Evaluation of SPACE Structural Soil

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For

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1. Introduction

The following research paper has been prepared by Dr Martin Ely AILA for David Lawry of TREENET. The paper comprises a literature review of the different methods of assessing soil volume requirements for urban trees, and the effectiveness of a range of strategies for extending tree rooting zones in urban settings. In particular a comparison is made of the relative costs and benefits of installing SPACE structural soil as an alternative to stone-based' structural soils or commercial 'plastic root-cell' systems.

2. Trees and soils

There is a direct relationship between the size of a tree and its below-ground growing space. A tree requires an adequate soil volume to provide it with the resources necessary for growth. Craul and Craul (2006) identify the following range of soil related factors to consider in the design of the below ground space.

a) *Available soil volume for adequate root growth over the life of the tree and/or other plants, and for mechanical support.*
b) *Infiltration and available volume of soil moisture.*
c) *Water drainage of the soil itself and the drainage of the element.*
d) *Aeration of the soil.*
e) *Amount and availability of plant nutrients.*
f) *Relative heat loading of the plant.*
g) *Exposure to toxic or other harmful factors.*

Soil volume requirements can also be considered in terms of the root/shoot ratio (the ratio of the dry weight of the below and above ground parts of the tree). For most species this is in the range of 1:10 to 1:3 (Biddle 1998), and generally between 1:5 to 1:6 (Harris, Clark et al. 2004). The ratio depends on plant age, the proportion of crown decreasing as the tree matures. Conversely root volume is initially greater than crown but reverses as the tree grows. The root system can control the size of the crown and the ultimate size of the tree (Biddle 1998).

3. Required soil volumes

Traditional urban street tree planting practices have often involved digging a hole, of sufficient size to accommodate the rootball, in compacted soil which is hostile to root growth beyond the excavated tree pit. Soil surrounding tree pits is typically hostile to root growth due to severe compaction, restricting root growth to the confines of the tree pit (Kristoffersen 1999).

In 1992 Craul cited traditional street tree pit dimensions of 1.2 m x 1.2 m square by 0.6 m deep, with a rootable volume of about 0.86 m^3 (Craul 1992).Many tree pits were much smaller than this, some as small as 0.6 m x 0.6 m and 0.9 m deep (0.32 m^3 volume), containing very poor specimens. Urban (1996) suggests that these planting specifications developed from tree planting practices on large estates with good soil, but are inappropriate for planting in city centres.

Urban and others describe such tree pits as tree 'tombs' or 'coffins'. The effects of restricted rooting volume on tree size, growth rate, health and mortality have been noted by a number of observers (Krizek and Dubik 1987; Kopinga 1991; Urban 1996; Schwets and Brown 2000). Street trees must often survive with a fraction of the below ground resources required to grow to maturity. They are therefore vulnerable to resource deficiencies, especially water, unless provision is made for alternative soil resources (Lindsey and Bassuk 1992).

Published estimates of required soil volumes are usually of two main types. Some are empirically based on observations of existing urban trees (Helliwell 1986; Urban 1989). Others are based on the design of soil volumes to meet the water demands of trees, including soil volume and irrigation for containerized plantings (Lindsey and Bassuck 1991).

Estimates tend to vary widely due to differences in soils, climate and assumptions regarding tree species and size. It is also difficult to predict how tree roots will colonize planting sites and increase accessible soil volumes in urban situations (Frank 2003). Table 1 presents a summary of a number of such estimates from various sources.

Table 1: Estimates of required soil volumes.

