Tree Transplanting

TR84 at Penny's Bay

Tree Transplanting

Scope

Tree transplanting
..... cutting a tree out of the ground, pruning the canopy (to balance root loss), packaging, transporting it to a new location, and re-establishing it there

Can happen multiple times during a tree's life, from small seedling right up to fully mature tree.

Process is essentially the same for all sizes, only the effort involved in transplanting gets greater as the tree gets bigger

Photos courtesy of project teams

Tree Transplanting

Key objectives in transplanting

- Keeping the tree alive and healthy
- Minimise impact on growth potential and aesthetic look
- Minimise transportation costs

Photo courtesy of project team

Tree Transplanting

Nursery production transplanting

Transplanting as part of field or container grown commercial nursery production operations, from seedlings to semi-mature trees.

Nursery process germination, potting up, transplanting

Tree Transplanting

Nursery production transplanting

In production a tree should be regularly root pruned to promote the development of strong root systems (esp. fine roots / water absorbing)

Nursery seedlings
in Guangzhou

Tree Transplanting

Nursery production transplanting

Nursery production in Southern China is low cost / mass volume

- lack of local quality standards / regulation of the industry
- plants bought and sold, moved several times with different parties responsible for different stages of production
- high potential for tree damage in production
- processes based on agricultural production e.g. use of clay soils because they are cheap and impact resistant

Low success rate in production (>50% losses)

Production nurseries in southern China

Urban Tree Transplanting in Hong Kong (M. Pryor)
Seminar on Urban Greening in Hong Kong, Chinese University of Hong Kong

Urban Tree Transplanting in Hong Kong (M. Pryor)
Seminar on Urban Greening in Hong Kong, Chinese University of Hong Kong

Tree Transplanting

Nursery production transplanting

Semi-mature - maximum size of field grown tree prepared and planted to a reasonable quality / growth potential, when transplanting in a horizontal position.

Semi-mature nursery trees

Tree Transplanting

Transplanting mature trees in an horizontal position

Many hundreds of mature trees are transplanted every year to make way for development as an environmental remediation measure

Physical and operational constraints:

- short time frame
- limited working space
- problems of road transportation
- difficult finding suitable receptor sites

Photos courtesy of project team

Tree Transplanting

Transplanting mature trees in an horizontal position

Transplanting not seen as a valid practice by many practitioners, and tends to be done for administrative convenience rather than as a worthwhile green measure.

Key problems

- standard practice is based on practice (rather than science) combined with misinterpretation of indirectly technical guidelines from overseas.
- poor practical skill
- no incentive to follow the rules / cheaper not to and replace

High failure rates typically ~30%

Photos courtesy of project team

Tree Transplanting

Transplanting mature trees in an upright position

Transplanting of established mature trees from their current locations to a new location in a vertical (upright) position.

Trees usually can only be moved over short distances due to size. The mechanics of lifting and moving huge trees pose serious engineering and arboricultural challenges

Some 30-40 large scale examples in HK in the last 20 years, using a wide variety of lifting and moving techniques

It is spectacular, high profile, highly expensive, and really only justified to preserve the most important heritage trees

Transplanting at Penny's Bay

'Large trees must be moved vertically for various reasons'
Photograph, Charles F Irish (c.1961)

Tree Transplanting

Happy Valley, Sports Road (1995)

Photos courtesy of Dr. Eric Lee

Tree Transplanting

Happy Valley, Sports Road (1995)

Photo courtesy of Dr. Eric Lee

Tree Transplanting

Tamar Basin (1995)

Urban Tree Transplanting in Hong Kong (M. Pryor)
Seminar on Urban Greening in Hong Kong, Chinese University of Hong Kong

Tree Transplanting

Penny's Bay (2004)

Tree Transplanting

Che Kung Mui Road, Tai Wai (2006)

Urban Tree Transplanting in Hong Kong (M. Pryor)
Seminar on Urban Greening in Hong Kong, Chinese University of Hong Kong

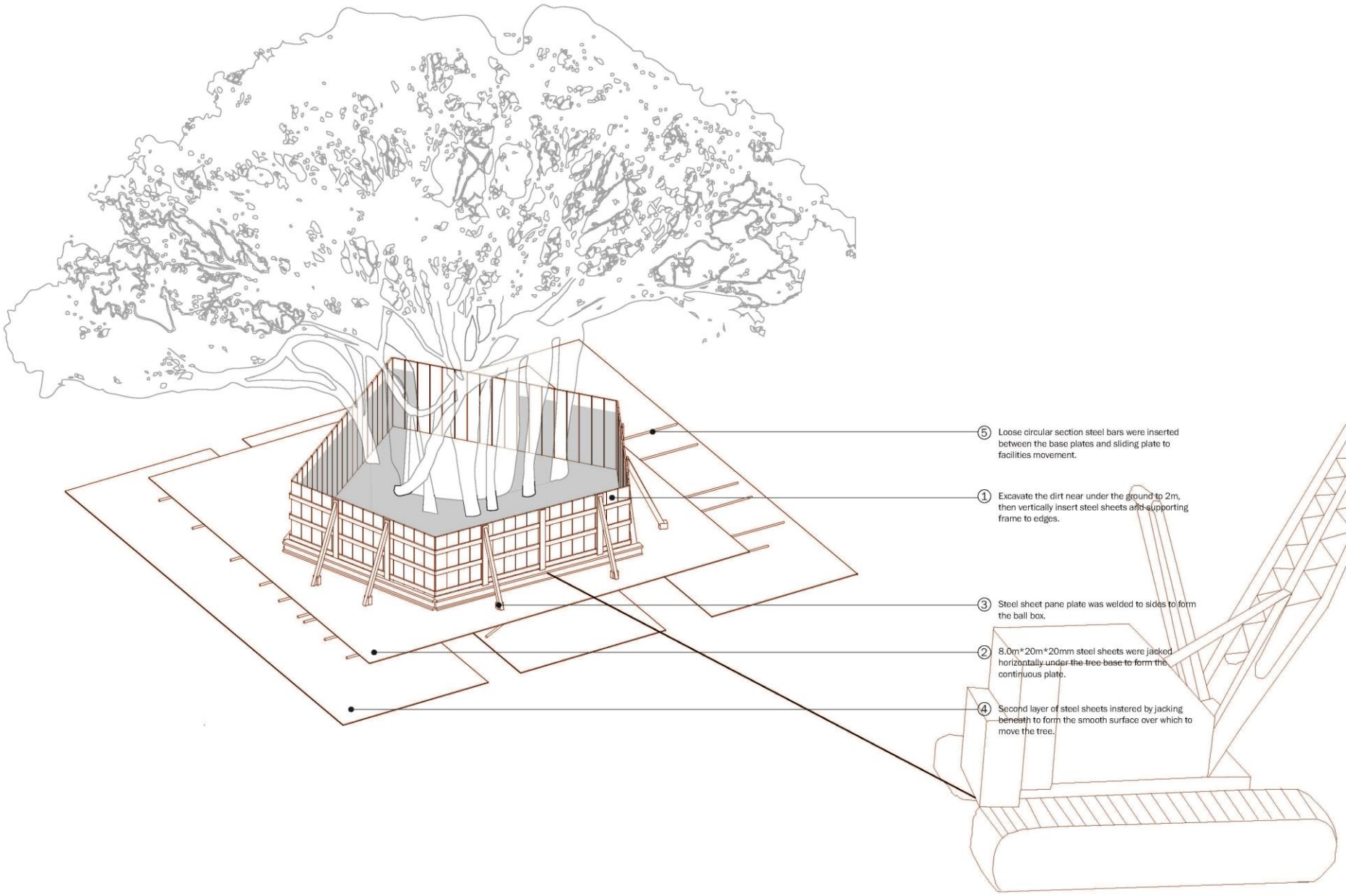
Photos courtesy of Yee Sun Garden

Tree Transplanting

Sha Po Tsuen, Yuen Long (2011)

