Centre for Urban Greenery & Ecology
CUGE Standards

GUIDELINES ON **PLANTING OF TREES, PALMS AND TALL SHRUBS ON ROOFTOP**

CS E09:2012

Guidelines on Skyrise Greenery

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

CUGE® CENTRE FOR URBAN GREENERY AND ECOLOGY

BCA / NPARKS GREEN MARK FOR PARKS

NATIONAL PARKS

CS E: Skyrise Greenery

CUGE STANDARDS CS E09:2012

GUIDELINES ON
PLANTING OF TREES, PALMS AND TALL SHRUBS ON ROOFTOP

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

The CUGE Standards Series is a set of published guidelines for adoption in the landscape and horticulture industry. They are written through a formal process that involves consultation with relevant bodies and reaching a consensus across all interested parties so that the final document meets the needs of business and industry. The standards take the form of either specifications, methods, vocabularies, codes of practice or guides.

The CUGE Standards Series comprises:

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

DISCLAIMER

ISBN 978-981-07-4726-8

Planting of Trees, Palms and Tall Shrubs on Rooftop

First Edition: CS E09:2012

The CS E09:2012 was prepared by the CUGE Standards Technical Committee (CS E09:2012).
The Technical Committee was represented by:

Mr. Edmund Koh Liang Teck (National Parks Board)
Mr. Poh Choon Hock (National Parks Board)
Mr. Ho Wan Weng (International Green Roof Association)
Mr. Wong Ngian Chung (Building and Construction Authority)
Ms. Tay Ah Ching (Building and Construction Authority)
Mr. Alan Tan (Housing and Development Board)
Mr. Tan Sze Tiong (Housing and Development Board)
Mr. Lim Peng Hong (Association of Consulting Engineers Singapore)
Mr. Russell Cole (Association of Consulting Engineers Singapore)
Mr. Siva. M. Sivakumaran (Association of Consulting Engineers Singapore)

The CS E09:2012 was reviewed during the industry consultation in June 2012. The industry consultation was represented by Singapore Institute of Architects (SIA), Singapore Institute of Landscape Architects (SILA), Landscape Industry Association Singapore (LIAS), Institution of Engineers Singapore (IES) and representatives of the Technical Committee.
NParks Contributors: Simon Longman, Daniel Burcham, Genevieve Ow.

The CS E09:2012 was approved by the CUGE Standards Review Panel in September 2012.
The CUGE Standards Review Panel was represented by:

Dr. Leong Chee Chiew (National Parks Board)
Mr. P. Teva Raj (National Parks Board)
Mr. Henry Steed (Singapore Landscape Industry Council; Singapore Institute of Landscape Architects)
Mr. John Tan (Singapore Landscape Industry Council; Landscape Industry Association Singapore)
Mr. Vincent Low (Landscape Industry Association Singapore)

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

Enquiries:
Poh Choon Hock
poh_choon_hock@nparks.gov.sg

CONTENTS

Planting of Trees, Palms and Tall Shrubs on Rooftop

SECTION 1 SCOPE

1.1 INTRODUCTION

This specification sets out the basic requirements and considerations for planting of trees, palms and tall shrubs on roof gardens and the related works.

This shall not, in any way, replace, substitute or supersede, whether in whole or part, any existing and/or prevailing relevant statutory rules and regulations, including building codes and standards.

1.2 OBJECTIVE

This specification is intended as a guide for the planning and planting of trees and palms on building rooftops.

It is intended to act as a reference point for quality assurance of rooftop tree-scape design and construction.

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

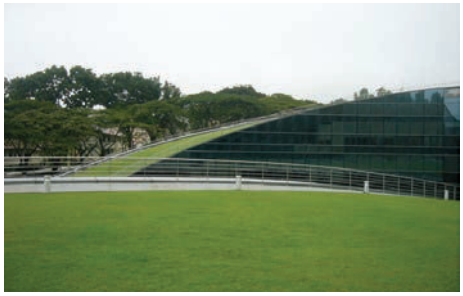
It is advisable to engage and consult suitably qualified and experienced arboriculture / horticulture-trained professionals and experienced building professionals to ensure the design intent and planting of rooftop trees and palms is well-considered and executed.

1.3 DEFINITIONS

Green roof

Extensive green roofs are generally not designed for active recreational use. They are developed mainly for aesthetic and ecological benefits. Distinguished for being low in installation cost, lightweight (90-150 kg/m^2) and with shallow mineral substrates, minimal maintenance is expected. Inspection should be performed, at the minimum, once or twice a year. Plants selected are usually of low maintenance and are self-generative. Generally, extensive systems can also be

placed on pitched roofs of up to an inclination of 30 degrees. They are common in European countries, especially Germany and increasingly being installed in North American cities as well.



Roof garden

Intensive green roofs, or roof gardens, are developed 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 lawn, shrubs, and bushes to trees. As they are designed for usage, regular maintenance such as mowing, fertilising, watering and weeding is required.

1.4 PERFORMANCE REQUIREMENT

The planting of rooftop trees, palms and tall shrubs should fulfill the following:

- The placement and planting of trees/palms on the high-rise environment of a rooftop must not pose potential hazards to the users, general public and maintenance workers.

- Consider the current and long term maintenance of rooftop trees/palms, which includes tree canopy maintenance and pruning. Make provisions for feasible and safe maintenance of these rooftop trees/palms.

- Consider and provide for the current and long term health of the rooftop tree/palm.

- The structural integrity, loading capacity and waterproofing integrity of the roof structure must not be compromised by the introduction and planting of the rooftop trees/palms.

SECTION 2 PLANTING CONSIDERATIONS

2.1 ROOFTOP MICROCLIMATE

Rooftops are usually exposed to intense sunlight, wind and rain. The rooftop environment can be challenging for plants. Successful rooftop greening often respects and considers the site's unique microclimatic conditions.

2.1.1 Sunlight and shade conditions on rooftop

- In Singapore's equatorial location, at latitude 1°30' North, the sun is typically overhead and traces across the sky directly from east to west, with an average 12 hours of sunshine daily. Temperature ranges from 31 – 33 degree celsius in the day to 23 – 25 degree celsius at night. Humidity is high all year round, with mean annual relative humidity at 82.4%.

- A rooftop, without taller neighboring buildings, structures and/or land-forms, receives full sunlight without obstruction. A rooftop, with taller neighboring buildings, structures and/or land-forms, may be partly or fully shaded during certain times of the day. Placement of rooftop trees and palms should therefore address the growth conditions and needs of the selected plant species.

2.1.2 Wind conditions on rooftop

- Wind condition in Singapore is generally light but variable, with prevailing wind speed of 6 - 10 m/s. During the monsoon seasons, occasional wind gusts range from 12 - 22 m/s. Where necessary, check with National Environment Agency (NEA) Singapore on the current wind data. Please refer to the following link for NEA's Guide to Singapore's Weather: http://app.nea.gov.sg/data/mss/pdf/26March07.pdf

- In general, the wind speed intensifies with increased altitude. This, however, is dependent on the rooftop's location and its surrounding environment. Wind stresses on a roof are experienced both as positive and negative wind pressures and are especially evident along roof edges and roof corners. Other structures on the roof such as water tanks and air-conditioning units can create wind eddies, turbulence and localized magnification of wind forces. Excessive turbulent wind can be stressful for rooftop vegetation.

- Consideration should also be given to the potential for wind to be funnelled between two higher neighbouring buildings (perhaps along a road or laneway) or between taller elements on the same building. The resulting acceleration of air speed will result in more turbulence and higher wind pressures. The resultant changes in wind speed and wind pressure, in such high rise context, should be computed by certified structural engineer based on relevant codes or standards as prescribed in Building Control and Regulations. Where necessary, wind tunnel testing can be programmed.

- In general, the denser and larger the tree canopy spread, the larger the 'sail area' exposed to wind loads. Small trees with open canopies allow wind to pass through easily and are more suited for windy rooftops. The negative impact of wind loads on trees and palms on a roof garden include:
  - Safety being compromised by falling plant debris. There is the possibility of tree uprooting, if rooftop trees and/or palms are not adequately cabled, staked and/or root-ball-anchored in place.
  - Damages to property by plant parts or debris falling from a height.
  - Desiccating of tree and palm by windy and hot rooftop environment. Evapo-transpiration from vegetation increases with increased wind and temperature on rooftops. Roof surface temperatures can be close to 60°C under the mid-day tropical sun.

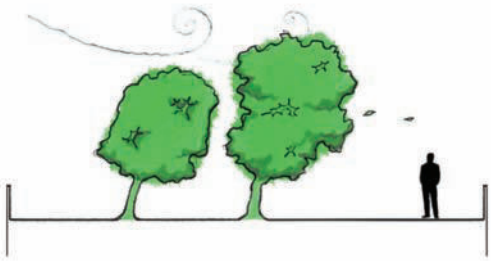


Fig1:
Tall trees with dense canopy experience higher wind loads and moment of force.

Fig 2:
Porous canopy allows wind to pass through, thus reducing wind loads and impacts.

- For the design of building structures to support the green roof and roof garden, the wind load shall be computed based on relevant codes or standards as prescribed in Building Control and Regulations. It is to be noted that a roof top tree will increase the wind frontage and should be taken into account.

- Wind loads on trees and palms on a roof garden are affected by (1) tree/palm height, (2) drag, (3) tree/palm crown form, (4) wind speed and (5) material properties.

- Periodic canopy thinning through selective removal of branches to improve air movement through the tree canopy can help mitigate excessive wind load on rooftop trees and palms. As a general rule, rooftop trees and palms can be pruned once every three to six months, depending on the species and rate of growth.

- Pruning strategies to reduce wind loads are (1) crown reduction to reduce plant height, (2) crown thinning to reduce drag and (3) structure pruning to improve crown form.

- Please refer to CS E07:2012 – Guidelines on General Maintenance for Rooftop Greenery, section 2.3 on pruning.

- All pruning works shall conform to the practices and standards specified in the latest ANSI A300 Part 1.

2.1.3 **Study rooftop microclimate**

- During design phase, visit neighboring rooftops to assess general rooftop microclimatic conditions such as sun-path, sun-angle, shadow of neighboring buildings, general wind direction and intensity, sight-lines, or complete building physics assessments that can quantify these parameters. Rooftops of shorter buildings are often blocked by taller surrounding blocks at certain time of the day and do not receive a full day of sun. Rooftops of tall buildings, with little obstruction, are usually windier. Such visits may help designers make better decisions in terms of species selection and their final placements on the roof garden. For appropriate rooftop plant selection, it is advisable to seek professional advice from the landscape architect, certified horticulturist and/or arborist.

2.2 ROOFTOP TREE/PALM SIZE AND WEIGHT

2.2.1 **Rooftop tree/palm size**

- With limited soil volume and rooting space in rooftop planter pits, small trees/palms are suitable for roof gardens. The height of small rooftop trees/palms can range from 3m to 8m. Some large shrubs can easily grow up to 3m in height. Periodic pruning is advisable to manage the size and form of rooftop trees/palms.