Source	Estimate	Notes
(Perry 1985)	An area of approx. 6.5 m x 6.5 m x 0.45 m deep (19 m^3).	For a 75 mm calliper tree to grow quickly to 300 mm calliper.
(Kopinga 1985)	7 m^3	Minimum, not optimum, for growth of individual elms in The Netherlands.
(Helliwell 1986)	200 m^3 for a 20 m tree with 12 m crown.	For very large trees in southern England. Anecdotal rule-of-thumb method.
(Urban 1989)	Available soil, minimum 8.5 m^3 for tees with adequate vigour, 17 m^3 for healthiest trees.	Examined nearly 1500 trees in five eastern US cities.
(Urban 1990)	Planting sites less than 3 m^3 cannot sustain long term growth. Increased surface area more beneficial than increasing depth below 600 mm, except for large growing trees.	Examined thirteen 11-27 year old plantings in US cities.
(Lindsey and Bassuck 1991)	On average 0.06 m^3 of soil volume for every 1 m^2 of crown projection.	Based on measuring transpirational loss from mature trees without supplementary watering. Applies in most US climatic zones except desert regions with high evaporation and little rainfall.
(Urban 1992)	Produced graph which quantifies relationship between tree size (trunk diam. and crown projection) and required soil volumes.	Averaged data from Perry (1982), Kopinga (1991) and Lindsey & Bassuck (1991).
(Lindsey and Bassuk 1992)	5 m^3 To sustain a 'typical specimen tree' through summer.	Empirical relationship between evaporation and tree size.
(Urban 1996)	0.03 m^3 of useable soil for every 0.2 m^2 of mature canopy.11 m^3 (if other soil in locality with some capacity for root development).	
(DeGaetano 2000)	Varies.	Refined Lindsey and Bassuk (1991) method using daily, rather than average, climatic data to estimate soil volumes and irrigation specifications.
(Urban 2008)	34 m^3 for a large shade tree (22 m^3 minimum).	
(Landcom 2008)	5-15 m^3 for small tree (4 m diam. canopy) 20-40 m^3 for medium tree (9.8 m. diam. canopy) 50-80 m^3 for large tree (16 m diam. canopy). Assumes 1m deep, unobstructed root volume.	Street Tree Design Guidelines for new subdivisions in subdivisions in NSW.
Source: Compiled from various sources as stated.		

James Urban in the United States has produced a widely published graph which attempts to quantify the relationship between tree size and required soil volume. Urban averaged data from a number of sources (Perry 1982; Kopinga 1991; Lindsey and Bassuck 1991) to relate soil volume to tree size as measured by both crown area and trunk diameter. The graph, though not precise, gives a useful indication of approximate soil volume requirements. The graph has been reproduced in a number of publications including the 2007 edition of *Landscape Architecture Graphic Standards* (Urban 2007).