Photo courtesy of Lai Sai Hong

Diagram of lifting process, Tree No. 1318

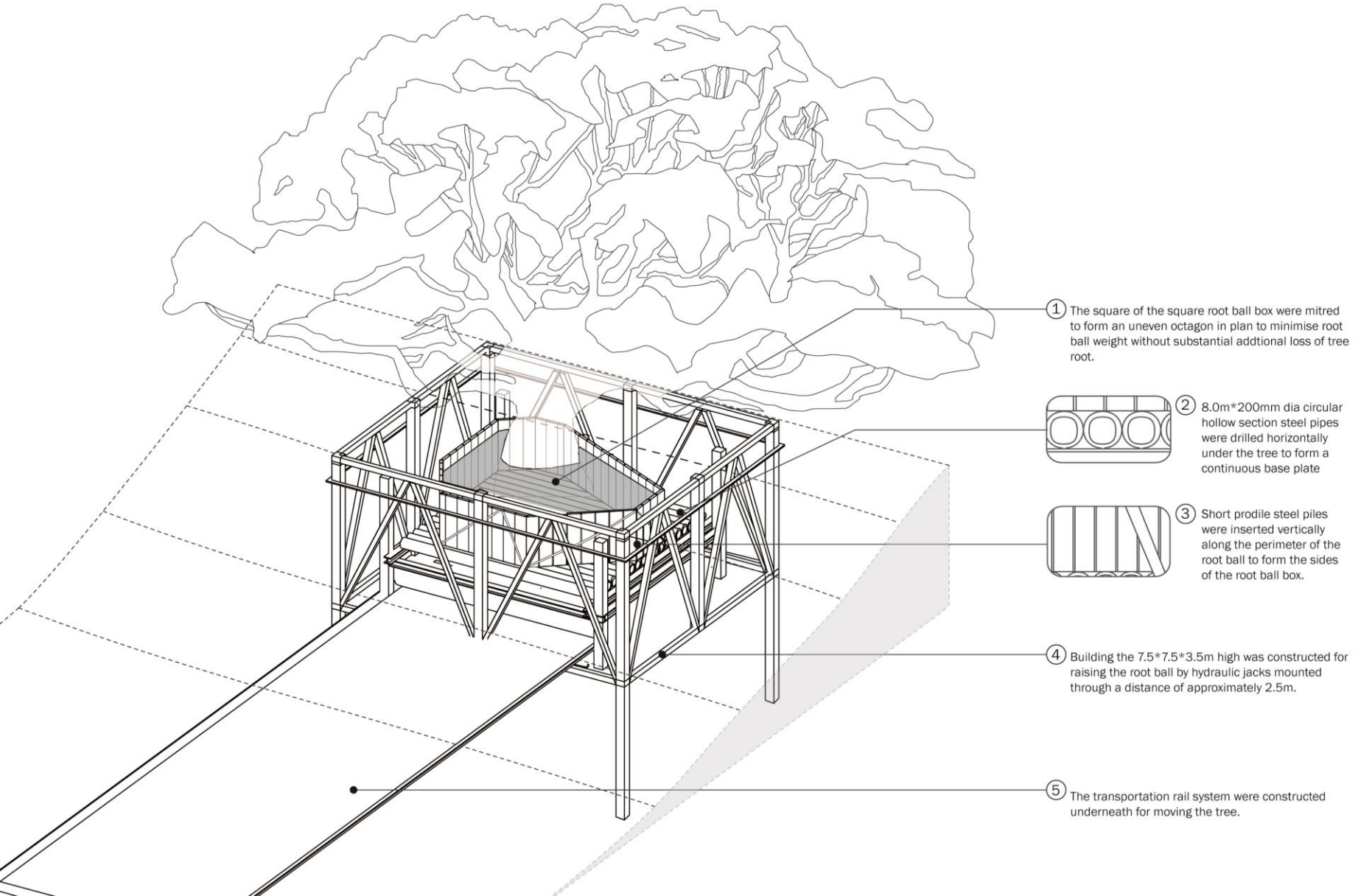


Tree Transplanting

Yuet Wah Street (2011)

Photos courtesy of project team

Diagram of lifting process, Tree T99, Yuet Wah Street, Kwun Tong



1 The square of the square root ball box were mitred to form an uneven octagon in plan to minimise root ball weight without substantial addtional loss of tree root.

2 8.0m*200mm dia circular hollow section steel pipes were drilled horizontally under the tree to form a continuous base plate

3 Short prodile steel piles were inserted vertically along the perimeter of the root ball to form the sides of the root ball box.

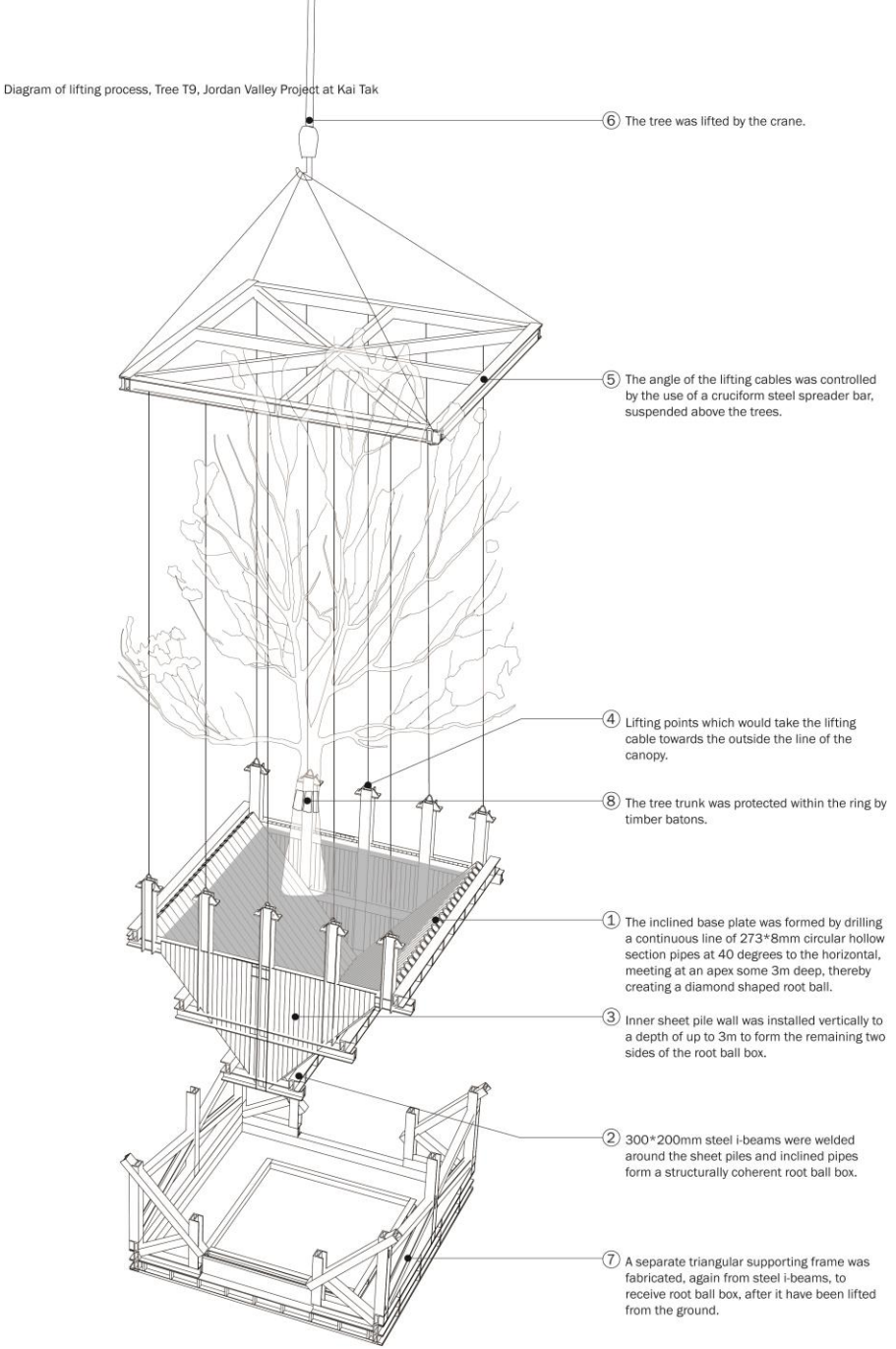
4 Building the 7.5*7.5*3.5m high was constructed for raising the root ball by hydraulic jacks mounted through a distance of approximately 2.5m.

5 The transportation rail system were constructed underneath for moving the tree.

Tree Transplanting

Kai Tak (2012)

Photo courtesy of project team



Melia azedarach

Photo courtesy
of project team

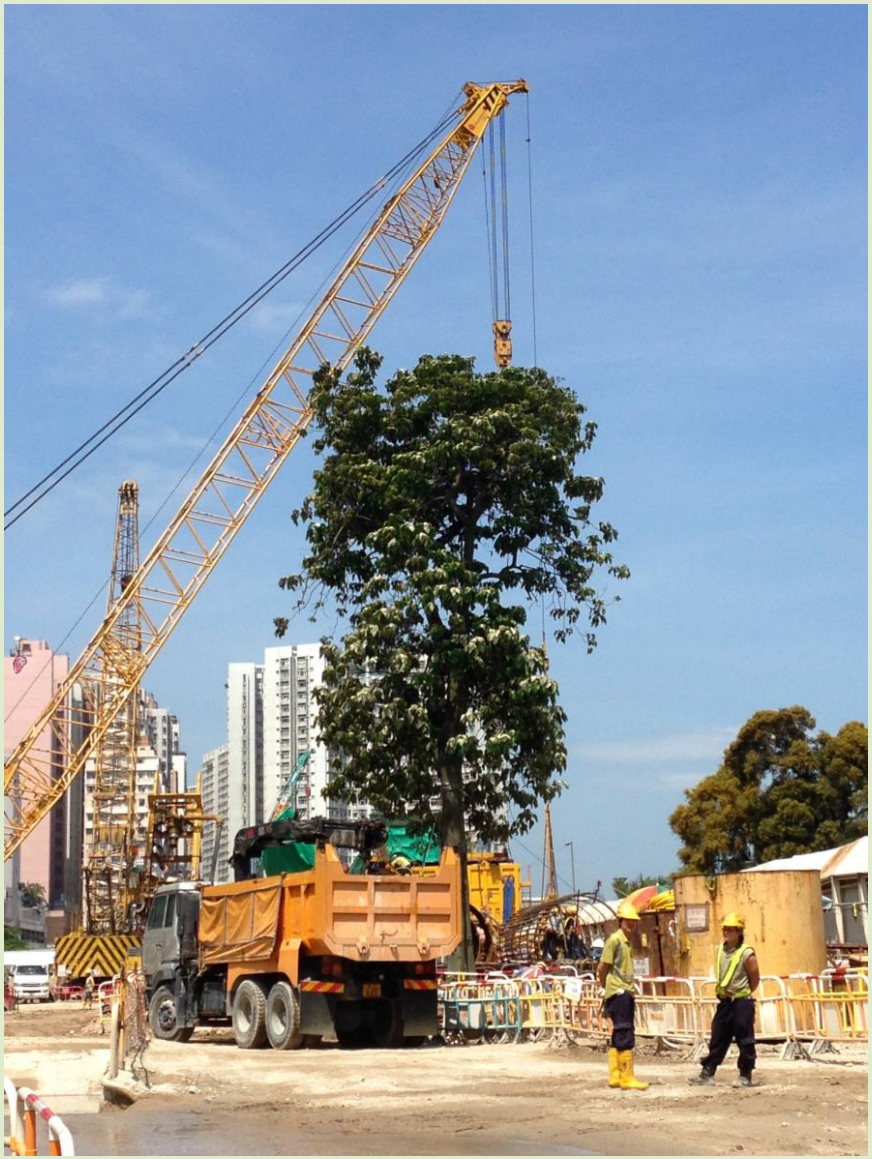
Tree Transplanting

HKU West Gate (2011)

Photos courtesy of Oriental

Tree Transplanting

Former North Point Housing Estate (2014)



Urban Tree Transplanting in Hong Kong (M. Pryor)
Seminar on Urban Greening in Hong Kong, Chinese University of Hong Kong