- Set-back distances of rooftop trees/palms from roof edges, should be in relation to the expected plant height. Please refer to the Tree Set-Back diagram in section 2.3

2.2.2 **Rooftop tree/palm Load**

- Static loads - Rooftop trees/palms live weight and the soil volume saturated weight are static loads.

- Dynamic loads - Rooftop trees/palms may also experience dynamic loads such as the lateral and/or multi-directional wind loads on a rooftop tree/palm.

2.2.3 **Rooftop tree/palm live weight calculation (Static load)**

- The following are algorithms to estimate the live weight of trees and palms. There are numerous such algorithms. The following are non-exhaustive and are intended as examples to serve as generic guide.

Tree Live Weight calculation (in kilograms)	
Small tree	Biomass (above ground) = $0.0776 \times (\rho D^2 H)^{0.940}$
ρ = wood specific gravity (g/cm^3) (oven-dry wood over green volume) D = Diameter (cm) at 1.37m above ground H = Height (m)	
Adapted from: J.Chave (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145:87-99 (ρ) - Wood specific gravity can be sourced from the FAO (Food and Agriculture Organization of the United Nations) Corporate Document Repository website: http://www.fao.org/docrep/w4095e/w4095e0c.htm	
Illustration:	
For a tree (*Cassia fistula*, approximately 8m tall) that bears a trunk of 20 cm in diameter, the **above ground Biomass weight** is estimated at	
$= 0.0776 \times (\rho D^2 H)^{0.940}$ $= 0.0776 \times (0.71 \times 20^2 \times 8)^{0.940}$ $=$ **111 kg**	
For tropical trees a good estimate of the root:shoot ratio is 0.24. Therefore, the (Root biomass) **below ground Biomass weight** is estimated at Adapted from: Cairns, MA, S Brown, EH Helmer, and GA Baumgardner. 1997. Root biomass allocation in the world's upland forests. Oecologia 111:1-11.	

=0.24 x 111 kg =**27 kg**
Moisture in a tree is estimated to range from 30% to 200% of the estimated Biomass. Therefore, if a tree has 100% moisture, the **live-weight** is estimated at
= (111 kg + 27 kg) x 2 = **276 kg**

Palm Live Weight calculation (in kilograms)	
Small palms (up to 11m height)	Biomass = $23.487 + 41.851 \times (\ln(\text{height}))^2$
Height of palm is in meter	
Adapted from: Winrock International Ecosystem Services website	
Illustration:	
For a palm tree 6 m tall, the **Biomass weight** is estimated at	
$= 23.487 + 41.851 \times (\ln(\text{height}))^2$ $= 23.487 + 41.851 \times (\ln(6))^2$ = **158 kg**	
Moisture in a palm is estimated to range from 30% to 200% of the estimated Biomass. Therefore, if a palm has 100% moisture, the **live-weight** is estimated at	
= 158 kg x 2 = **316 kg**	

- Strategic placement of heavy plants over structural elements such as columns, beams and structural cores optimizes load transfer. All loads must be safely transferred from the roof, through the building structures, to the building foundation and to the ground.

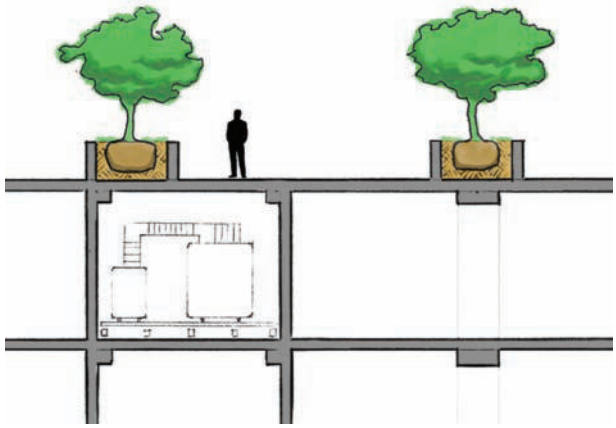


Fig 3:
Strategic placement of heavy plants over structural elements

2.2.4 **Saturated soil weight calculation (Static load)**

- Soil as a growth media comprises diverse mineral constitutes such as sand particles, gravels, clay, minerals, organic matters, microbes, stone aggregates with soil mixes from different sources of varying compositions and densities. For convenience of calculation, soil saturated weight is estimated at 1920 kg/m^3 (120 lb/ft^3).

Saturated Soil Weight calculation (in kilograms)
Saturated weight = Soil volume x 1920 kg/m^3
Adapted from: www.engineeringtoolbox.com
Illustration:
For a planter pit 2m wide, 2m long and 1m deep, the **saturated weight** of the soil the planter pit can contain is estimated at
= 2m x 2m x 1m x 1920 kg/m^3 = **7680 kg*** *This is inclusive of the tree/palm root zone.

- The following is a list of densities of common soil materials:

Material	Density (kg/m³)
Top soil, loose dry	1220
Top soil, loose moist	1250
Clay, dry	1600
Clay, wet	1760
Gravel, dry	1680
Gravel, wet	2000
Perlite, expanded	48
Pumice	721
Sand, dry	1555
Sand, wet	1905
Vermiculite, expanded	272
Approved Soil Mix, dry	800 - 1200
Compost, dry	500 - 800
LECA, dry	450 - 800

Source: Adapted from http://www.engineeringtoolbox.com/dirt-mud-densities-d_1727.html

Please refer to section 2.4 for rooftop soil criteria.

2.3 ROOFTOP TREE/PALM SET-BACK REQUIREMENTS

- Wind loads on a rooftop tree/palm are generally contributed by tree/palm movements (e.g. swaying of canopies and trunks, etc.) usually caused by wind. Wind loads are directly proportional to the trees/palms (1) height, (2) canopy size and (3) canopy density.

- Considering the complexity of wind loads, the diverse development of bio-mechanical characteristics of different tree/palm species and specimens over time and the paramount issue of rooftop tree stability, it is recommended that rooftop trees/palms be adequately set back from roof edge, to directly address safety concerns and manage risk.

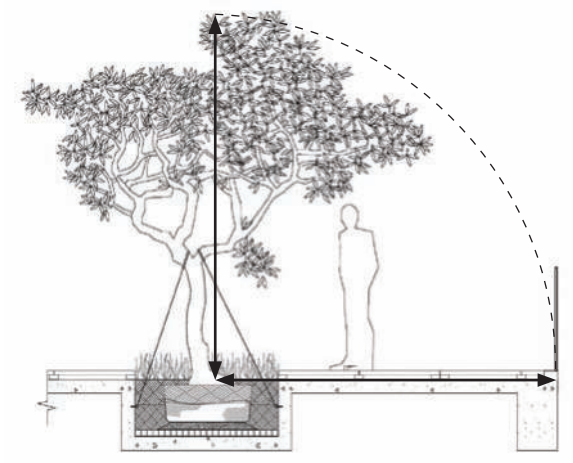


Fig 4:
Ideally tree should be set back from the railing by the estimated grown rooftop tree height

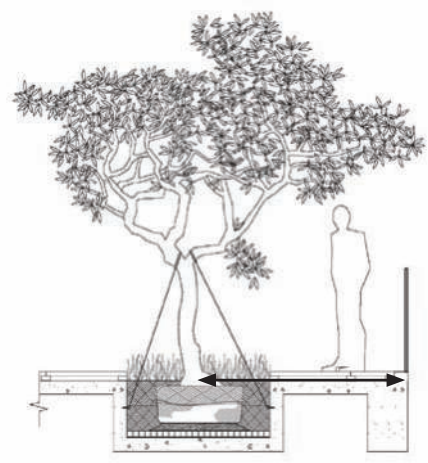
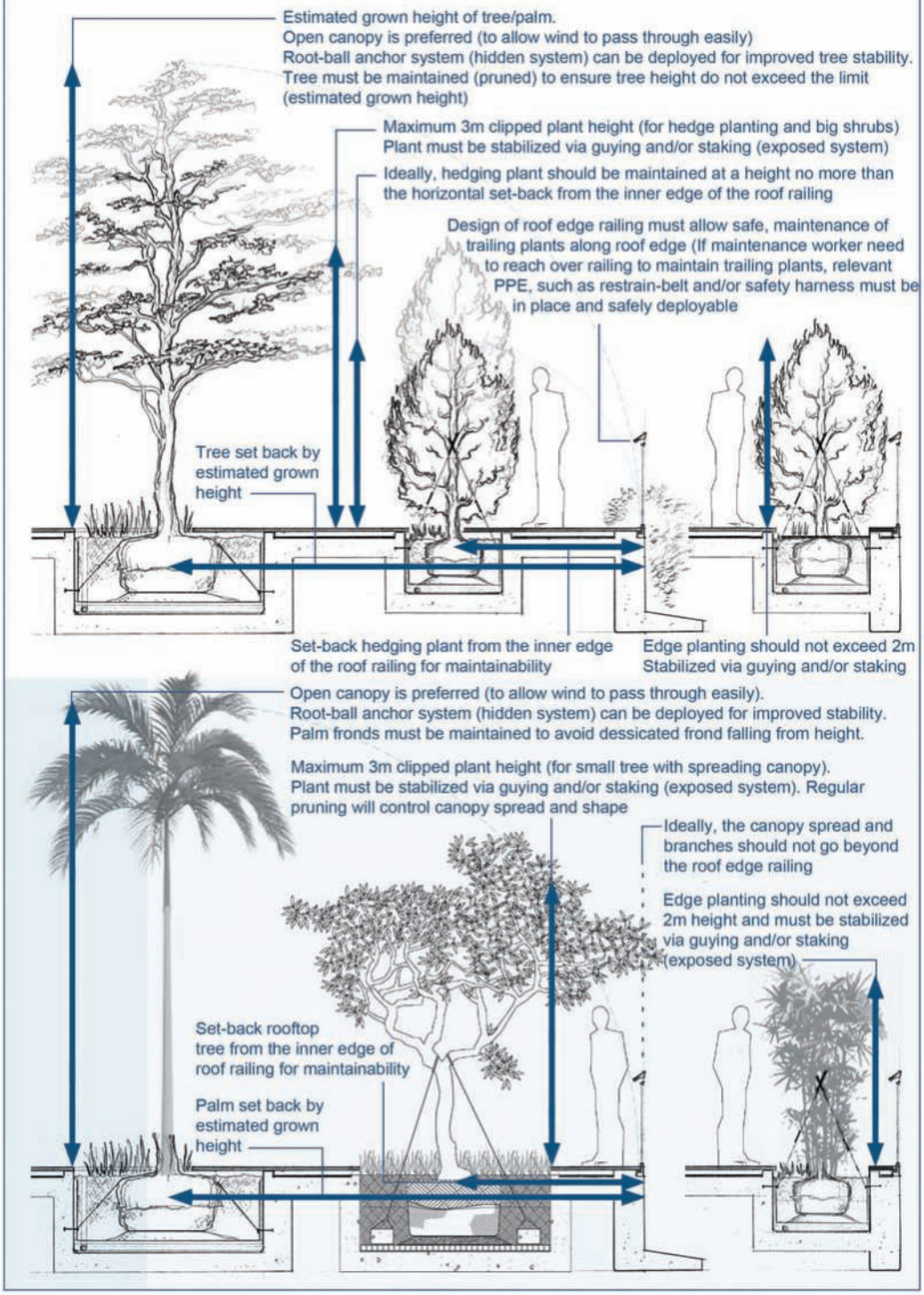


Fig 5:
Set back rooftop tree for maintainability

- The following are considerations when choosing suitable locations for rooftop tree/palm:

  - Tree/Palm loads should be optimally transferred through the building, safely to the ground.
  - Trees/Palms should be planted in locations with ample sunlight for healthy growth.
  - Trees/palms can be maintained safely, with safe mean of access to the tree/palm and its canopy.
  - Rooftop trees/palms and tall vegetation (such as large shrubs exceeding 2m in height) should be located such that these can be stabilized on the rooftop using A) staking, B) guying, C) support-frames and/or D) root-ball anchors.
  - Avoid planting trees/palms right up to roof edge. Canopies that spread beyond roof edges cannot be easily reached for pruning and maintenance.
  - Wind speed is expected to increase with building height. Rooftop trees/palms can be subjected to unexpected periodic wind gusts. Whenever allowed for by design, the trees/palms should be sited at a safe distance (equal to or more than the expected grown-height of the rooftop tree/palm) away from the roof edge to create a buffer zone in the event that the tree/palm is uprooted by unforeseen wind effects.