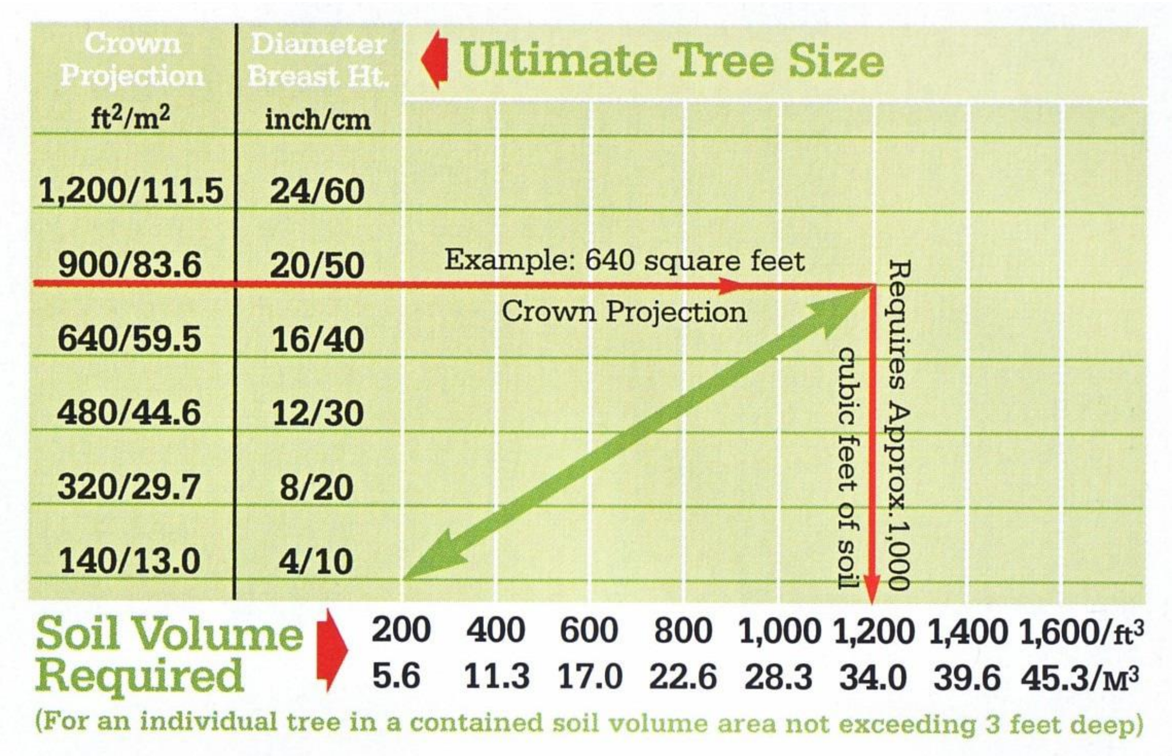

Figure 1: Soil Volume Requirements. Source (Urban 1996).

Urban stresses that soil quality is critical in calculating useable soil volumes and that useable volume can include soil sources that the tree can access beyond the actual tree pit. Urban defines soil volume as all the soil that is available to the roots of a tree which is of a suitable quality for root growth (well drained, uncompacted and possessing adequate pore space). The maximum depth for this calculation is usually 75 cm. Similarly Craul (1992) emphasizes the need to consider other soil limiting factors as well as soil volume. Never-the-less the graph does indicate that soil volumes provided in a typical urban tree pit tend to be well below the optimum requirements.

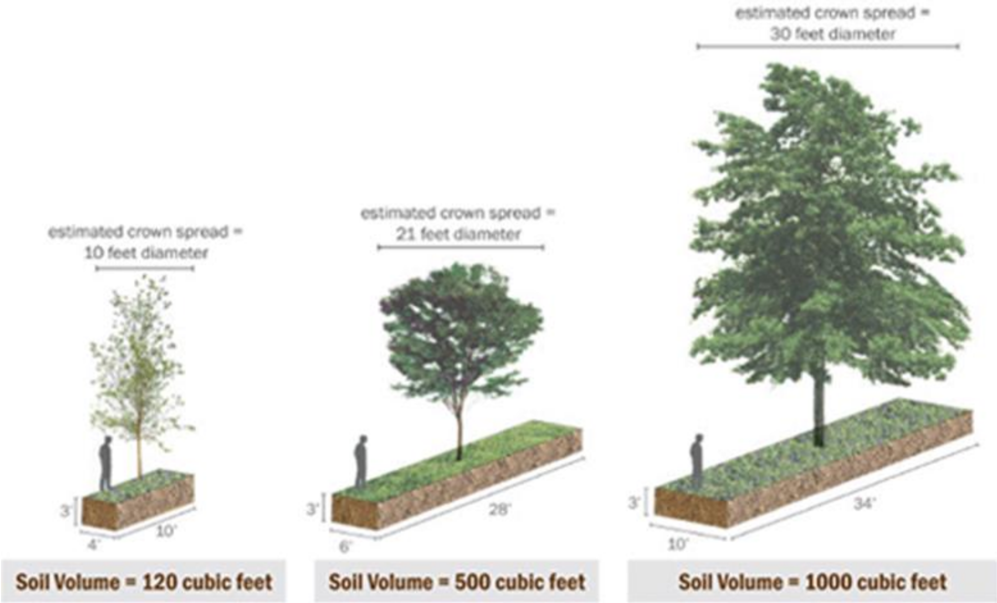

Figure 2: Illustration of tree size and soil volume relationships.