Photos courtesy of Dr. Eric Lee

Tree Transplanting

Victoria Park (2014)

Photos courtesy of Yee Sun Garden

Photos courtesy of Yee Sun Garden

Tree Transplanting

Sydney, Australia- Transplant Industries

Photos : Transplant Industries, Australia

Tree Transplanting

Extreme tree transplanting

No roots - no canopy

For commercial sale (mainly to property developers)
Value (?) = mature trunk size and height with greenery, complex trunk forms (immediate effect)

Extreme transplanting in Guangzhou nursery


Tree Transplanting

Extreme tree transplanting

Trees come from Southern / Western China, Malaysia, Vietnam, (from road / development projects or harvesting of natural forests)

Trunk - 800-3000mm (dbh)
Height - 18-25m, cut to 8-12m

~5000 currently on sale, but only a few species

- *Bischofia polycarpa / B. javanica (30%)*
- *Ficus microcarpa (25%),*
- *Cinnamomum camphora (20%)*
- *Ficus altissima, F. benjamina F. virens (15%)*
- *Litchi chinensis, Dimocarpus longan, Sapindus mukorossi, Ilex rotunda, Hibiscus tiliaceus, Artocarpus nitidus (10%)*

Tree Transplanting

Extreme tree transplanting

Specially constructed root balls using heavy clay

Very intensive aftercare, with constant watering and trunk wrapping

Bischofia javanica
(transplanted about 3 years ago)

Trees wrapped with plastic film

Tree Transplanting

Extreme tree transplanting

High losses, due to failure to recover from water imbalance

Those that survive have a short life expectancy after re-planting (usually less than 10 years until the rot and disease gets them)

Tree Transplanting

Extreme tree transplanting

This extreme practice can tells us about the responses of mature trees to massive damage inflicted on their root and canopy systems

Urban Tree Transplanting in Hong Kong (M. Pryor)
Seminar on Urban Greening in Hong Kong, Chinese University of Hong Kong

The Science of Tree Transplanting

What we know of the science behind tree transplanting comes from the study of the effects of transplanting on field grown nursery trees in (temperate climates) in the USA and Europe.

Photos courtesy of Kijiji.ca, Bali.org.uk

The Science of Tree Transplanting

Transplanting success

Transplanting is successful when …
"the tree survives and regains normal patterns of shoot and root growth, and without significant impact on its future growth potential and life expectancy."

The Science of Tree Transplanting

Transplanting shock

"Extended period of slow growth after extensive loss of root system and reduction in crown volume during transplanting."

Morphological symptoms

shorter twig and root elongation, stunting and crown dieback

Physiological symptoms

low shoot water potential, reduced photosynthesis, tissue inelasticity and desiccation

(South and Zwolinski 1997)

The Science of Tree Transplanting

Transplanting shock

Transplant shock is a response to water stress arising from sudden water imbalance as a result of a change in the shoot : root ratio

Degree of change in shoot : root ratio influences the severity of the symptoms of shock and the length of time over which they occur
(Watson 1985, Watson 2010).

Before / after transplanting

The Science of Tree Transplanting

Transplanting shock

Water stress continues until roots have re-grown sufficiently to be able to re-establish water balance.
(Harris et al. 2004)

Time required to overcome transplanting shock depends on its species and morphological characteristics
(Harris and Gilman 1991)

The Science of Tree Transplanting

Transplanting shock

Transplant shock is influenced by:

- physiological impact on the transplant
- proportion of root biomass and canopy volume retained extent of disruption
- transplant timing
- environmental condition
- cultural practice after replanting

(Struve et al. 2000), (Gilman 1990)

The Science of Tree Transplanting

Transplanting shock

Trees with higher shoot : root ratios have less chance of surviving transplanting and grow more slowly afterwards
(Harris and Gilman 1991)

Species with a greater capacity to regenerate roots and withstand water stress have a higher chance of surviving

Transplanting when transpiration rates are low can also reduce water stress

The Science of Tree Transplanting

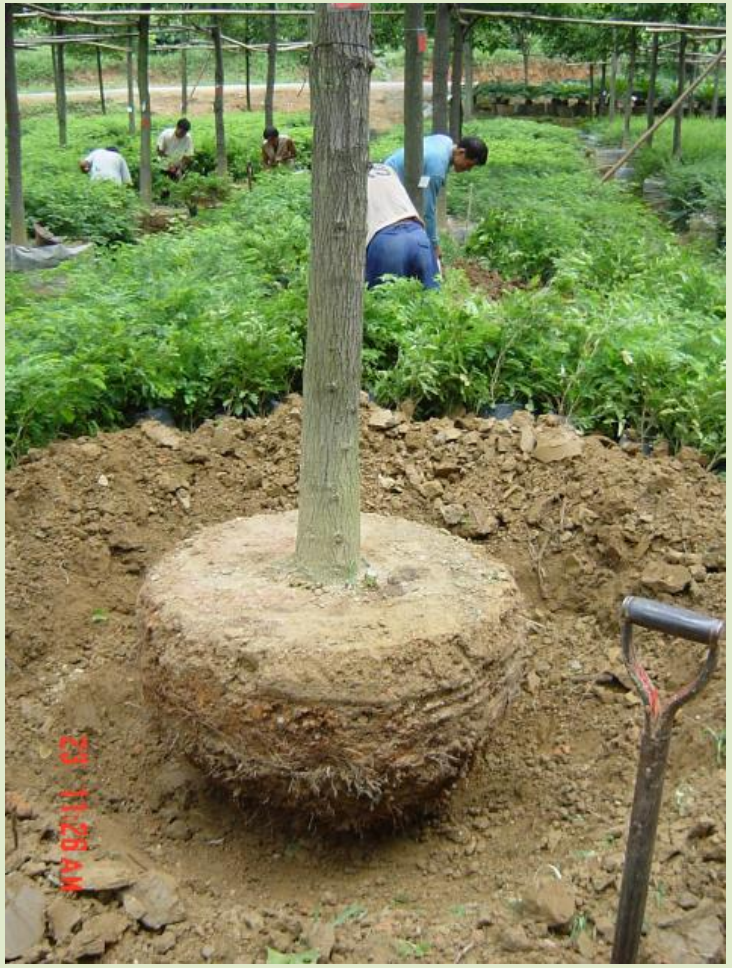
Root pruning

Percentage of the root system lost in forming the root ball for transplanting for field grown trees maybe >98% of their roots (measured by length)
(Watson and Sydnor 1987; Gilman 1988b).

Proportion of root biomass retained total in the root ball is higher, due to the greater concentration of root biomass near the base of the tree.

- 53%–100% of the root biomass retained in trees up to 60mm (dbh)
  (Gilman and Beeson 1996b; Gerhold and Johnson 2003)

- 29%–83% in trees 60-200mm (dbh)
  (Gerhold and Johnson 2003).



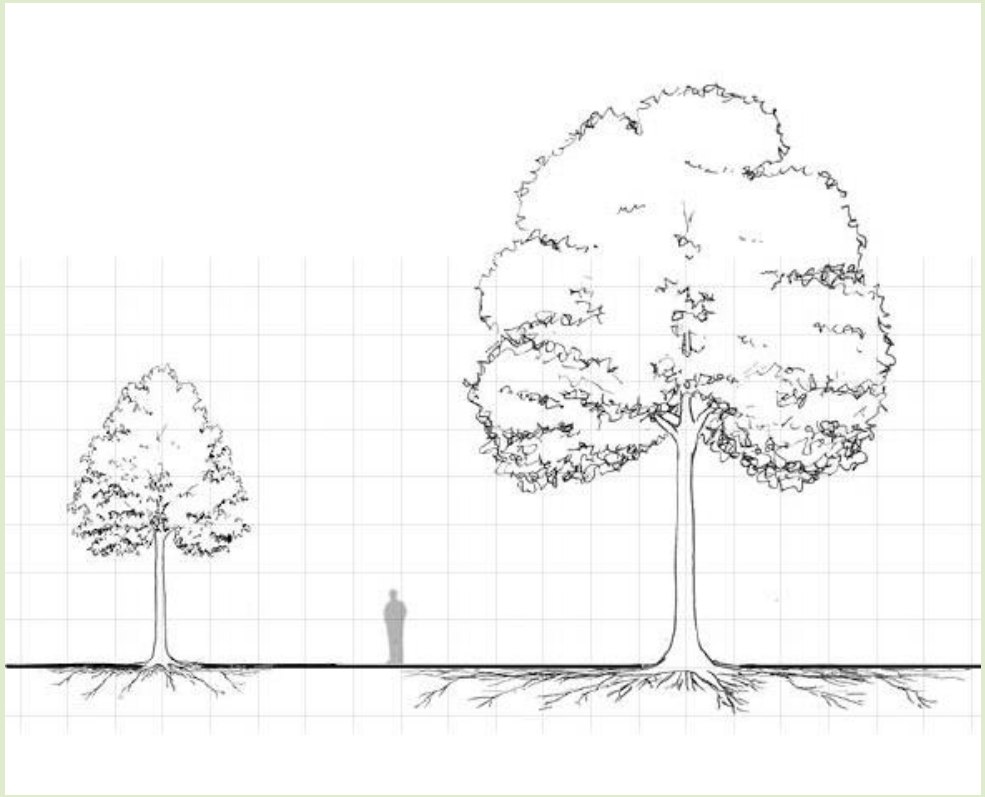
Tree Transplanting

Extreme tree transplanting

In both young and old trees the concentration of carbohydrates usually is higher in the roots than in the shoots, but the root : shoot ratio decreases with age and the amount of carbohydrates stored in the trunk and branches increases
(Kozlowski and Pallardy 1997)

On smaller, landscape size trees, the majority of the large roots that store carbohydrates are contained in the root ball of a transplanted trees (Gilman and Beeson 1996b, Gerhold and Johnson 2003)

In adult trees, the stem branches and leaves make up more of the dry weight than do the roots and may store more carbohydrates than the root system
(Kozlowski and Pallardy 1997)



The Science of Tree Transplanting

Root pruning

Only 5%–18% of the fine, water absorbing roots (< 2 mm) were found to have been retained during transplanting resulting in high levels of water stress.