- The following are some illustrated landscape scenarios relevant to rooftop greenery. Landscape architects are to advice on the maintainability of the rooftop greenery, especially for greenery near and/or along roof edges.


Estimated grown height of tree/palm.
Open canopy is preferred (to allow wind to pass through easily)
Root-ball anchor system (hidden system) can be deployed for improved tree stability.
Tree must be maintained (pruned) to ensure tree height do not exceed the limit (estimated grown height)
Maximum 3m clipped plant height (for hedge planting and big shrubs)
Plant must be stabilized via guying and/or staking (exposed system)
Ideally, hedging plant should be maintained at a height no more than the horizontal set-back from the inner edge of the roof railing
Design of roof edge railing must allow safe, maintenance of trailing plants along roof edge (If maintenance worker need to reach over railing to maintain trailing plants, relevant PPE, such as restrain-belt and/or safety harness must be in place and safely deployable
Tree set back by estimated grown height
Set-back hedging plant from the inner edge of the roof railing for maintainability
Edge planting should not exceed 2m
Stabilized via guying and/or staking
Open canopy is preferred (to allow wind to pass through easily).
Root-ball anchor system (hidden system) can be deployed for improved stability.
Palm fronds must be maintained to avoid dessicated frond falling from height.
Maximum 3m clipped plant height (for small tree with spreading canopy).
Plant must be stabilized via guying and/or staking (exposed system). Regular pruning will control canopy spread and shape
Ideally, the canopy spread and branches should not go beyond the roof edge railing
Edge planting should not exceed 2m height and must be stabilized via guying and/or staking (exposed system)
Set-back rooftop tree from the inner edge of roof railing for maintainability
Palm set back by estimated grown height

- Hedge planting alongside roof edge should be appropriately set back from the inner surface of the roof balustrade, for maintainability of foliage. Ideally, these hedge plantings should be maintained at no more than 2m height, which is adequate for effective screening. Should there be the intention to grow these hedges beyond 2m height, appropriate cabling and staking will be necessary to ensure stability in the event of strong wind gusts. These hedge plantings should not grow beyond the cap of 3m height.

- Should hedge planting be against the roof balustrade, the hedge must not exceed 2m height. Appropriate cabling and staking is necessary. Regular hedge maintenance is necessary to prevent falling plant debris.

2.4 ROOFTOP SOIL QUALITY AND QUANTITY

2.4.1 Types of rooftop growth media

- In general, there are two types of growth media for rooftop greenery:
  - Substrate. This is generally used for green roofs.
  - Soil-based growth media. This is generally used for roof gardens.

- Substrate - This, in the context of green roofs, is a formulated mix of materials that may be naturally occurring or man-made, organic or inorganic. The required physical and chemical properties can be found in CUGE Standards CS E03:2010 Guidelines on Substrate Layer for Rooftop Greenery.

- Soil-based growth media - This is commonly used for planting on roof gardens. Poor soil quality and quantity contribute to poor rooftop tree/palm health, reduced tree/palm lifespan and failure on rooftop. For example, soil with high clay content has poor aeration and is prone to water-logging, affecting root health and tree growth. Small planter pits have limited soil volume and rooting space, stunting tree growth.

2.4.2 Approved Soil Mixture (ASM)

- With regards to the use of soil-based growth media on roof gardens, NParks' Approved Soil Mixture (ASM) is recommended. This is made up of:
  - 3 parts volume of approved loamy soil, to 2 parts volume of compost and 1 part volume of washed sand (or granular aggregates, such as crushed pumice and crushed expanded clay aggregates).
  - The three components are to be thoroughly mixed to ensure even distribution.
  - The following is the ASM specification as referenced from CS A01:2009 – Specifications for Soil Mixture for General Landscaping Use.

ASM Specification for General Landscape	
Parameters	Required Range/Value
pH	6.5 – 7.5
Electrical Conductivity	Less than 2.0 dS/m
Organic Matter	10 - 20% by dry weight
Cation Exchange Capacity (CEC)	Greater than 10 meq/100g soil by dry weight
Bulk Density	Greater than 800 kg/cubic m
Soil Texture Composition	Sand (0.05 – 2.00 mm) Max 75% Min 20% Silt (0.002 – 0.05 mm) Max 60% Min 5% Clay (< 0.002 mm) Max 30% Min 5%
Heavy Metal Concentration	No sewage sludge component. To comply with national standards under public health and pollution control, whenever such standards are applicable.
Organic Contaminants	To comply with national standards under public health and pollution control, whenever such standards are applicable.
Pathogens	Fecal coliforms, < 1000 MPN per g total solids. To comply with national standards under public health and pollution control, whenever such standards are applicable.

- The following are characteristics that good quality soil-based growth media should possess:

  - Soil mixes must be prepared in dry conditions in order to thoroughly mix the ASM materials.
  - The soil should be aerated and remain so for the long term. Aerated soil promotes healthier root growth and spread.
  - The soil should not be overly compacted, and remain so for the long term. Soil compaction damages the delicate fine roots, reduces air and moisture content and capacity, adversely affecting plant health.
  - The soil mix should be moisture-retentive. (Moisture retaining materials, such as LECA, etc., can be mixed into the soil to improve moisture retention.)

- The soil should be firm and stable (to improve tree stability). Adding loam and some clay into the soil mix will provide better cohesion of particles.
- The soil should not be prone to water-logging. The structure of the soil mix should allow for water to flow through gradually, consistently and eventually be drained away; and remain so in the long term. However, soil with high clay content is prone to water logging and soil compaction over time. In the event of such occurrence, the growing media should be amended or replaced.

- Compost is commonly used as a soil organic amendment and/or as mulch. For composts and mulch criteria, please refer to CS A02:2009 – Specifications for Composts & Mulches.

2.4.3 **Soil depth**

- Soil depth for a rooftop tree ranges from 800 mm to 1500 mm.

- Soil depth for rooftop palms ranges from 600 mm to 1500 mm.

	Big Shrub (up to 3m) & hedging palms	**Small tree & palm (3 to 6m)**	**Tree & palm (>6m)**
Planter depth	Minimum 0.6m	0.8 – 1.0m	1.2 – 1.5m

The above table shows the average depth of growing media required by trees and palms of different sizes.

- Sufficient soil depth is necessary for tree/palm stability. Root-ball anchoring system, such as the dead-man root-ball anchor will require soil volume exceeding 1.5m depth.

2.4.4 **Soil Volume**

- As a general guide, every 1 square meter of tree crown projection area should be supported by 0.3 to 0.6 cubic meter of soil volume. (The crown projection area of a tree is simply the vertically projected area of the tree's canopy onto the ground. It is estimated as the two-dimensional area of the ground area covered by the tree's canopy.)

- For example, to support a tree with a crown area of 12 square meters, an estimated soil volume of 7.2 cubic meters will be necessary. The planter pit internal clearance should be 2.7m wide, 2.7m long and 1.0m deep.

- The following demonstrations on soil volume sizing recommendation for rooftop tree, are not exhaustive, and are intended as recommendations to serve as a generic guide:

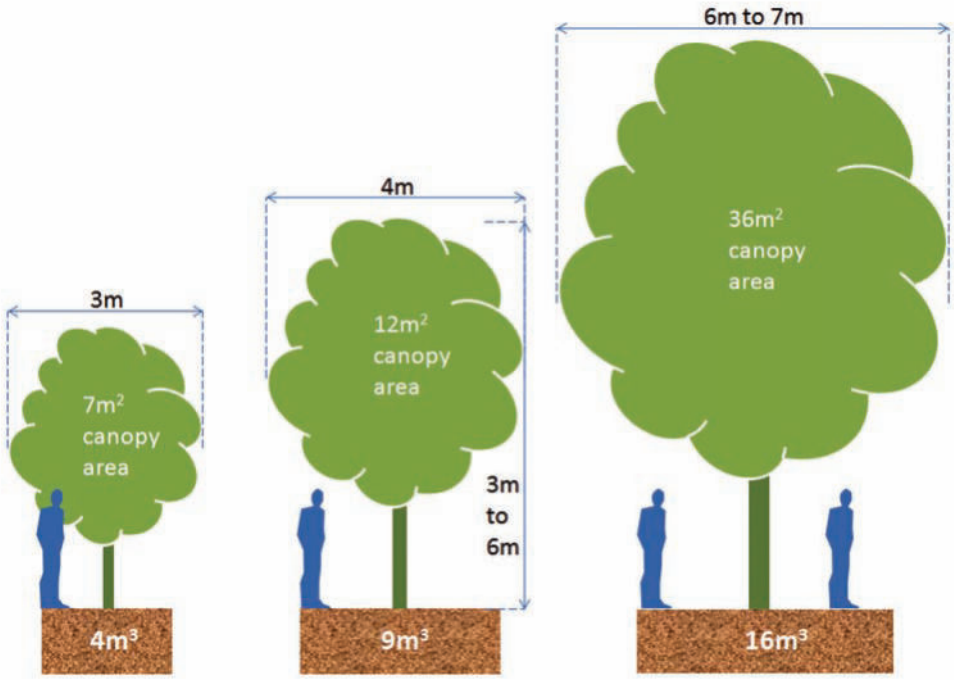


Fig 6:
Depth of 900-1000 mm is assumed for the above examples as modern roof garden systems using substrate prove that such a depth is adequate. For soil-based practices, a depth of 1200 mm is encouraged where possible. (The proposed depths exclude the underlayers.)

