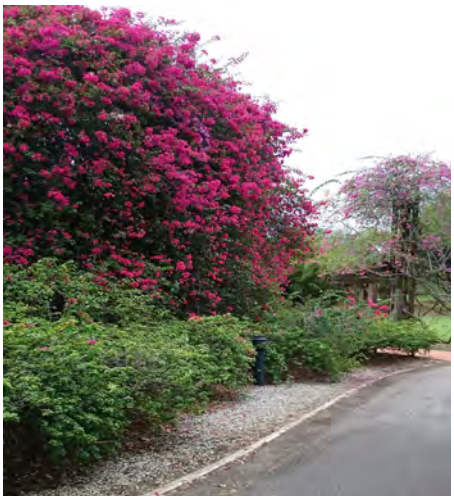
Remnant grass patches are unproductive for grasscutting. Narrow strips should be fully replaced by groundcovers.

Mulches and covering plants can protect trees from soil compaction.

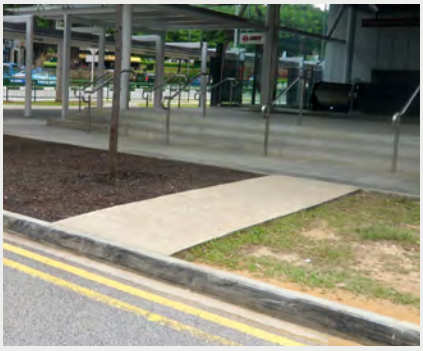
The young establishing tree is affected by overgrowth of weeds.

Mulching reduces weed growth around the base of the establishing tree.

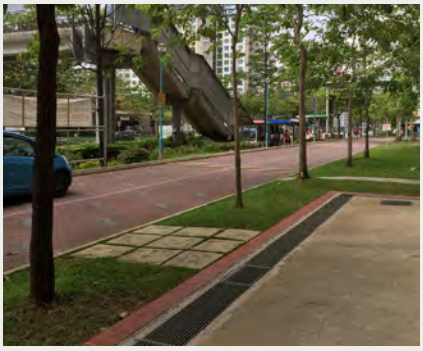
The narrow grass strip along the path edge creates excessive maintenance.



Gravel can serve as mulch to protect soil surface and reduce weeding maintenance.



Mulch can deter people from trampling over the area and protect trees from soil compaction.



Laying precast slabs over bare patches can quickly protect grass or planting from further damage.

Benches on soft surfaces and near groundcovers require regular weeding.

Hard paving beneath benches can avoid the need for plant maintenance.

6. Micro-irrigation

Impact of automated watering

	SCENARIO A	SCENARIO B
		
Site Description	▪ Landscaped bed ▪ Watered by hand with water supply from an approved water source	▪ Landscaped bed ▪ Retrofitted with an automatic micro irrigation system for watering
Maintenance Activities	Hand watering	Check timing controls and functioning on automatic micro irrigation system
Maintenance Labour	Ground maintenance crew	Ground maintenance crew
Maintenance Machinery/ Equipment	Garden hose	Automatic micro irrigation system
Maintenance Cycles per Year	52	52
Productivity Triggers	▪ Efficiency in watering practices ▪ High water use	▪ Effective delivery of irrigation ▪ Lower water use ▪ Adequate soil moisture content
Maintenance Implications	▪ Labour intensive ▪ Water intensive ▪ Watering undertaken during daytime shifts, often in the middle of the day when evaporation rates are high	▪ Labour saving ▪ Water saving ▪ Flexible hours of operation
Design & Construction Implications		Irrigation design and specifications by irrigation specialist
Life Cycle Investment over 10-year period (site area 500m²)	$1,050	$750
Life Cycle Investment Ratio	1.4	1

Annex B: Checklist for Sustainable Landscape

This checklist may be used during site inspections to identify landscaped areas that need to be refurbished for better maintenance, and prior to commencement of design and laying out of a park, garden or greenery that complements a building. Look up the contents of this book for ideas and tips for good design, implementation and maintenance.

Requirements for Development Plan Submission

☐ 1. The link provides details into NParks' greenery provision and tree conservation requirements for works along the roadside and within developments:
https://www.nparks.gov.sg/partner-us/developers-architects-and-engineers/development-plan-submission-requirements

Steep Slopes

☐ 2. Alternative planting such as groundcover may be considered for steep slopes that show signs of erosion or are becoming unsafe for grasscutting.

☐ 3. Grass can be left to self-establish into low vegetative cover to reduce maintenance needs, if it does not cause other problems.

Lawns

☐ 4. Improve the gradient, layout and access of lawns to allow the use of machine mower. Lawns should be reasonably flat without bumps or holes.

☐ 5. Remove minor obstacles (loose or temporary objects) or improve housekeeping to facilitate machine mowing, which is more productive.

☐ 6. Upgrade the access, kerbs and edging, turning radius, etc. of large lawns to allow machine mowing.

Plant Selection and Grouping

☐ 7. Group plants that have the same water requirements for ease of maintenance.

☐ 8. Underplanting of groundcovers can be implemented (replacing grass) to reduce weeding and the straggly effect of taller and established shrubs.

☐ 9. Manage quick-growing plants to prevent overgrowth and avoid smothering slower-growing desired species.

☐ 10. Sun- and shade-loving plants to be grown in correct and suitable locations.

Mulches and Groundcovers

☐ 11. Mulches and groundcovers to be provided around tree bases.

☐ 12. Horticultural waste materials to be reused or shredded for composting within the same site.

Micro-irrigation

☐ 13. Organise plants that have the same water requirements in the same landscaped beds.

List Of Contributors

NO.	NAMES	CHAPTERS
1.	Chang Hyun Jung	Waterway Planting
2.	Chang Yi Ning	Waterway Planting
3.	Cheng Siew Lee	Roadside Planting
4.	Foke Andrew	Parks
5.	Fong Yok King	Waterway Planting
6.	Galistan Amanda Grace	Parks
7.	Govindasamy Vivek	Lawns
8.	Hwang Yun Hye	Spontaneous Vegetation
9.	Kobayashi Tamako	Parks, Skyrise Greenery
10.	Liu Huei Lyn	Waterway Planting
11.	Ng Yin Seng	Skyrise Greenery
12.	Ow Lai Fern Genevieve	Roadside Planting
13.	Poh Choon Hock	Skyrise Greenery
14.	Yong Wai Weng Jason	Roadside Planting
15.	Yang Pih Foon	Innovation in Automation and Mechanisation; Annexes

List of CUGE Publications

(Available for purchase at www.cuge.com.sg/research/catalog.php.)

1. Guidelines on Design Loads for Skyrise Greenery
2. Guidelines on Design for Safety of Skyrise Greenery
3. Specifications for Soil Mixture for General Landscaping Use
4. Guidelines on Water Quality Monitoring for Tropical Ponds
5. Guidelines on Water Quality Assessment and Management for Tropical Ponds
6. Guidelines for Tropical Turfgrass Installation and Management
7. Guidelines on Design Loads for Rooftop Greenery
8. Guidelines on Design for Safety for Rooftop Greenery
9. Guidelines on Substrate Layer for Rooftop Greenery
10. Guidelines on Filter, Drainage and Root Penetration Barrier Layers for Rooftop Greenery
11. Guidelines on Waterproofing for Rooftop Greenery
12. Guidelines on Irrigation for Rooftop Greenery
13. Guidelines on General Maintenance for Rooftop Greenery
14. Guidelines on Design and Construction of Pitched Green Roof
15. Guidelines on Planting of Trees, Palms and Tall Shrubs on Rooftop