(Watson and Sydnor 1987; Gilman 1988a; Gilman et al. 1992; Gilman and Beeson 1996b)

Photos courtesy of project team

Photos courtesy of project team

The Science of Tree Transplanting

Root pruning

Root pruning well before transplanting can stimulate the generation of new fibrous water absorbing roots from the callus tissue around the severed ends of roots at the edge of the root ball (Harris 1992).

Repeated pruning can increase the proportion of fine roots, and promote a more branched and dense root system (Gilman et al. 2002, Gilman and Anderson 2006) (Watson and Sydnor 1987; Gilman et al. 2002).

New roots can restore water and nutrient uptake capability and also increase carbohydrate reserves.

Photos courtesy of project team

The Science of Tree Transplanting

Root pruning interval

Longer the root pruning intervals the greater the mass of new roots that are likely to be formed.

Root pruning most effective in periods of active root growth.

Regeneration most rapid when canopy growth is least rapid i.e. outside periods of active shoot growth.
(Watson and Himelick 1982)

The Science of Tree Transplanting

Optimal time for transplanting

In temperate climates best time to transplant is considered to be fall and spring, coinciding with periods of active root elongation, and when soil moisture and temperature are favourable for root regeneration

(Harris et al 1995; Harris and Fanelli, 1999; Richardson-Calfee and Harris 2005).

In subtropical climates ... it is not so clear.

The Science of Tree Transplanting

Re-planting

Backfill soil is usually much better quality, than the root ball soil, and can promote rapid rooting outside the root ball and absorption of water required for a tree to re-establish water balance and recover from transplanting shock
(Watson 1992)

Post transplanting root growth and tree survival in seedlings can be increased with:

- soil injections of carbohydrates
- addition of auxins into the growing media
- use of arbuscular mycorrhizal fungi

(Percival and Fraser 2005), (Percival and Gerritsen 1998)

Photos courtesy of project team

The Science of Tree Transplanting

Root ball formation

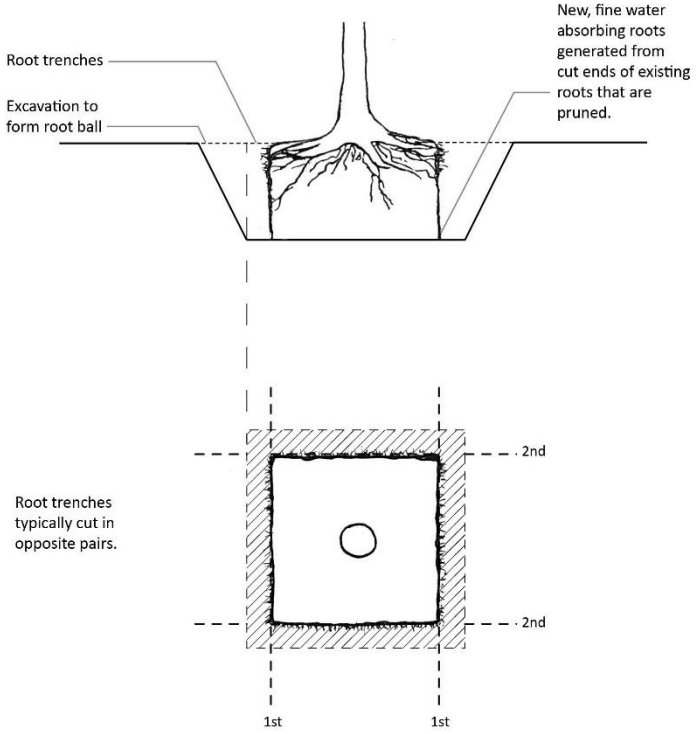
Root pruning for transplanting in Hong Kong is typically conducted in three stages to minimize the effects of substantial root loss while maximizing the period for new root growth prior to transplanting.

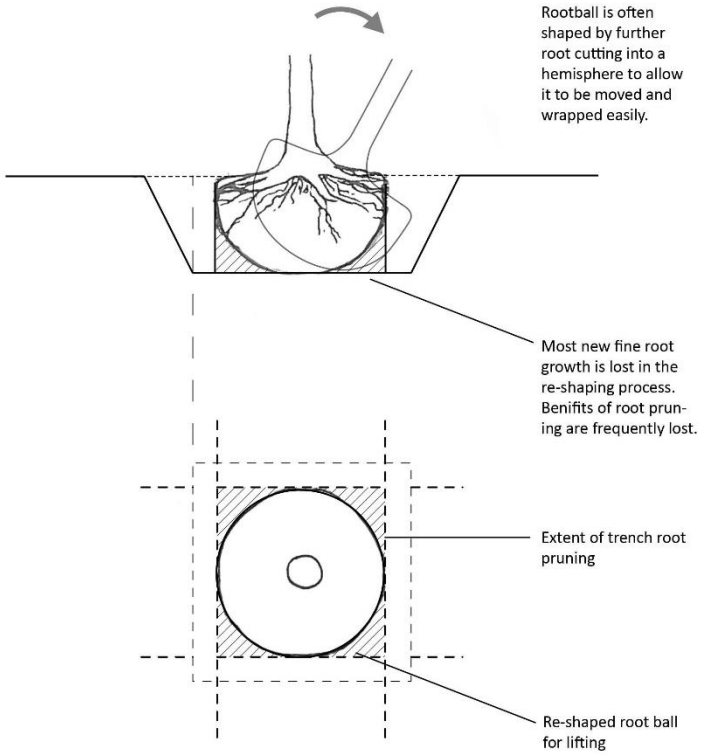
i. root pruning trenches dug and backfilled on two sides,
ii. repeat for the other two sides,
iii. undercut and lift.

The Science of Tree Transplanting

Root ball formation

Much of the new root generated through root pruning (square trenches) is often lost in formation of (round) root balls for transportation.





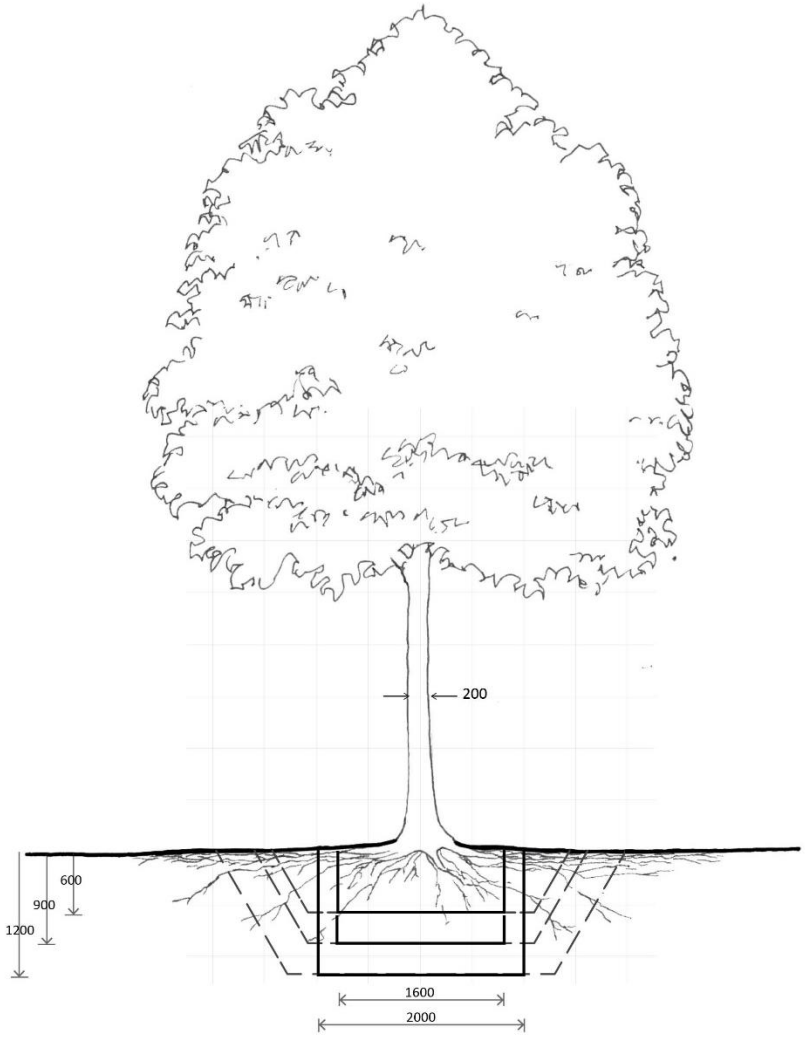
The Science of Tree Transplanting

Root ball size

Root ball size represents a balance between the practicalities of moving the tree and attempts to maximize the volume of original root system retained to support the tree immediately after transplanting.

American arboriculture (A300, Part 6 citation) standards specify root ball (diameter /trunk diameter) ratio for field grown nursery trees:

10:1 for trees < 300mm diameter,
9:1 for trees 300-450mm diameter
8:1 for trees > 450mm diameter



Weights of different size of root balls for a 200mm caliper tree			
Root ball diameter(mm)	1600 (@8:1)	1600 (@8:1)	2000 (@10:1)
Root ball depth(mm) (@60%)	600	900	1200
Root ball volume(m^3)	1.53	1.81	3.77
Root ball weight (@1750kg/m^3)	2670kg	3170kg	6600kg

The Science of Tree Transplanting

Root ball size

Root ball ratio for mature trees growing in urban locations root systems distinctly asymmetric, may be significantly less

The Science of Tree Transplanting

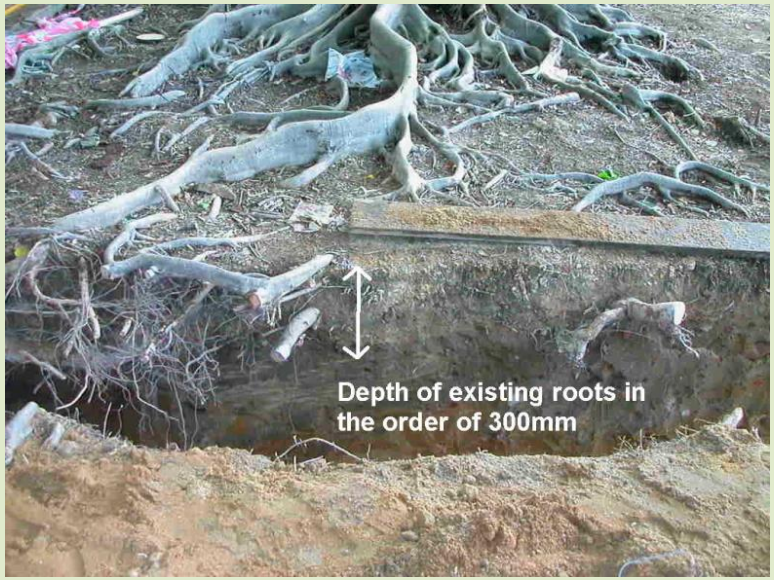
Root ball size

Root ball depth for small transplants is suggested as 60% of root ball diameter.