2.4.5 Planter Width & Root-ball Dimensions

- Planter pit width should be approximately double the root-ball diameter or more. Please refer to figure 7.

- Tree root-balls are commercially available in the following forms:
  - Balled and Burlapped (B&B)
  - Container grown
  - Bare root (contained in Grow-Bags)

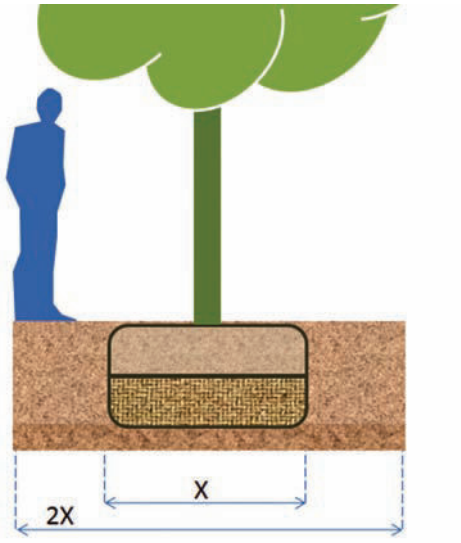


Fig 7:
Planter pit width in relation to root-ball diameter

- In general, the tree minimum root-ball diameter should be approximately 10 times the tree caliper (measured 15cm above the soil line.). That is to say, if a tree caliper (measured 15cm above the soil line) is 10cm, the minimum root-ball diameter should be approximately 10 x 10cm = 100cm.

- For minimum root-ball sizes, please refer to ANSI Z60.1 – 2004.

- The following are estimates of palm root-ball sizes.

Overall Palm Height	Width of Palm Root Ball*	Depth of Palm Root Ball
< 4.5m	200mm	360mm
4.5m – 7.5m	250mm	450mm
7.8m – 9.0m	300mm	600mm
> 9.0m	350mm	600mm

*Width shall be partial radius measured from the base of the trunk in single trunked palms, or from the base of the stem farthest from the center of the cluster in clustering palms to the edge of the ball.

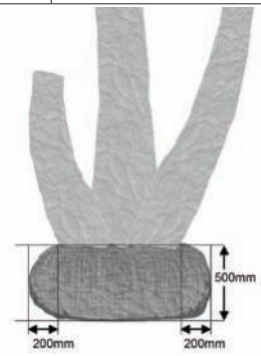


Fig 8:
Measuring the width and depth of a root ball.

Adapted from: http://www.freshfromflorida.com/pi/plantinsp/publications/g&s_palms.pdf

- Compared to trees, palm root-balls tend to be smaller, with fibrous roots different from trees. With its relatively smaller root-ball palms can make do with a smaller planter pit. Ideally, planter pit widths should be approximately double the root-ball width or more.

2.5 ROOFTOP TREE/PALM SUPPORT SYSTEMS

- To improve stability, trees and vegetation more than 3m tall, and trees along roof edges, should be anchored to reduce risk of injuring people and damaging property. Vegetation along roof edges and corners tends to experience more wind stress.

- Design and application of rooftop tree/palm support systems, such as cables, stakes and anchors, are to be suitably advised by the landscape architect, to ensure optimum performance on the supported vegetation and safe use of the roof garden space.

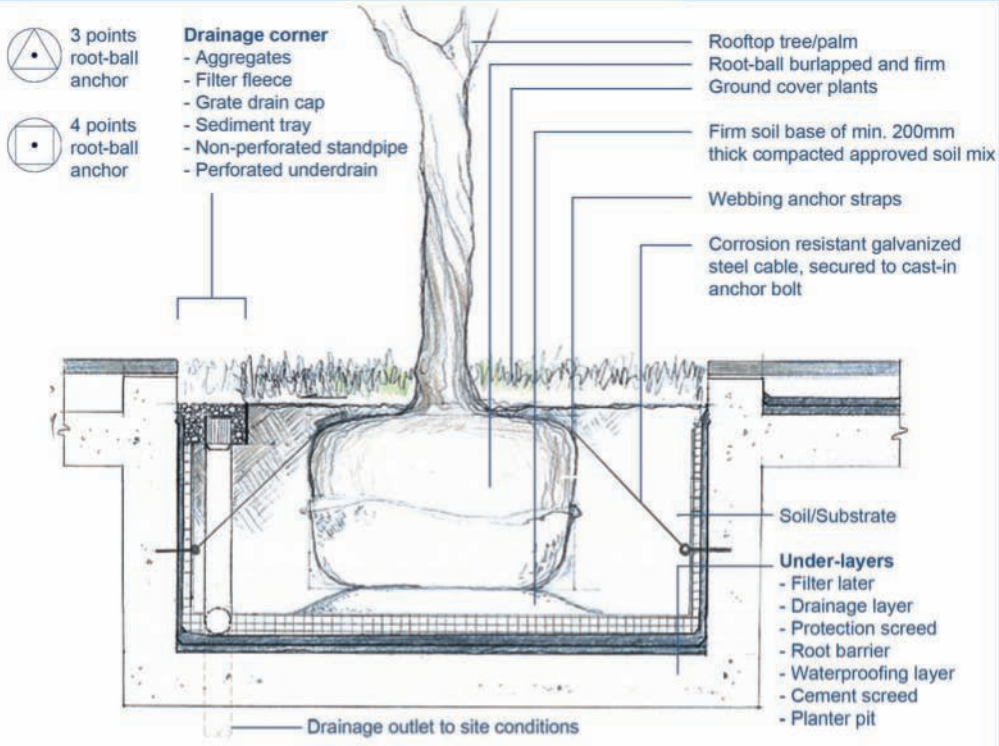
- Rooftop tree/palm support systems (both the root-ball anchoring types and the tree/palm stabilizing types) must be periodically inspected and maintained to avoid potential girdling and damage to the trunks, roots, branches and/or barks. For example, hose of tree-tie may have slipped off exposing bark to cuts by guy-wires. A trunk which has grown in girth over time may end up being strangled by unadjusted poorly installed root-ball anchor straps. Appropriate periodic inspections, maintenance and necessary system adjustments will ensure tree/palm health and growth is not compromised by these support systems. Guying system should be reviewed periodically to determine if the guying systems can be removed.

- Rooftop instant tree requires rooftop tree/palm support system for the following reasons:
  - The soil (or growing media) is loose and needs time to settle and compact around the tree root ball.
  - Large, container-grown trees and field-harvested trees with only a fraction of their original root system remaining do not have enough root spread and mass for adequate stability at planting stage. The new roots will need time to grow out into the soil.
  - An instant tree with an already defined and sizeable canopy that has not been pruned may need additional support for added stability when planted.

2.5.1 **Tree/Palm Support Systems for Instant Rooftop Tree/Palm**

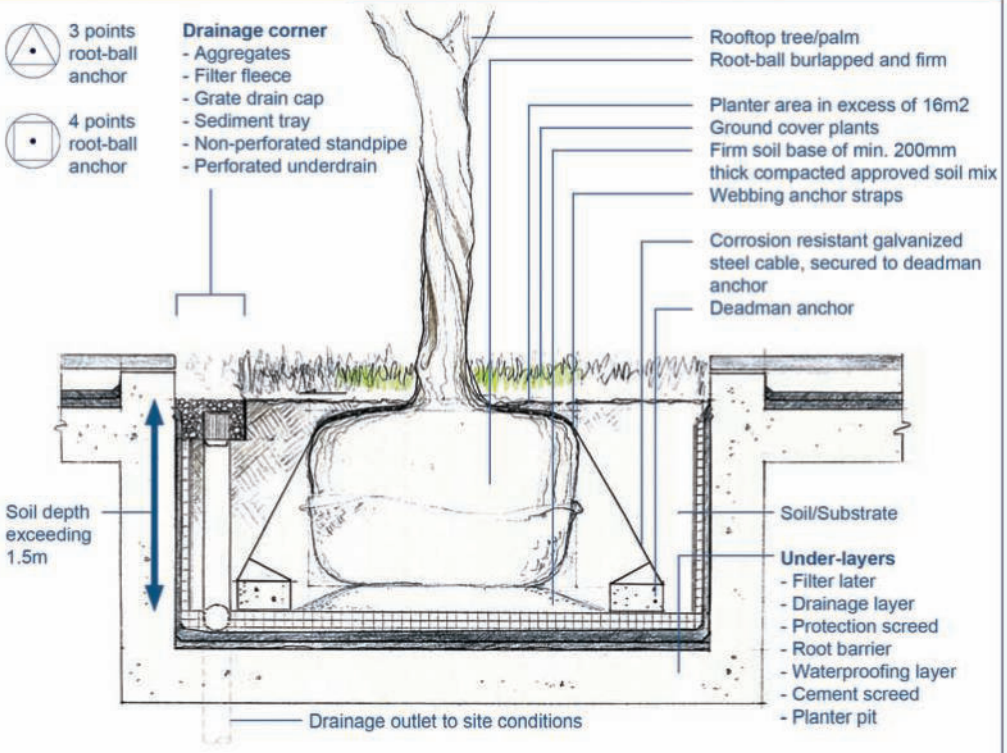
The following are recommended rooftop tree/palm anchoring systems.