Tree root density with respect to depth is dependent on species and soil environment.
A large proportion of root biomass is in the upper soils layers, 0-450mm deep
(Jonsson et al. 1988, Toky and Bisht 1992).

(60%) figure is not effective for larger size trees, and the maximum root ball depth should be no more than 1200mm for any tree

For street trees where there are existing underground physical constraints, root balls can be much less deep (600-800) without affecting the outcome.



The Science of Tree Transplanting

Root ball size

Moisture holding capacity of the root ball soil, the cohesion and integrity of the root ball during handling, are likely to influence transplanting success.

The Science of Tree Transplanting

Canopy pruning

Canopy pruning undertaken in tandem with root pruning can help to reduce water stress, i.e. balancing the loss of water absorbing capacity with the corresponding reduction in the capacity to lose water through leaf transpiration.

Shoot pruning can significantly increase transplant survival and subsequent tree growth
(Percival 2007)

Canopy volume should be reduced by no more than 25% in Hong Kong
(Tree Management Office 2010)

☐ canopy pruning – example

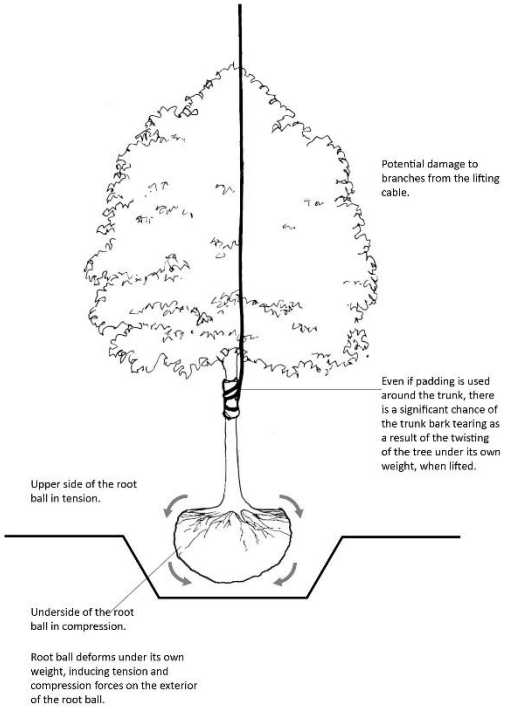
Photo courtesy of project team

Tree Transplanting

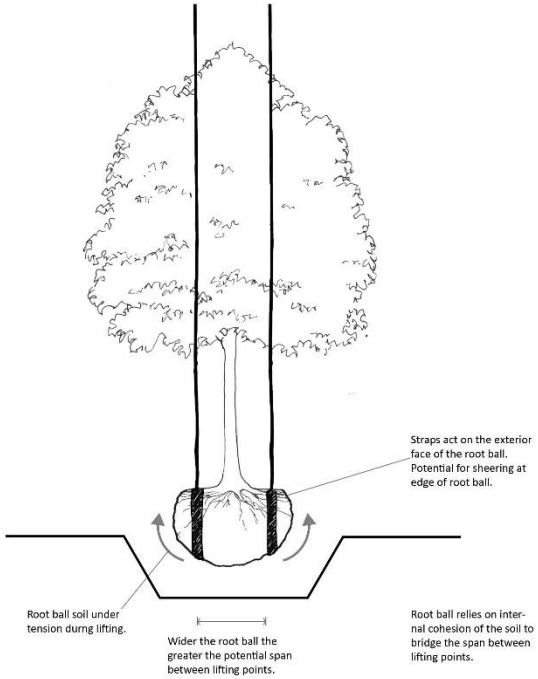
Nursery production transplanting

Lifting the tree by the trunk

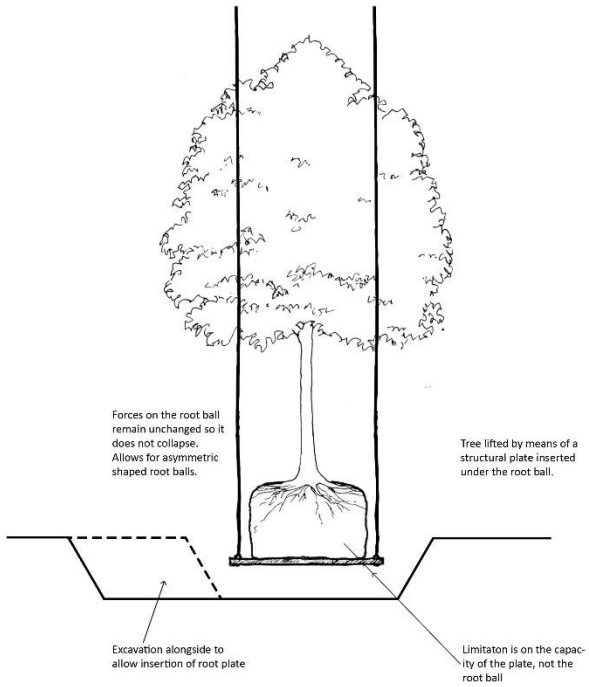
(most common lifting method as it is the quickest)



Lifting the tree by straps around the root ball



Lifting the tree by plate inserted underneath



The Science of Tree Transplanting

Canopy pruning

Canopy pruning can reduce photosynthate production, slow potential root re-growth and create competition with the roots for stored carbohydrates
(Coder 1997, Harris et al. 2004).

Removing live branches can deplete energy reserves.
Hagen (2001)

If undertaken in spring, canopy pruning may inhibit cambial activation and, possibly, the movement of auxin from the buds to the roots tips that is required for transplant recovery
(Hamilton 1988).

The Science of Tree Transplanting

Physical impacts during lifting and transportation

Accidental impact wounds (cuts, abrasions, bark torsion and compression) are common.

Impacts from change in environmental condition e.g. sun and wind exposure in transit and at the receptor site, also occur frequently.

Desiccation can occur within a few days if root balls are not kept fully hydrated
(Gilbertson et al. 1985)

Transplanting wounds increase vulnerability to disease and pest attack which may compound the effects of water stress
(Peltier and Watson 2000).

The Science of Tree Transplanting

Physical impacts during transportation

Transplanting shock can be exacerbated by the disturbance of the root-soil contact during transportation.
(Sands 1984)

Trees are tolerant of low levels of disruption, but above a certain level disruption can it significantly impact on the potential for root re-growth and survival
(Tabbush 1986; McKay 1996; Koeser and Stewart 2009).

Photo courtesy of project team

The Science of Tree Transplanting

Physical impacts during transportation

Disruption of the interface between roots and the surrounding soil may result from weight re-distribution in the root ball during lifting and from vibration and percussive impacts during handling and transportation.

Photos courtesy of project team

The Science of Tree Transplanting
Aftercare

Aftercare re-establishment, use of additives,

- Daily watering (root ball and trunk)
- Pest control
- Application of fertilizer

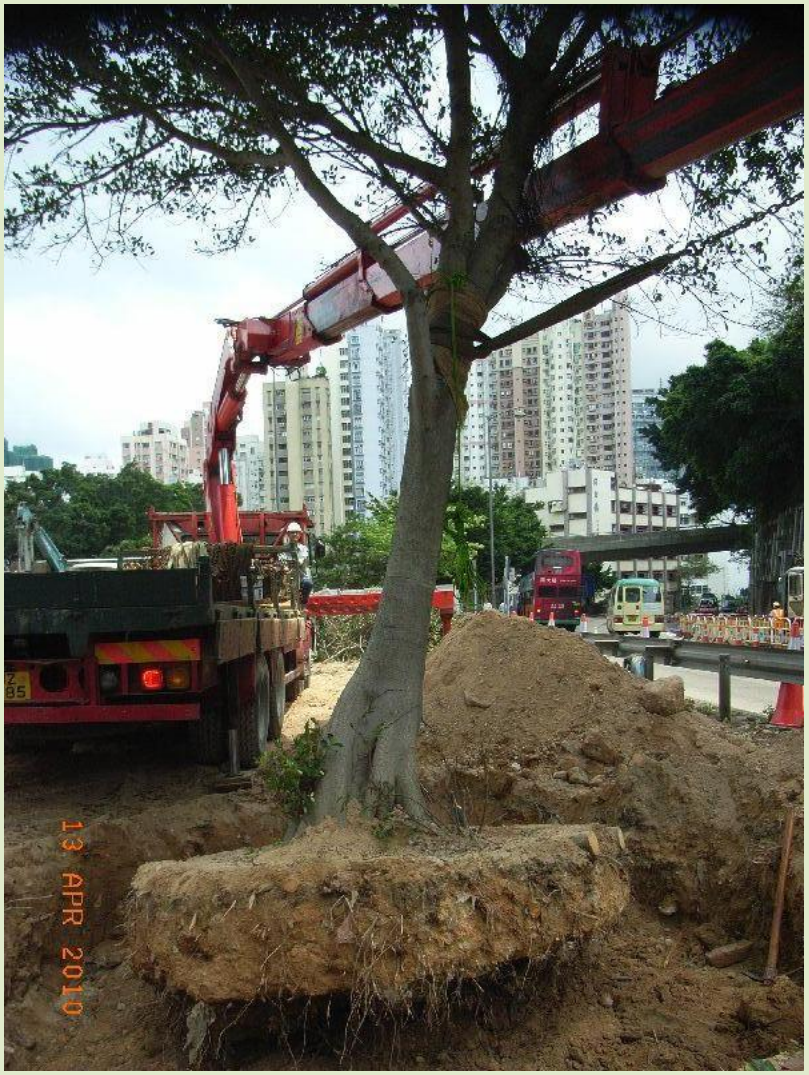
Photos courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Questions

1. Which factors in the transplanting process were influential in determining the success / failure of transplanting operations on nine common street tree species in Hong Kong,

2. Do the adaptations that trees make to survive poor quality street environments also make them more tolerant of transplanting.



Photos courtesy of project team

Street Trees in Hong Kong
Survival

Poor growing environment results in short average life expectancy for street trees
(Nowak et al. 1990, Nowak et al. 2004).

Estimated average life expectancy of a street tree in Hong Kong <20 years.

Only those species that are tolerant of the conditions on the street and have ability to respond rapidly to changes in environment will survive.



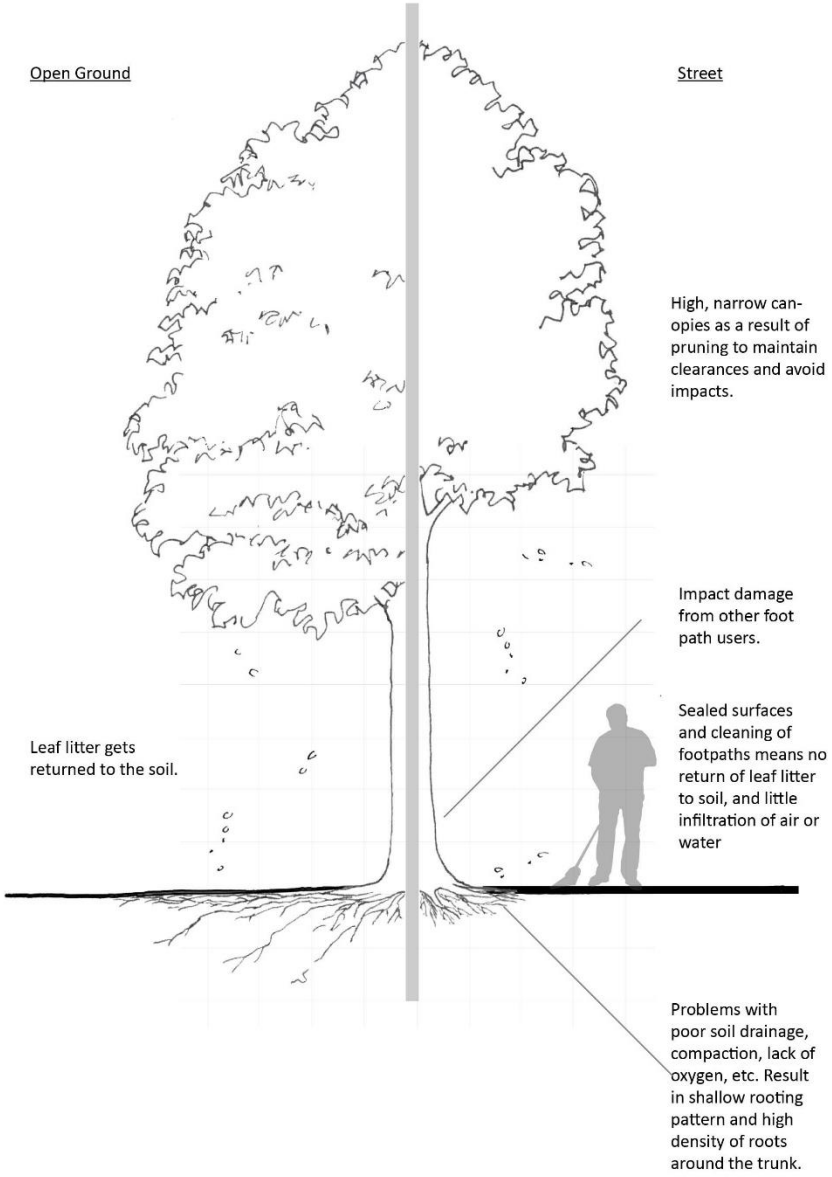

Street Trees

Morphology of urban street trees

Morphology of urban street trees differs from field trees due to poor quality above and below ground conditions

Differences can affect survival of newly planted trees.
(Gilbertson et al. 1985)

Field trees vs Street trees



Street Trees
Characteristics

Characteristics that make a good street trees should make them tolerant of transplanting.

•ability to adapt rapidly to the various environmental conditions
•dense, restricted root systems
•small, narrow canopies

Street Trees
Urban soils

Street tree soils in Hong Kong are typically heterogeneous, nutrient poor and heavily compacted
(Jim 1998).

Little organic matter or soil organisms and are subject to high levels of salt and contaminants.

Although soils are poorly drained urban street trees often experience drought due to the very slow movement of water within them.

Street Trees
Urban soils

High levels of compaction are common, plus high penetration resistance and limited macro pore space limit root establishment and growth
(Alberty et al 1984, Rolf 1994, Day et al 2000, Smith et al. 2001, Reichwein 2002)

Soil quality is a significant inhibitor of tree root growth and a constraint on tree growth generally
(Gilbertson and Bradshaw 1990), (Coder 1998)

Street Trees
Root depth

Root depth depends on species and soil condition
(Day et al 2010).

Roots of street trees are very largely concentrated in the upper zones due to the increasingly poor soil conditions at depth.
(Crow 2005), (Wang et al. 2006)

High incidence of surface roots on street trees
(Henwood 1973).

Street Trees
Root spread

Limited soil volume restricts root spread and overall growth of street trees
(Kopinga 1991, Grabosky and Gilman 2004, Sherman 2012).

Root system architecture of street trees is more complex and asymmetric

Roots biomass (in particular fine water absorbing roots) is likely to be more concentrated around the trunk.

Tree height, spread and trunk diameter have not been found to be good predictors of root spread in street trees
(Day et al 2010).

Photos courtesy of project team

Street Trees
Roots

Highly constrained root systems repeatedly observed on street trees in Hong Kong

Street trees form dense root systems close to the trunk, with a high frequency of girdling roots

Photos courtesy of project team

Street Trees

Canopies of street trees

Canopy space is restricted by structures and buildings, passage of vehicles and allowance for sightlines. Canopies frequently pruned and lifted to avoid such impacts.

High levels of air borne pollutants can also stunt growth of roadside trees (Sjöman 2010).

Research Study into Transplanting Street Trees in Hong Kong

Research study

Based on the observation and measurement of transplanting operations for 535 mature street trees, of nine common broad-leaved tree species.

Bombax ceiba, Cotton tree (57 no.)
Celtis sinensis, Chinese hackberry (43)
Crateva unilocularis, Spider Tree (37)
Ficus benjamina, Weeping fig (59)
Ficus microcarpa, Chinese banyan (129)
Melaleuca quinquenervia, Paper bark tree (117)
Peltophorum pterocarpum, Yellow Poinciana (42)
Pongamia pinnata, Wild Bean (25)
Syzygium cumini, Jambolan Plum (26)

Photo courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Research study

Trees were relocated from urban street locations in various parts of Hong Kong to off-site planting locations within a 12 month period.

Trees had been growing in pavement pits, narrow raised planters, or larger open planting beds.

Height - 3.0 to 14.0m
Trunk diameter (dbh) - 0.1 to 0.7m
Canopy spread - 2.5 to 8.0m

Research Study into Transplanting Street Trees in Hong Kong

Research data source

Data from tree surveys, contractors works records, observations of the transplanting operations and physical measurements of the tree.

The transplanting works undertaken to a standard tree works specification timing of the transplanting operations was dictated by project constraints.

Research Study into Transplanting Street Trees in Hong Kong

Transplanting operations

Specified root ball ratio (8:1) for all trees

Actual root ball ratios that were achieved (3:1 to 13:1), (ave. 7.8:1).

Photos courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Transplanting operations

Canopy had to be physically reduced (by pruning or tying up) to fit within a box 2.5 x 3.5 x 12.0m long

Rigid branching structure of many trees resulted in high proportion of canopy (average 38.5%) having to be removed