TREE SUPPORT SYSTEM - TYPE 1 | **ROOT-BALL ANCHOR** | **HIDDEN SYSTEM**



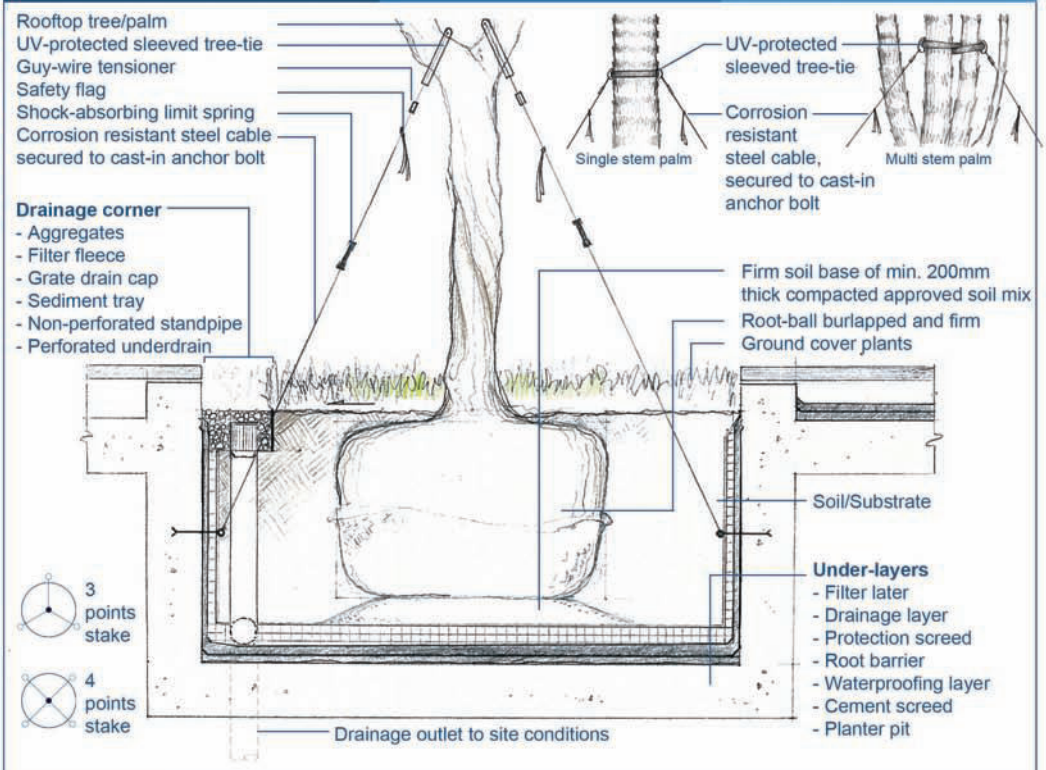
Application	• Small rooftop tree • Small rooftop palm
Plant requirements	• Root-ball must be firm and properly burlapped. • Tree and/or palm must be of sufficient strength, proportion and health to be supported by the root-ball anchor method. (Landscape Architect to ascertain the tree/palm conditions.) • If the stem/trunk is not adequately strong, such that when pushed, the stem/trunk moves while the root-ball does not, exposed tree supports (such as guy-wires and stakes, etc.) will be more suitable. Root-ball anchor system alone will not be adequate.
Location	• Only recommended for rooftop trees/palms experiencing lower wind load and/or away from roof edge.
Planter requirements	• Adequate planting area (planter width is approximately twice root-ball width). • Adequate substrate volume and depth.
System requirements	• Root-ball anchor system is typically made of materials resistant, treated and installed against corrosion. • Root-ball must be secured firmly to minimum 3 to 4 cast-in anchor bolts by webbing anchor straps per tree/palm for stability. Please refer to section 2.5.5 on anchor points' performance requirements. • Adjustable webbing anchor straps with ratchet buckle (both to be corrosion resistant and of adequate tensile and breaking strengths) for periodic tightening (when necessary), must firmly support root-ball without damaging roots. (Steel cables, where used, must not be in direct contact with the root-ball to avoid pressure points which can cut and damage roots.)
System benefits	• Tree root-ball anchor is fully hidden within the substrate, away from view. • Future adjustments (if necessary) are possible with fitted tightening mechanism (ratchet buckle) to assure tautness of root-ball webbing anchor straps.

TREE SUPPORT SYSTEM - TYPE 2 | ROOT-BALL ANCHOR | HIDDEN SYSTEM



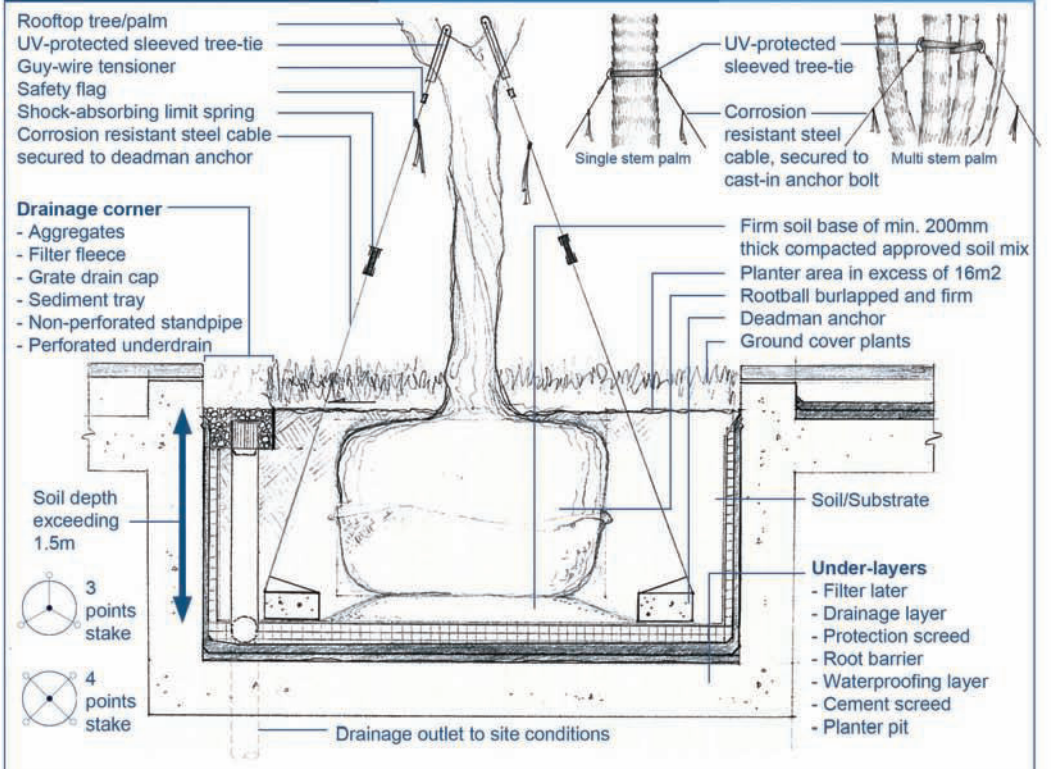
Application	• Small rooftop tree. • Small rooftop palm.
Plant requirements	• Root-ball must be firm and properly burlapped. • Tree and/or palm must be of sufficient strength, proportion and health to be supported by the root-ball anchor method. (Landscape Architect to ascertain the tree/palm conditions.) • If the stem/trunk is not adequately strong, such that when pushed, the stem/trunk moves while the root-ball does not, exposed tree supports (such as guy-wires and stakes, etc.) will be more suitable. Root-ball anchor system alone will not be adequate.
Location	• Only recommended for rooftop trees/palms experiencing lower wind load and/or away from roof edge.
Planter requirements	• Broad planting area in excess of 16m2. • Adequate substrate volume and depth exceeding 1.5m.
System requirements	• Root-ball anchor system is typically made of materials resistant, treated and installed against corrosion • Root-ball must be secured firmly to the deadman anchor plinths by minimum 3 to 4 webbing anchor straps per tree/palm for stability. • Adjustable webbing anchor straps with ratchet buckle (both to be corrosion resistant and of adequate tensile and breaking strengths) for periodic tightening (when necessary), must firmly support root-ball without damaging roots. (Steel cables, where used, must not be in direct contact with the root-ball to avoid pressure points which can cut and damage roots.)
System benefits	• Tree root-ball anchor is fully hidden within the substrate, away from view. • Future adjustments (if necessary) are possible with fitted tightening mechanism (ratchet buckle) to assure tautness of root-ball webbing anchor straps.

TREE SUPPORT SYSTEM - TYPE 3 | ANCHORED CABLING | EXPOSED SYSTEM



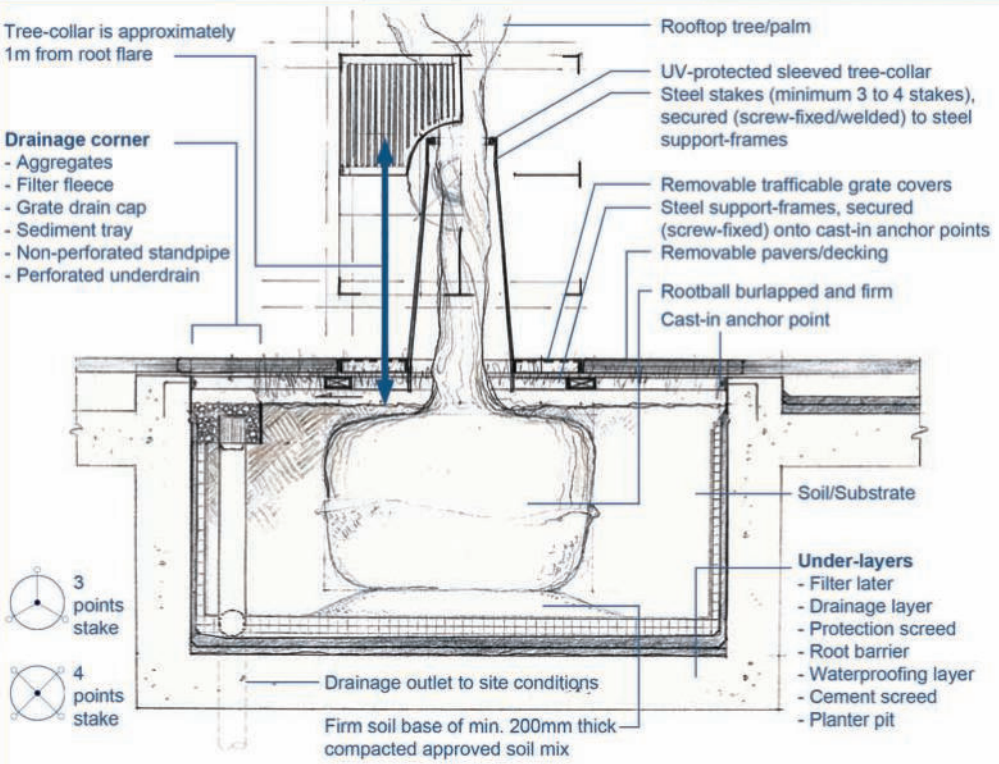
Application	• Small rooftop tree • Small rooftop palm
Plant requirements	• Root-ball must be firm and properly burlapped. • Suitable for tree/palm with stem/trunk needing additional support. (Landscape Architect to ascertain the tree/palm conditions.)
Location	• Suitable for rooftop trees/palms in windy rooftop conditions and/or planted nearer roof edge.
Planter requirements	• Adequate planting area (planter width is approximately twice root-ball width) • Adequate substrate volume and depth
System requirements	• Guy-wires and cast-in anchor bolts are typically made of steel resistant, treated and installed against corrosion. • For stability, each tree/palm must be adequately stabilized by minimum 3 to 4 appropriately tensioned guy-wires secured to cast-in anchor bolts. Please refer to section 2.5.5 on anchor points' performance requirements. • Ideally, each guy-wire should be angled less than 60 degree to the horizontal. • Tree-tie (at the end of each guy-wire) must be sleeved to avoid damaging tree/palm bark. • Safety flag the guy-wires so that people can see them, avoiding injury. • Steel cables, where used as guy-wires, must not be in direct contact with the tree/palm bark to avoid pressure points which can injure the tree/palm.
System benefits	• Tension in guy-wires can be appropriately adjusted, with the fitted guy-wire tensioner, to correct leaning of tree/palm. • The exposed tree support system reduces excessive crown movement by strong wind.

TREE SUPPORT SYSTEM - TYPE 4 | ANCHORED CABLING | EXPOSED SYSTEM



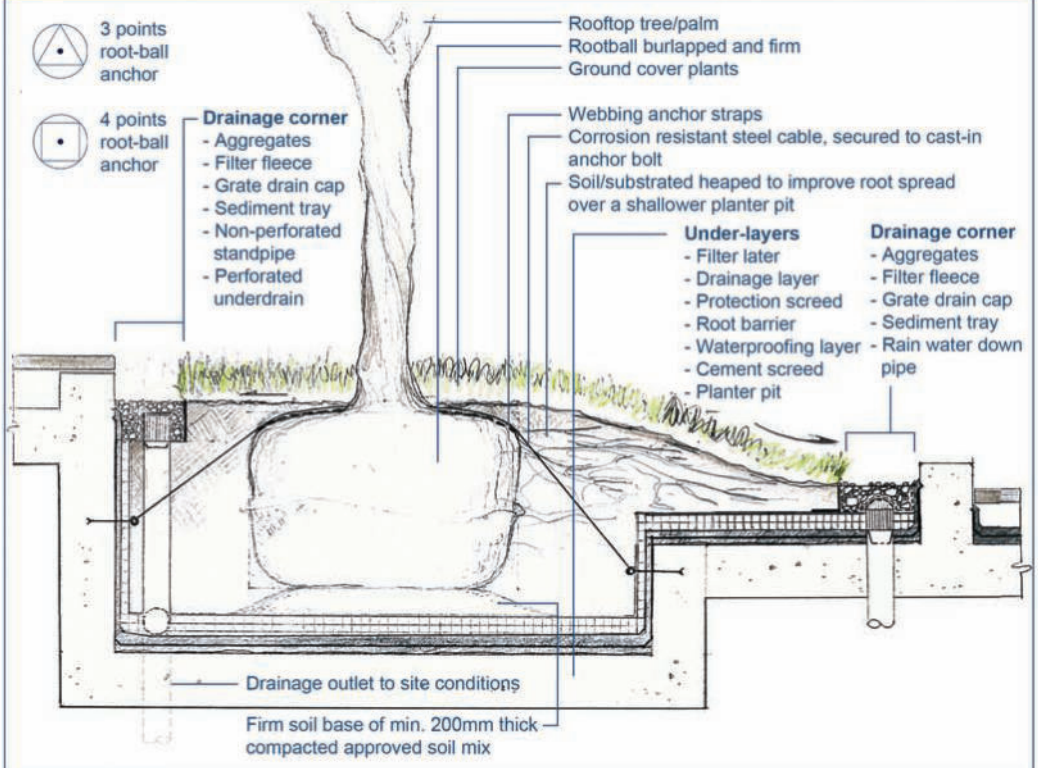
Application	• Small rooftop tree • Small rooftop palm
Plant requirements	• Root-ball must be firm and properly burlapped. • Suitable for tree/palm with stem/trunk needing additional support. (Landscape Architect to ascertain the tree/palm conditions.)
Location	• Suitable for rooftop trees/palms in windy rooftop conditions and/or planted nearer roof edge.
Planter requirements	• Broad planter area in excess of 16m2. • Adequate substrate volume and depth exceeding 1.5m.
System requirements	• Guy-wires and cast-in anchor bolts (if any on deadman anchors) are typically made of steel resistant, treated and installed against corrosion. • For stability, each tree/palm must be adequately stabilized by minimum 3 to 4 appropriately tensioned guy-wires secured to deadman anchors. • Ideally, each guy-wire should be angled less than 60 degree to the horizontal. • Tree-tie (at the end of each guy-wire) must be sleeved to avoid damaging tree/palm surface. • Safety flag the guy-wires so that people can see them, avoiding injury. • Steel cables, where used as guy-wires, must not be in direct contact with the tree/palm surface to avoid pressure points which can injury the tree/palm.
System benefits	• Tension in guy-wires can be appropriately adjusted, with the fitted guy-wire tensioner, to correct leaning of tree/palm. • The exposed tree support system reduces excessive crown movement by strong wind.

TREE SUPPORT SYSTEM - TYPE 5 | ANCHORED GRATE & STAKES | EXPOSED SYSTEM



Application	• Small rooftop tree • Small rooftop palm
Plant requirements	• Root-ball must be firm and properly burlapped. • (Landscape Architect to ascertain the tree/palm conditions.)
Location	• Suitable for rooftop trees/palms in windy rooftop conditions and/or planted nearer roof edge.
Planter requirements	• Adequate planting area (planter width is approximately twice rootball width) • Adequate substrate volume and depth
System requirements	• Grate covers, support stakes, support frames and cast-in anchor bolts are typically made of steel resistant, treated and installed against corrosion (such as stainless steel). • For stability, each tree/palm must be adequately stabilized by minimum 3 to 4 stakes secured to the support frames whereon the grate covers rest. The support frames are in turn structurally secured to cast-in anchor points, for effective load transfer. • Tree-collar (encircling but not in contact with stem/trunk), approximately 1m above root flare, must be sleeved to avoid damaging tree/palm surface. The tree-collar is intended to brace the tree/palm against any excessive movement of the stem/trunk by strong wind gusts. • The system must be periodically maintained to avoid roots growing onto the grate covers and support frames.
System benefits	• Support stakes, grate covers and support frames are detachable for future maintenance of planter pit. • The exposed tree support system reduces excessive crown movement by strong wind. • The system increases walking space and avoids soil compaction by human traffic.

TREE SUPPORT SYSTEM - TYPE 6 | ROOT-BALL ANCHOR (BERMED) | HIDDEN SYSTEM



Application	• Small rooftop tree • Small rooftop palm
Plant requirements	• Root-ball must be firm and properly burlapped. • Tree and/or palm must be of sufficient strength, proportion and health to support the root-ball fixing method.(Landscape Architect to ascertain the tree/palm conditions.) • If the stem/trunk is not adequately strong, such that when pushed, the stem/trunk moves while the root-ball does not, exposed tree supports (such as guy-wires and stakes, etc.) will be more suitable. Root-ball anchor system alone will not be adequate.
Location	• Only recommended for rooftop trees/palms experiencing lower wind load and/or away from roof edge.
Planter requirements	• Adequate planting area (planter width is approximately twice root-ball width) • Adequate substrate volume and depth
System requirements	• Root-ball anchor system is typically made of materials resistant, treated and installed against corrosion. • Root-ball must be secured firmly to minimum 3 to 4 cast-in anchor bolts by webbing anchor straps per tree/palm for stability. Please refer to section 2.5.5 on anchor points' performance requirements. • Adjustable webbing anchor straps with ratchet buckle (both to be corrosion resistant and of adequate tensile and breaking strengths) for periodic tightening (when necessary), must firmly support root-ball without damaging roots. (Steel cables, where used, must not be in direct contact with the root-ball to avoid pressure points which can cut and damage roots.)
System benefits	• Tree root-ball anchor is fully hidden with the substrate, away from view. • Future adjustments (if necessary) are possible with fitted tightening mechanism (ratchet buckle) to assure tautness of root-ball webbing anchor straps. • The heaped soil/substrate improve root spread over the shallower planter pit.

- For conventional tree planting in the ground, tree supports such as guy-wires and staking are removed upon tree root establishment (no more than a year from planting). However, for rooftop trees, tree supports may be permanent and must be periodically inspected and maintained (re-tensioned, replaced, etc.) for optimal performance. The tree supports can effectively minimize movement of tree root-balls during strong winds.

- Should the rooftop tree grow and increase in tree trunk caliper size, the supports must be duly adjusted or replaced to fit but not restrict the tree.

- Consult landscape architects and certified arborists, to ensure planted rooftop trees/palms are stable with good growth. Subsequent checks are necessary to ensure stability of tall vegetation.

- The selected tree anchoring methods, for the planting of instant rooftop trees, should complement the conditions of (1) the relevant tree/palm specimen, (2) the rooftop microclimate and (3) the roof garden design intention.

2.5.2 **Planting Rooftop Tree Saplings**

- Tree/palm saplings have smaller root-balls or may be planted bare-root. Root-ball anchoring methods are not suitable.

- Rooftop tree/palm sapling can be stabilized using temporary staking (single-stake or multiple-stakes). For stability, installed temporary stake(s) must be sturdy and driven at least 50cm into the substrate without compromising the under-layers of the planter pit.

- When the tree/palm sapling, planted near the roof edge, matures into a small tree/palm, exposed tree supports (such as installed surplus anchor points) can be necessarily deployed to support the small tree/palm against strong wind gusts.

2.5.3 **Staking and Guying**

- Installation of staking and guying can take reference from the methods and standards specified in the latest ANSI A300 Part 3 and should be read in conjunction with the rest of the ANSI A300 when carrying out such installations.

2.5.4 **Maintenance of Staking, Guy-wires and Anchors**

Maintenance of staking and guy-wires include:

- Check often for broken wires and ties;
- Check often for stakes rubbing on the tree;
- Check often for deterioration of ties and covers, or other problems;
- Staking, guy wire tension and ties may need adjustment;
- Anchors may have shifted and so, need re-setting
- Replace loose or pulled stakes immediately;
- Chances of girdling and injury increase with the length of time a tree is staked or guyed
- Landscape architects and experienced horticulturist should be consulted for good judgment of staking and guying supports to encourage strong growth and healthy trees

2.5.5 **Anchor points' performance requirements:**

- Anchor points and the root ball anchoring system must be chemically inert to be durable.

- Root ball anchors must be designed and engineered by certified civil and structural engineers to withstand the expected forces cause by wind effects.

- Anchor points must not compromise installed waterproofing layer (to safeguard water-tightness of the planter pit). The anchor should be put in place by the Main Contractor before the waterproofing is installed, to ensure waterproofing and concrete are not compromised by others. Special details for the water proofing may be needed to avoid leaks at this weak point. It is prudent to install surplus anchors to allow for any future circumstances or for redundancy.

- Early coordination by the Landscape Architect is needed to ensure that the provision of good quality anchor points is covered in the Main Contractor documents.

- All steel components (such as steel cables, steel anchors, steel stakes, etc.) should be made of stainless steel of grade 316 (or at least of grade 304) for long-term durability.

2.6 ROOFTOP TREE/PALM PLANTING AND SITE COORDINATION

2.6.1 **Preparing the tree/palm for transporting to site**

- A tree/palm sapling can be moved by two people. However, a pre-grown tree will require machines to transport and handle it during planting. Heavy machines (i.e. fork-lift, trailer and/or mobile crane, etc.) are deployed to transport and move trees, whether from the nursery to the site, within sites and/or onto the roof site.

- Ideally, schedule transportation of trees/palms to site for immediate planting (within 2 hours upon reaching planting site). Upon unloading and general inspection of the plants, irrigate adequately. Tree/Palm carelessly left out in the open, with roots exposed, will deteriorate rapidly.

- During transportation, secure the trees and palms adequately to the truck to avoid excessive movement so that the root balls do not risk cracking. Protect the plant parts from rubbing or bouncing/knocking on the tailboard of the lorry.

- Where possible, irrigate the trees/palms before the journey and keep them sheltered, shaded and/or covered to reduce desiccation.