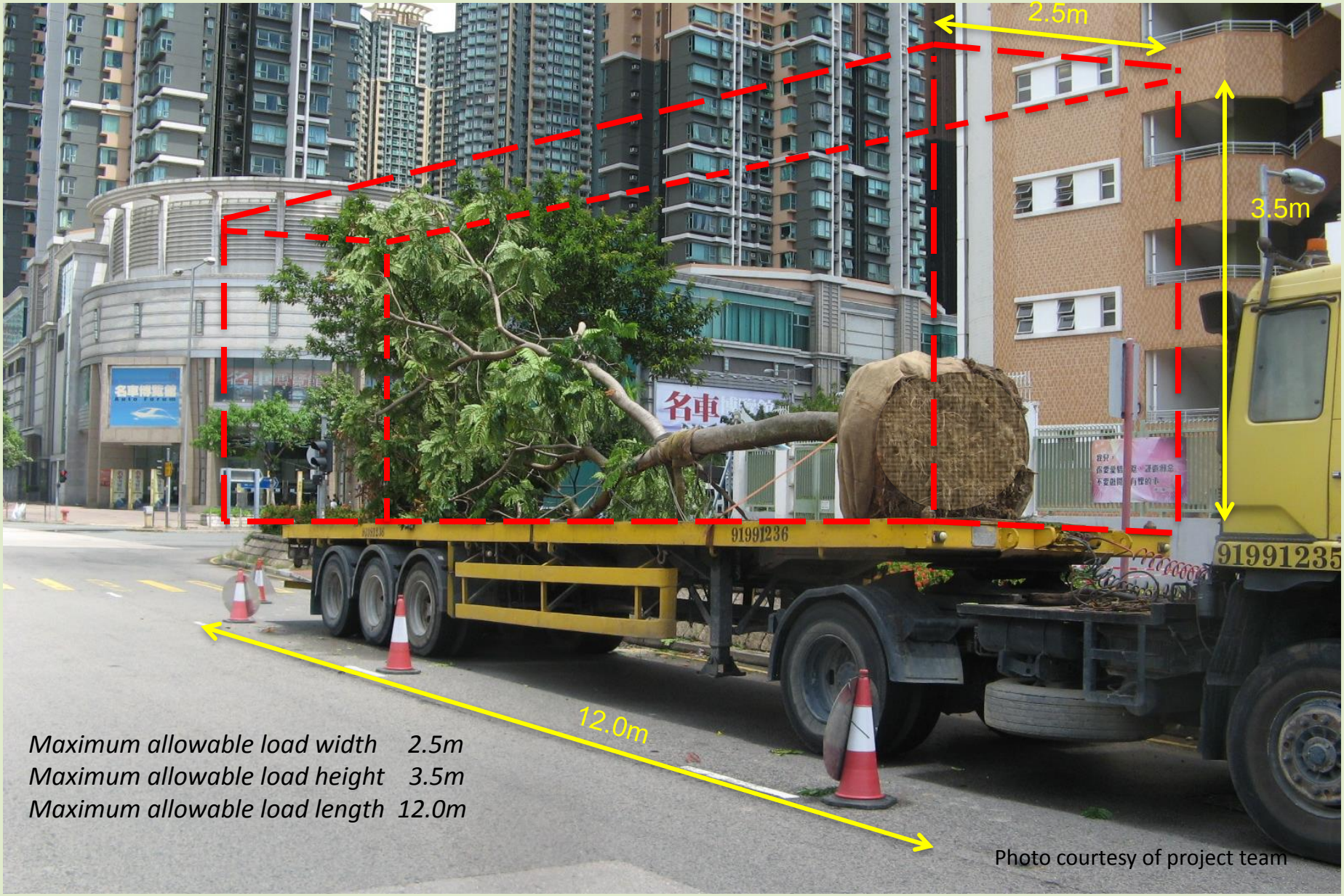
Large pruning cuts (up to 250mm dia.) made trees vulnerable to pests and fungal infection.

Photos courtesy of project team

Street Trees

Pruning for transportation

Road traffic regulations meant that root ball, trunk and canopy need to be physically reduced (by pruning or wrapping)



Maximum allowable load width 2.5m
Maximum allowable load height 3.5m
Maximum allowable load length 12.0m

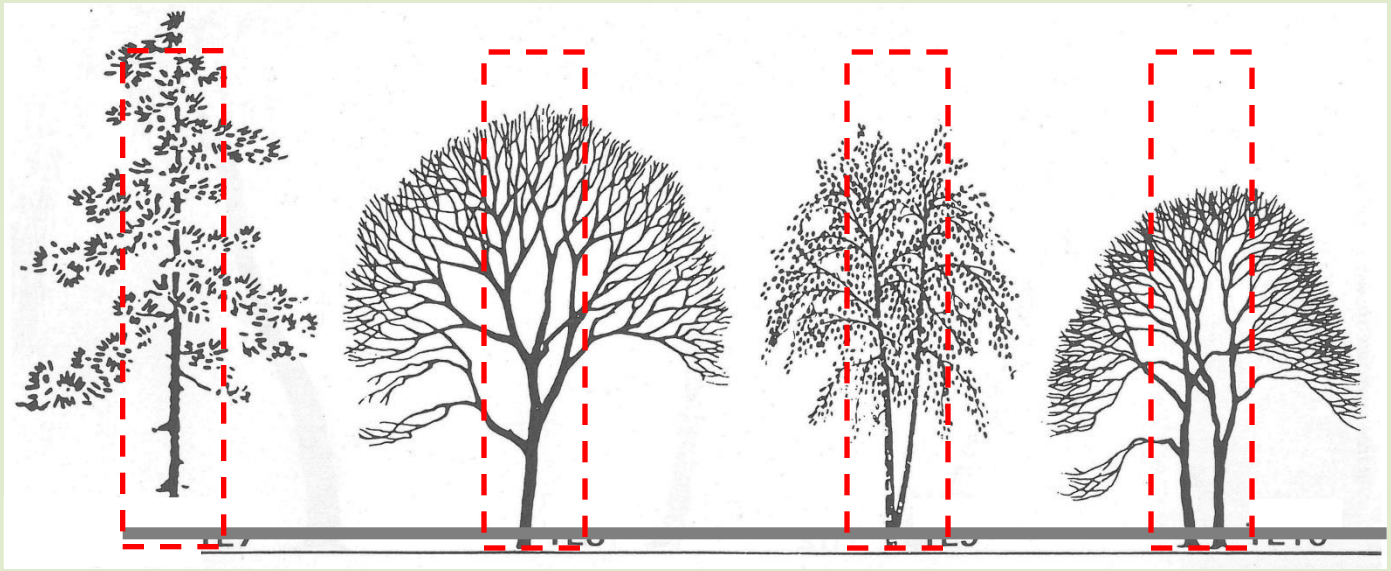
Photo courtesy of project team

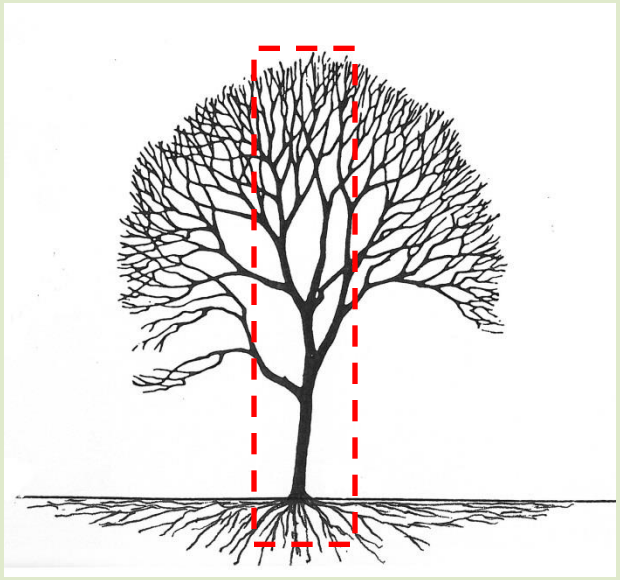
Street Trees

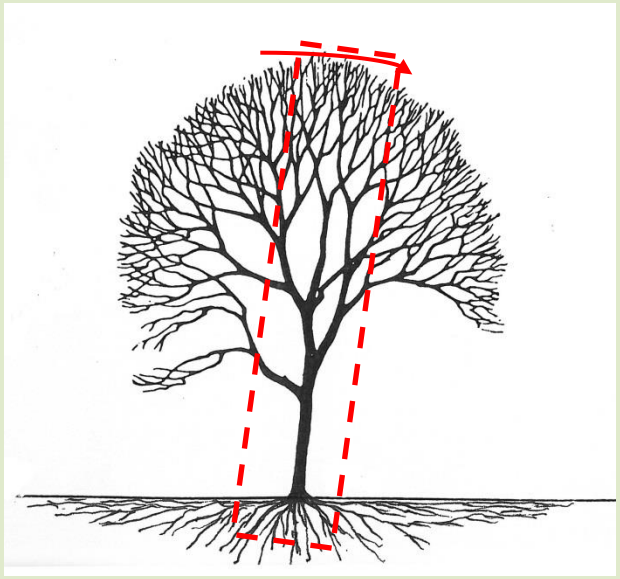
Pruning for transportation

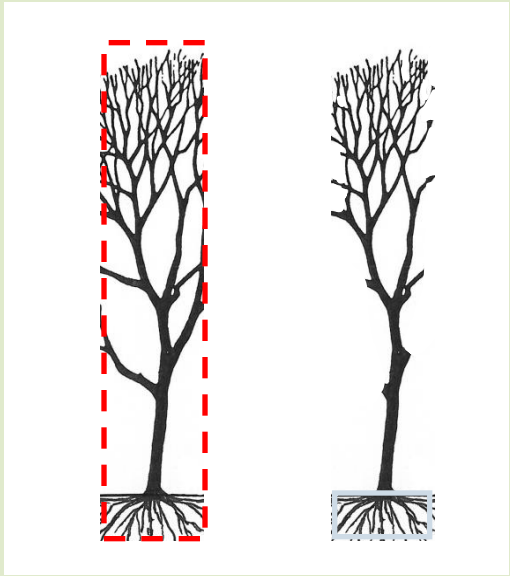
What of the original tree is it possible to fit (cut or bend) inside the box ?

How far will the form and health of the tree be compromised by doing so ?









Research Study into Transplanting Street Trees in Hong Kong

Transplanting operations

Trees moved by road to temporary receptor sites, and re-planted at ~5.0m spacing, in above ground, geofabric lined wire mesh planter boxes 1.0-1.5m high and 20-30% wider than the root ball.

Environmental conditions (temperature, wind exposure etc.) across the receptor sites was broadly identical

Arboricultural aftercare, included daily irrigation, weeding, mulching, fertilizing, and disease / pest control.

Photo courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Transplanting factors

Variables in tree transplanting that might affect success / failure

(a) Characteristics of the tree
- species
- tree size (height, trunk diameter)
- original health and form (good : fair : poor , using standard survey method)

(b) Existing growing conditions
- soil type (sandy loam : silty loam : silty clay)
- space available at planting location (pavement pits : raised planter : open ground, as a reflection of confined rooting environment)

(c) Transplanting operations
- crown pruning (% reduction in canopy volume)
- root ball ratio (trunk diameter (dbh) : root ball diameter)
- root ball depth
- time of year of first root pruning, categorised into 2 month intervals
- pruning interval (in months) (0 months : 6 months)
- time of year of transplanting, categorised into 2 month intervals
- handing (good : poor , i.e. trees that had suffered notable damage during transplanting)

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Transplanting outcomes

Success = tree making a full return to normal growth patterns.

Did not take account of the substantial reduction in form that some species suffer. If a return to previous both health and form are taken into account the success rate is likely to be lower.