- For palms, the fronds and multi-stems must be neatly gathered, tied and protected to reduce damage during transportation. For trees and big shrubs, the branches and the foliage can be likewise gathered and secured using ties and fabric-wraps (such as tarpaulin or canvas sheets, etc.) These precautions will help reduce mechanical damage to the foliage.

- Inappropriate carrying and handling can severely injure the tree/palm root ball, damaging and exposing the sensitive fine feeder roots, adversely affecting tree/palm survival.

- Tree/Palm should always be lifted by the root ball, never by the trunk or branches. When lifted by cranes, the root ball needs to be strapped and/or bagged so that the load is taken up by the strap and/or the bag and not by the root ball itself. Trees/palms must also not be dropped as that will dislodge the contact the soil has with the roots, cracking the root-ball, and damaging the fine feeder roots responsible for water uptake. Burlap when used should be firmly wrapped to secure the root-ball. It is advisable to engage experienced contractors to lift trees/palms onto building.

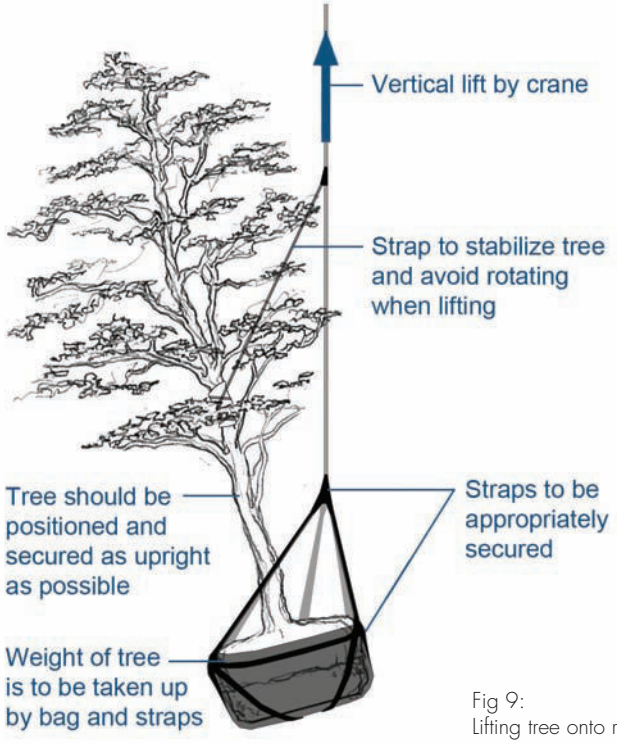


Fig 9:
Lifting tree onto rooftop

- Root-balls are very sensitive and must be handled with care to avoid affecting the tree/palm survival. Trees/Palms with root-balls planted in stiffer containers, such as plastic containers, are able to handle rough handling better, compared to those balled-and-burlapped and in fabric containers.

- At the installation site, crane availability (when needed for lifting and planting of trees/palms on the roof) will need to be specified during the early phase of site planning and coordination. The planting of trees/palms on rooftop should be planned and coordinated with the engineers.

2.6.2 **Tree/Palm holding area on site**

- If planting cannot be on the same day, the tree/palm must be managed and kept adequately irrigated (at least twice a day) at the holding area on site to sustain root health.

- The holding area must be already set up before the trees/palms arrive on site.

- The holding area for trees/palms on site should:
  - Avoid holding trees/palms in areas with high mechanical traffic, to reduce likelihood of mechanical damage to trees/palms. Where appropriate, holding area for trees/palms should be cordoned off from human and machine traffic.
  - Tree/palm holding area must be sheltered from the harsh environment of the construction site to protect from mechanical injury, overheating and drying out. Ideally, trees/palms should be lightly shaded with overhead shade-netting.
  - Whilst at the holding area, the root ball of the trees/palms must be kept moist, to avoid drying out and overheating.

2.6.3 **Managing trees/palms on site**

- Upon arrival at site, tree/palm root ball should be protected around its sides with moisture-retaining materials such as sack-cloth, etc. to help prevent root desiccation. The sack-cloth and covers will also help retain moisture around the root ball for uptake. The root ball top should not be covered, with trees/palms positioned upright to allow ease of moisture seepage into the root-ball.

- Trees/Palms can be grouped closely to reduce exposure of root-balls to the harsh surroundings and the sun. Root-balls, all round the edge of the group, exposed to sunlight (even those in containers) will get heated up, severely damaging the sensitive roots within hours, increasing tree/palm fatality. This is especially the case for root-balls grown in dark-colored containers or shrink-wrapped in any type of plastic. These exposed and/or container root-balls must be promptly covered and wet to protect from overheating and wind.

- Plastic wrapped root-balls must have drainage holes at the bottom and sides.

- Thoroughly spray-irrigate or drip-irrigate the entire root-ball if possible to avoid excessive runoff. Holding area grounds should be graded to avoid water-ponding.

2.6.4 **Planting**

- When moving the tree/palm, do not injure the trunk and growing parts (such as the spear of the palm, etc.).

- Planter pits should be about 2-3 times the width of the root ball, to accommodate the trees/palms comfortably.

- Prior to planting, damaged and girdling roots should be removed using hand-pruner. Roots growing out of organic burlap should be retained. Any synthetic burlap, ties and ropes around the trunk and roots must also be removed to avoid future girdling as the trees/palms establish and grow in size.

- The top of root ball (root collar or trunk flare) must be level or slightly higher than surface grade of the filled planter pit. It is necessary to locate natural root flare before planting. (About 10 cm of root-ball should protrude above the surrounding grade.) It is important that the root-ball be planted at the appropriate depth and not deeper than necessary. Root-balls must be seated on firm and compacted base soil so as to prevent tree/palm settlement.

- The substrate/soil media should be firmed to stabilize the root-ball.

- Once planted, any secured foliage, branches, fronds, and/or multi-stems can be untied.

- The planted rooftop tree/palm must be irrigated adequately and regularly, so that the substrate/soil media will settle properly, stabilizing the root-ball and to promote new root growth.

2.6.5 **Work safety considerations**

- Adequate numbers of work-men certified and experienced with work scope and safety.

- Adequate engineered load-bearing capacity of building structure to support loadings of building materials, landscape materials, machines and expected human-traffic, during rooftop tree planting and future maintenance.

- During rooftop site work, provisions such as guardrails must be in place to prevent workmen falling from height. Work scope and provisions, along roof edge must include safety provision and its effective deployment.

- Site work must be phased, coordinated and scoped, allowing safe access for workmen to conduct site work effectively. Safe access can be in the form of structurally sturdy staircases (permanent and temporary ones), maintained and operable gondolas, aerial platforms, etc.

- Lightning protection for rooftop greenery must be designed and installed with compliance to the relevant standards.

2.7 ROOFTOP TREE AND PALM LISTS

- Tree/Palm specimens from different sources may vary in quality. Selected specimens are to be suitable for the relevant rooftop environment. Landscape architect to advice.
- For the suggested list of trees and palms suitable for roof gardens, please refer to Annex 1.
- For the list of certified arborists in Singapore, please refer to the following web link: http://www.cuge.com.sg/Listing-of-Certified-Arborists

Annex 1 (Plant List)

SUGGESTED ROOFTOP VEGETATION - (SHRUB)					
LARGE SHRUBS (Can grow to 2- 3m height, or formed as a small tree)					
KEY. * Can be grown as a small tree ~ Can be pruned to control height ∞ Herbaceous, non woody.					
~	*Acalypha siamensis* (hedge)	∞	*Costus speciosus/ stenophyllus*	*~	*Manihot spp*
*~	*Aglaia odorata*	∞	*Crinum amabile*	~	*Megaskepasma erythrochlamys*
∞	*Alocasia macrorrhizos*		*Cyathea latebrosa* (Tree Fern)	*~	*Murraya koenigii*
∞	*Alpinia spp* (taller spp)		*Cycad spp* (taller spp)	*~	*Murraya paniculata*
~	*Bambusa spp* (mid height spp)	∞	*Cyperus papyrus*	∞	*Musa spp*
~	*Baphia nitida* (tall hedge)		*Dracaena spp* (taller spp)	*~	*Nerium oleander var*
*	*Bixa orellana*	*~	*Duranta erecta*	*~	*Ochna kirkii*
*~	*Caesalpinia pulcherrima var.*	*~	*Duranta* 'Dark Purple'	*	*Pandanus spp* (taller spp)
∞	*Calathea lutea*	*	*Euphorbia pulcherrima*	*~	*Pisonia alba*
*~	*Calliandra haematocephala*	*	*Eugenia uniflora*	*~	*Plumeria pudica*
*	*Cassia alata*	∞	*Heliconia spp* (taller spp)	*~	*Psidium guajava* (Guava)
~	*Cestrum nocturnum*	*~	*Hibiscus spp*	~	*Scaevola taccada*
	Clerodendrum paniculatum	~	*Ixora javanica vars*	*~	*Schefflera arboricola*
	Clerodendrum quadriloculare	*~	*Jatropha integerrima*	*~	*Synsepalum dulcifium*
	Cnidoscolus chayamansa	*~	*Kopsia singapurensis*	*~	*Tabernaemontana corymbosa*
	Codiaeum variegatum cultivars	*~	*Lagerstroemia indica*	*~	*Tabernaemontana divaricata*

∞	*Colocasia gigantean*	*~	*Leea guineensis* 'Burgundy'	*~	*Thevetia peruviana*
*	*Combretum constrictum*	*~	*Magnolia figo*	*~	*Wrightia religiosa*
	Cordyline spp (taller spp)				

MEDIUM SIZED SHRUBS (Can grow to 1-2 m height or pruned to control size)					
KEY. * Can be grown as a small tree ϕ Good for shade/semi shade ~ Can be pruned to control height ∞ Herbaceous, non woody.					
~	*Acalypha hispida*	~	*Galphimia glauca*	~	*Malphigia coccigera*
~	*Acalypha wilkesiana cultivar*	~	*Gardenia jasminoides*	~ ϕ	*Osmoxylon lineare*
∞	*Artemisia scoparia*	∞	*Heliconia psittacorum vars*	~	*Polyscias filicifolia*
∞	*Crinum asiaticum*	~	*Jasminum sambac*	~	*Pseuderanthemum spp.*
∞ ϕ	*Costus woodsonii*	~	*Hamelia patens*		*Rhodomyrtus tomentosa*
~	*Excoecaria cochinchinensis*	~	*Ixora spp* (mid height spp)	~	*Tecomaria capensis*
~ϕ	*Ficus deltoidea*	~	*Leucophyllum frutescens*	~ ϕ	*Thunbergia erecta*
~ϕ	*Ficus microcarpa* 'Green Island'	~	*Loropetalum chinense*	~	*Tibouchina urvilleana*