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Transplanting outcomes

Key measure of transplant shock - twig elongation gauged on an annual basis, against reference specimens in the surrounding landscape

Other symptoms of transplant shock included:
- significantly reduced tree vigour
- Poor root growth /elongation
- limited new foliage growth, reduced shoot length and leaf size
- increasing degree of crown dieback (decline in canopy volume)
- desiccation / bark cracking
- little or no new root growth

Often accompanied by incidents of insect attack and fungal infection.

Measurement of twig elongation against comparable control specimens for each species (~ 300-600mm)

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Results

By the end of the third year it was possible to identify an outcome all trees

Transplant shock recovery rates were faster than anticipated. Trees either lived or died.

Species	Number	Success (no./%)	Failure (no./%)
Bombax ceiba	**57**	**54 / 94.9%**	**3 / 5.1%**
Celtis sinensis	**43**	**33 / 76.7%**	**10 / 23.3%**
Crateva unilocularis	**37**	**31 / 83.8%**	**6 / 16.2%**
Ficus benjamina	**59**	**38 / 64.4%**	**21/ 33.6%**
Ficus microcarpa	**129**	**100 / 77.5%**	**29 / 22.5%**
Melaleuca quinquenervia	**117**	**87 / 74.4%**	**30 / 25.6%**
Peltophorum pterocarpum	**42**	**27 / 64.3%**	**15 / 35.7%**
Pongamia pinnata	**25**	**20 / 80.0%**	**5 / 20.0%**
Syzygium cumini	**26**	**20 / 76.9%**	**6 / 23.1%**
Total	**535**	**410 / 76.7%**	**125 / 23.3%**

Bombax ceiba, fastest growing species, had the highest success rate. Plus majority were growing in pavement pits with the most restricted rooting environments,

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Correlation between each variable and Success/Failure

Analysis of correlation between each of the transplant variables and the outcome for each of the species

Results were based on observation of commercial operations (not under controlled conditions) so data sets tended to be skewed.

Where only a few failures in the set (*Bombax ceiba, Crateva unilocularis, Pongamia pinnata*) not possible to draw specific conclusions.

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Correlation analysis between each variable and success/failure

Variables / Success/ Failure	Original root space	Height	Trunk Diameter	Form	Health	Pruning Time	Pruning interval	Transplanting Time	Root ball depth	Root Ball Ratio	Extent of Crown Pruning	Handing
Bombax ceiba	0.146	-0.181	-0.292	0.134	0.109	-0.329*	-0.032	-0.293	-0.167	0.181	-0.147	-0.243
Ficus benjamina	0.450*	-0.466*	0.154	0.245	-0.250	-0.316*	0.455*	0.155	-0.348*	-0.252	-0.059	-0.056
Ficus microcarpa	-0.336*	-0.098	0.118	0.157	-0.001	0.332*	0.004	-0.150	0.381*	0.138	-0.049	-0.122
Melaleuca quinquenervia	-0.442*	-0.353*	-0.242	0.463*	0.150	0.500*	-0.577*	-0.389*	-0.299	0.005	-0.130	0.055
Celtis sinensis	0.165	-0.100	-0.152	0.205	0.038	-0.109	0.296	-0.337*	-0.007	0.188	-0.021	-0.203
Crateva unilocularis	-0.281	-0.269	-0.131	0.181	0.153	0.079	-0.155	0.025	-0.075	0.154	0.033	-0.041
Peltophorum pterocarpum	-0.092	0.229	0.497*	0.136	-0.043	-0.559*	0.085	0.185	0.382*	-0.206	-0.103	0.085
Pongamia pinnata	--	0.059	-0.205	0.169	0.000	--	0.102	--	-0.248	0.129	-0.329*	0.185
Syzygium cumini	-0.272	-0.559*	-0.175	-0.455*	-0.455*	-0.252	0.252	-0.110	0.041	0.146	0.127	0.234

(*) Correlation significant at the 0.01 level (2-tailed).
As the data was from practice and did not have a uniform distribution, values more than 0.3 (less than -0.3) were considered to indicate a strong linear relation and values between 0.2 and 0.3 (-0.2 and -0.3) indicate a moderate linear relationship).

Note: Distinct differences were observed between the species in the study as to which of the transplant variables was influential in the outcome of a transplanting operation.

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Regression analysis between the dependent variable and each of the independent variables for all nine species

Independent Variables	**Species**	**Original root space**	**Height**	**Trunk diameter**	**Form**	**Health**	**Pruning time**	**Pruning interval**	**Transplanting time**	**Root ball depth**	**Root ball ratio**	**Extent of Crown pruning**	**Handling**
Standardized Coefficients	-0.055	-0.084	-0.147*	0.020	0.209*	-0.128*	0.036	-0.022	-0.142*	0.105	-0.043	-0.109	-0.109

(*) Correlation significant at the 0.01 level (2-tailed).

Regression analysis indicates how the typical value of the dependent variable changed when any one of the independent variables is varied, while the other independent variables are held fixed

Research Study

Influence of tree **species**

Tree **species** was not a significant factor in determine the outcome of these transplanting operations.

Note: These trees were specifically selected for transplanting based (in part) on the known tolerance of their species to transplanting operations, so species was not expected to be a factor. This result allowed a clearer view to be formed other transplant factors

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Correlation with **original soil quality (Location)**

Overall, original root space was not significant

Ficus microcarpa and *Melaleuca quinquenervia* more likely to survive where quality of soil was poor

Converse was observed for *Ficus benjamina*.

Note: Ficus microcarpa and Melaleuca quinquenervia both have fast and adaptable rooting characteristic, and can take advantage of variable ground conditions

Photo courtesy of project team

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Correlation with **original size**

Overall, height was significant

Shorter specimens of *Ficus benjamina, Melaleuca quinquenervia* and *Syzygium cumini* had a greater chance of success.

Overall, trunk diameter was not significant

Smaller diameter specimens of *Melaleuca quinquenervia* had a better chance of survival where for *Peltophorum pterocarpum* larger diameter trees had a better chance.

Note: Age of the tree might not be as important as overall size in determining the outcome, for street trees.

Photo courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Correlation with **original form and health**

Overall, both the original form and health of the tree were significant

Note: Results affected by the uneven distribution in these data sets with the large majority of specimens originally having good form and good health, due to the way specimens had been selected for transplanting.

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Correlation with **root pruning time of year / transplanting time of year**

Overall root pruning time of year was significant

Ficus microcarpa and *Melaleuca quinquenervia* did much better if root pruned in the autumn. *Peltophorum pterocarpum*, *Bombax ceiba* and *Ficus benjamina* were more likely to survive if pruned in early spring.

Note: Findings supports other research that indicates that for successful outcome the timing of pruning needs to be set within periods of active root elongation and outside periods of active shoot growth.

Overall transplanting time of year was significant

Melaleuca quinquenervia and *Celtis sinensis* had a higher chance of success if transplanted in the autumn. There was a very much lower success rate for all trees transplanted between November and February.

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Correlation with **root pruning interval**

Overall, root pruning interval was <u>not significant</u>

Note: This indicates that the intervals adopted in the contract were appropriate for the size of tree.

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Correlation with **root ball depth**

Overall, root ball depth was <u>not significant</u>

Note: Root balls were much deeper than the roots encountered.

Increasing the depth of the root ball would not increase the amount of root captured within it, and might be counterproductive as it increases operational difficulties and chances of root ball collapse

Research Study into Transplanting Street Trees in Hong Kong

Correlation with **root ball ratio**

Overall, root ball ratio was <u>not significant</u>

No correlation was found between success / failure and root ball ratio, even though a wide range of root ball ratios were achieved

Note: This challenges idea that root ball size needs to be proportionate to tree size. The highly constrained root systems of street trees with high density of root biomass close to the trunk, results in a high proportion of root being captured within the root ball.

Root pruning operations to generate a significant mass of new fine water absorbing roots, are likely to be more important for street trees.

Photos courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Correlation with **handling**

Overall, handling was not a significant factor.

No correlation was found between success / failure and the operational handling for any of the nine species

Note: Results are also likely to have been affected by the uneven distribution in these data sets.

Photo courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Correlation with **extent of canopy pruning**

Overall extent of canopy pruning was <u>not significant</u>

Correlation between success / failure and extent of canopy pruning only for *Pongamia pinnata* which indicated a greater chance of success with less canopy pruning.

Note: This result suggests that a balance was achieved between the (high) amount of root retained and the (smaller) amount of canopy retained, and root : shoot ratios had not been adversely affect.

Research Study into Transplanting

Conclusions / Observations

Variability in the transplanting process and that the factors influencing the outcome of **transplanting operations are both species and site specific**.

Research Study into Transplanting Street Trees in Hong Kong

Conclusions / Observations

Rapid rate of recovery / failure amongst these street trees, and the individual findings relating success / failure to original rooting environment, root pruning and canopy pruning support the contention that the **characteristics that make species able to survive in the street** (i.e. adaptable fast growing rooting systems, tolerant of poor ground conditions, tolerant of canopy pruning), **also make them tolerant of being transplanted**

Photo courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Conclusions / Observations

Specific **findings relating to root ball ratio and root ball depth** suggest that the general presumption that larger root balls are better should be challenged, and that forming root balls in response to actual root patterns (narrow spread, shallow), would make transplanting a lot easier without reducing success rates.

Photos courtesy of project teams

Research Study into Transplanting Street Trees in Hong Kong

Conclusions / Observations

The **results link success and to specific time of year for both pruning and transplanting**, and that these vary from species to species. This challenges the popular opinion that certain periods of the year are good for these operations all tree species in Hong Kong. The relationship between the timing of the root and canopy pruning operations and periods of active shoot growth in each of the species was also identified as important.

Photo courtesy of project team

Research Study into Transplanting Street Trees in Hong Kong

Conclusions / Observations

The overall failure rate amongst these common street species and of tree specimens original thought suitable for transplanting, was high. This **raises questions over the efficacy of transplanting as an environmental remediation measure.**

Tree Transplanting

Research funded by General Research Grant (751602) from HKSAR Government
and generously supported by various project clients landscape contractors and practitioners