NATIVE SHRUBS					
KEY. * Can be grown as a small tree ϕ Good for shade/semi shade ~ Can be pruned to control height ∞ Herbaceous, non woody					
∞	*Alocasia longiloba* Miq.	ϕ	*Donax canniformis* (G.Forst.)	* ϕ	*Memecylon caeruleum* Jack
∞	*Arundina gramminifolia*	~ϕ	*Ficus deltoidea* Jack	∞ ϕ	*Molineria latifolia*
*	*Chassalia curviflora*		*Grammatophyllum speciosum* Blume		*Pandanus odorifer* (Forssk.) Kuntze
∞	*Cheilocostus speciosus* (Koenig)	ϕ	*Hanguana malayana* (Jack)	ϕ	*Rhodomyrtus tomentosa* (Aiton)
∞ ϕ	*Crinum asiaticum L.*	* ~	*Leea rubra* Blume	~	*Syzygium myrtifolium*
	Cyathea latebrosa (Tree Fern)	ϕ	*Melastoma malabathricum*	* ~	*Tarenna odorata*

SUGGESTED ROOFTOP VEGETATION – (TREE)		
SMALL TREES (estimated at 3-6m mature height in constructed planters)		
NOTE: The estimated tree sizes can only be a general guide. Most trees on roof if grown in confined conditions will generally remain smaller than in natural ground (Bonsai is an extreme example). Soil depth, amount of sun, irrigation, shading and maintenance regime will all influence tree growth. Pruning also helps to restrict the size and weight of trees. Maintenance and monitoring of performance are essentials in roof landscapes.		
Aglaia formosana	*Dillenia suffruticosa*	*Pisonia grandis*
Albizia julibrissin	*Erythrina fusca*	*Platycladus orientalis*
Annona muricata (Soursop fruit tree)	*Erythrina glauca*	*Ploiarium alternifolium*
Ardisia elliptica	*Ficus auriculata*	*Plumeria spp.*
Ardisia lanceolata	*Ficus nitida*	*Podocarpus macrophyllus*
Averrhoa bilimbi	*Ficus roxburghii*	*Polyalthia longifolia*
Averrhoa carambola (Star fruit tree)	*Garcinia cymosa forma pendula*	*Pterocarpus indicus "pendula"*
Bauhinia spp.(tree forms)	*Garcinia subelliptica*	*Punica granatum* (Pomegranate tree)
Calliandra tergemina var. emarginata	*Gardenia carinata*	*Salix babylonica*
Calliandra surinamensis	*Grevillea baileyana*	*Schefflera actinophylla*
Callistemon spp.	*Gustavia superba*	*Schoutenia accrescens*
Carallia brachiata 'Honiara'	*Hibiscus (Taliparitì) tiliaceus*	*Senna alata*
Carallia suffruticosa	*Jacaranda filicifolia*	*Senna surattensis*
Cassia fistula	*Juniperus chinensis*	*Senna spectabilis*
Coccoloba uvifera	*Kopsia flavida*	*Suregada multiflora*
Cochlospermum religiosum	*Lagerstroemia speciosa*	*Syzygium aromaticum* (clove)
Conocarpus erectus var. sericeus	*Leptospermum brachyandrum*	*Syzygium campanulatum*
Cordia sebestena	*Manilkara zapota* (Chiku fruit tree)	*Tabebuia pallida*
Corymbia 'summer red'	*Melaleuca bracteata 'Gold'*	*Tabebuia haemantha*
Cratoxylum formosum	*Morinda citrifolia* (Noni fruit tree)	*Tecoma stans*
Dalbergia oliveri	*Muntingia calabura* (Wild Cherry tree)	*Ziziphus mauritiana*
Dillenia alata	*Myristica fragrans* (nutmeg)	

MEDIUM HEIGHT TREES (estimated at 6-8m mature height in constructed planters)		
NOTE: Trees that can naturally grow very large in open ground, (in excess of 15 m) are likely to have very large root systems and may be unsuitable for roof decks unless very large soil bodies can be provided. Stability of very big trees on roofs needs to be studied and determined to ensure that the trees do not topple.		
Aleurites moluccana	*Dalbergia latifolia*	*Maniltoa lenticella*
Barringtonia calyptrata	*Delonix regia*	*Michelia x alba*
Brachychiton acerifolius	*Dolichandrone spathacea*	*Pachira aquatica*
Bucida buceras	*Ficus bengalensis* (Yellow Leaf)	*Peltophorum pterocarpum*
Caesalpinia ferrea	*Ficus celebensis*	*Pouteria obovata*
Cananga odorata (tree form)	*Ficus lyrata*	*Saraca thaipingensis* (cauliflora)
Citharexylum spinosum	*Gnetum gnemon*	*Streblus elongatus*
Cratoxylum cochinchinense	*Lagerstroemia floribunda*	*Xanthostemon chrysanthus*
NATIVE SMALL TREES AND LARGE SHRUBS. (estimated at 3-8m height depending on species)		
Angiopteris evecta (Forst.) Hoffm. (elephant fern)	*Garcinia nervosa* Miq.	*Pittosporum ferrugineum*
Syzygium polyanthum	*Gardenia subcarinata*	*Podocarpus polystachyus*
Antidesma cuspidatum	*Horsfieldia superba*	*Pouteria linggensis* (Burck) Baehni
Ardisia elliptica	*Ilex cymosa* Blume	*Pouteria obovata* (R.Br.) Baehni
Cleistanthus malaccensis Hook.f.	*Lumnitzera littorea* (Jack)	*Premna foetida*
Dendrolobium umbellatum	*Memecylon edule* Roxb.	*Rapanea porteriana*
Dillenia (excelsa, indica, suffruticosa)	*Monocarpia marginalis*	*Scaevola taccada*
Diplospora malaccensis Hook.f.	*Myristica iners* Blume	*Sterculia cordata* Blume
Eurycoma longifolia Jack	*Neolitsea cassia*	*Sterculia parviflora* Roxb.
Fagraea racemosa	*Ochrosia oppositifolia*	*Syzygium glaucum*
Ficus heteropleura Blume	*Ormosia sumatrana* (Miq.) Prain	*Tristaniopsis obovata*
Garcinia atrovirdis Griff.	*Pemphis acidula*	*Tristaniopsis whiteana*
Garcinia hombroniana Pierre		

SUGGESTED ROOFTOP VEGETATION – (PALM)		
SMALL to MEDIUM SIZED PALMS (estimated at 3-8 m height: Solitary and Cluster Palms)		
Note. Designers need to study the growth performance of each and any species specified to be sure the plant will perform in the manner desired. The list below covers a wide range of shapes and sizes and each will have a specific character and spatial growth pattern, so research and observation are essential.		
Archontophoenix alexandrae (Alexandra Palm)	*Heterospathe humilis*	*Pelagodoxa henryana*
Areca catechu (Betel nut palm)	*Heterospathe woodfordiana*	*Phoenicophorium borsigianum*
Areca spp.	*Howea belmoreana*	*Phoenix roebelenii*
Bentinckia nicobarica	*Howea forsteriana*	*Phoenix spp.*
Brahea decumbens	*Hyophorbe indica*	*Pinanga patula*
Carpentaria acuminata	*Hyophorbe lagenicaulis* (Bottle Palm)	*Polyandrococos caudescens*
Butia capitata	*Hyophorbe verschaffeltii* (Spindle Palm)	*Ptychococcus lepidotus*
Caryota mitis (Fish-tail Palm)	*Hyphaene indica*	*Ptychosperma macarthurii* (Marcarthur Palm)
Brahea edulis	*Johannesteijsmannia altifrons*	*Raphia australis*
Caryota rumphiana	*Johannesteijsmannia lanceolata*	*Ravenala madagascariensis* (Traveller's Palm)
Chambeyronia macrocarpa	*Jubaeopsis caffra*	*Rhopaloblaste singaporensis*
Cocos nucifera (var. dwarf coconut)	*Latania spp.*	*Roystonea peregrina*
Cyrtostachys renda (Sealing Wax Palm)	*Licuala cordata*	*Sabal bermudana*
Cyrtostachys spp.	*Licuala grandis* (Vanuata Fan Palm)	*Sabal etonia*
Daemonorops draco (Rattan)	*Licuala spinosa* (Mangrove Fan Palm)	*Schippia concolor*
Dictyosperma album (Princess Palm)	*Livistona chinensis/rotundifolia*	*Satakentia liukiuensis*
Dypsis lutescens (Yellow-Cane Palm)	*Lytocaryum insigne*	*Siphokentia beguinii*
Dypsis madagascariensis	*Metroxylon warburgii*	*Synechanthus fibrosus*
Dypsis pinnatifrons	*Nenga pumila var. pachystachya*	*Pritchardia pacifica*
Dypsis procera	*Normanbya normanbyi*	*Pseudophoenix ekmanii*
Elaeis guineensis (Oil Palm)	*Neodypsis decaryi* (triangular palm)	*Thrinax spp.*
Euterpe edulis	*Neodypsis leptocheilos*	*Veitchia merrillii* (Manila Palm)

Euterpe oleracea	*Neoveitchia storckii*	*Wodyetia bifurcata* (Foxtail Palm)
Gronophyllum microcarpum	*Orania palindan*	*Zombia antillarum*
Gulubia costata	*Orbignya cohune*	

NATIVE SMALL PALMS (estimated at 3-6 m height)		
Caryota mitis	*Iguanura wallichiana*	*Pinanga pectinata*
Cyrtostachys renda Blume	*Licuala spinosa* Thunb.	*Pinanga disticha*

HEDGING AND MASSING PALMS (estimated at 2-3m height)		
Arenga hookeriana	*Iguanura wallichiana*	*Rhapis humilis*
Asterogyne martiana	*Licuala ferruginea*	*Rhapis multifida*
Calyptrocalyx micholitzii	*Pinanga patula*	*Sabal minor*
Chamaedorea cataractarum	*Pinanga kuhlii*	*Salacca graciliflora*
Chamaedorea spp.	*Reinhardtia gracilis var. gracilis*	*Salacca minuta*
Dypsis louvelii	*Rhapis excelsa*	*Salacca multiflora*
Iguanura borneensis	*Rhapis excelsa* 'Zuikonishiki'	*Serenoa repens*

There will be continuous efforts in expanding the above lists and we welcome suggestions on plant species from members of the public and the industry who have had positive experiences in planting them on roof gardens.

REFERENCES

Germany FLL – Guidelines for the Planning, Construction and Maintenance of Green Roofing – Green Roofing Guidelines 2008 edition

BS 4043:1989 Recommendations for transplanting root-balled trees

BS 4428:1989 Code of practice for general landscape operations (excluding hard surfaces)

BS 5837:2005 Trees in relation to construction. Recommendations

BS 7370-4:1993 Grounds maintenance. Recommendations for maintenance of soft landscape (other than amenity turf)

CP 79:1999 - Code of Practice on Safety Management System for Construction Worksite

CP33:1996 – Code of Practice for lightning and protection

SS 536:2008 – Code of practice for the safe use of mobile cranes

SS322:1987 - Specification for earthing and bonding clamps

Workplace Safety and Health Guidelines – Landscape and Horticulture Works (WSH Council)

Trees for Urban or Suburban Landscapes, Edward F. Gilman

Chave J (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia (2005) 145: 87-99