The Crown Projection Method (CPM) is a popular method for estimating soil volumes. Researchers at the Urban Horticulture Institute at Cornell University developed a step-by-step method which assesses crown projection (drip line) and allows 0.6 m^3 of soil for every m^2 of crown projection (allowing 1m deep root depth). Watson and Himelick also use the CPM but suggest that root space should be 60 cm deep within the crown projection (Watson and Himelick 1997). This is supported by Gilman (Gilman 1997)(1997) who found that fine root density is greater within the canopy than beyond. The formula can be adjusted for columnar and fastigate tree shapes, using mature tree height as the basis of the equation.

In Australia Ross Clark (2003) uses a simple formula using tree calliper as percentage of tree height:

- Soil volume (m^3) = Height (m) x Calliper (mm) divided by 100.

Clark's formula is a modification of CPM which provides an approximate guide only, but is easy to apply.

A number of local government and other authorities have developed minimum soil volume standards for urban tree planting. A recent example in Australia are the Landcom *Street Tree Design Guidelines* for new subdivisions in NSW (Landcom 2008). These specify minimum soil volumes (assuming 1 metre unobstructed depth) of:

- 5-15 m^3 for small tree (4 m diam. canopy).
- 20-40 m^3 for medium tree (9.8 m. diam. canopy).
- 50-80 m^3 for large tree (16 m diam. canopy).

A common requirement in a number of North American cities is for a minimum volume of 30 m^3 of high quality soil per tree in a single planter, or 15 m^3 per tree if in a shared trench (Marritz 2012).

4. Options for extending tree rooting zones

In recent years a number of innovations have been developed to extend tree rooting zones and available soil volumes in urban settings. These include:

- Suspended pavements.
- Structural soils.
- Plastic root cells.

Suspended pavements

An alternative to the use of structural soils is the installation of 'suspended pavement' where the paving is cantilevered over the tree pit or soil trench (Roberts et al. 2006). Tree roots can then grow in loose, uncompacted soil, and as the pavement does not contact the soil below, a void can be created which allows water and gaseous exchange. Suspended pavements, in the form of cantilevered slabs, however, are limited in the dimensions they are capable of spanning, and are best suited to relatively narrow width root trenches.

Structural soils

In the past two decades engineered or 'structural soils' have been developed in the United States, Europe and Australia. These represent an attempt to extend the tree rooting zone beyond the confines of the tree pit, below the surrounding hardscape in highly developed urban settings.

Plastic root cells

In the last 5-10 years, systems of plastic cells have been developed which provide load bearing support for pavements, while creating a matrix of soil filled voids which can support root growth.

5. Overview of structural soils

Structural soils are one attempt to reconcile the conflicting requirements of providing both the necessary engineering support for pavements, while still providing a satisfactory growing medium for tree roots. Traditionally there has been a conflict between these engineering and biological requirements. Pavement sub-surfaces need to be compacted to meet the specified load-bearing requirements. However compacted soils do not provide a satisfactory growing medium for tree roots.

Engineering requirements are generally for sub-surfaces to be compacted to within 95% of their peak density, to prevent settling under design loads (Roberts, Jackson et al. 2006) Road and pavement base layers are also usually gravel or sand with little silt or clay, and a low capacity to retain water or nutrients (Bassuk, Grabosky et al. 1998). The biological requirements for root growth, however, include: low bulk density between 1.45 for clay and 1.85 for sand; a distribution of pore sizes providing adequate storage capacity for available water, and for good drainage and aeration; and sufficient fertility to provide an adequate supply of macro and micro-nutrients (Roberts, Jackson et al. 2006).

It is important to recognize that structural soils comprise a 'family' of soils rather than a single commercial soil. And can include: natural compaction resistant sandy loams; sand based Amsterdam tee soil; lightweight porous-aggregate mixes; and crushed stone and soil mixes.

Perhaps the most widely recognized engineered soils are those known as 'skeletal' or 'gap graded' soils, in which interlocking crushed stones provide a load bearing matrix, while the voids between the stones are filled with loosely compacted soil which provides a growing medium for tree roots. The best known skeletal soil, known as CU-Soil, was developed in the 1960s at Cornell University in the United States (Grabosky and Bassuk 1995).

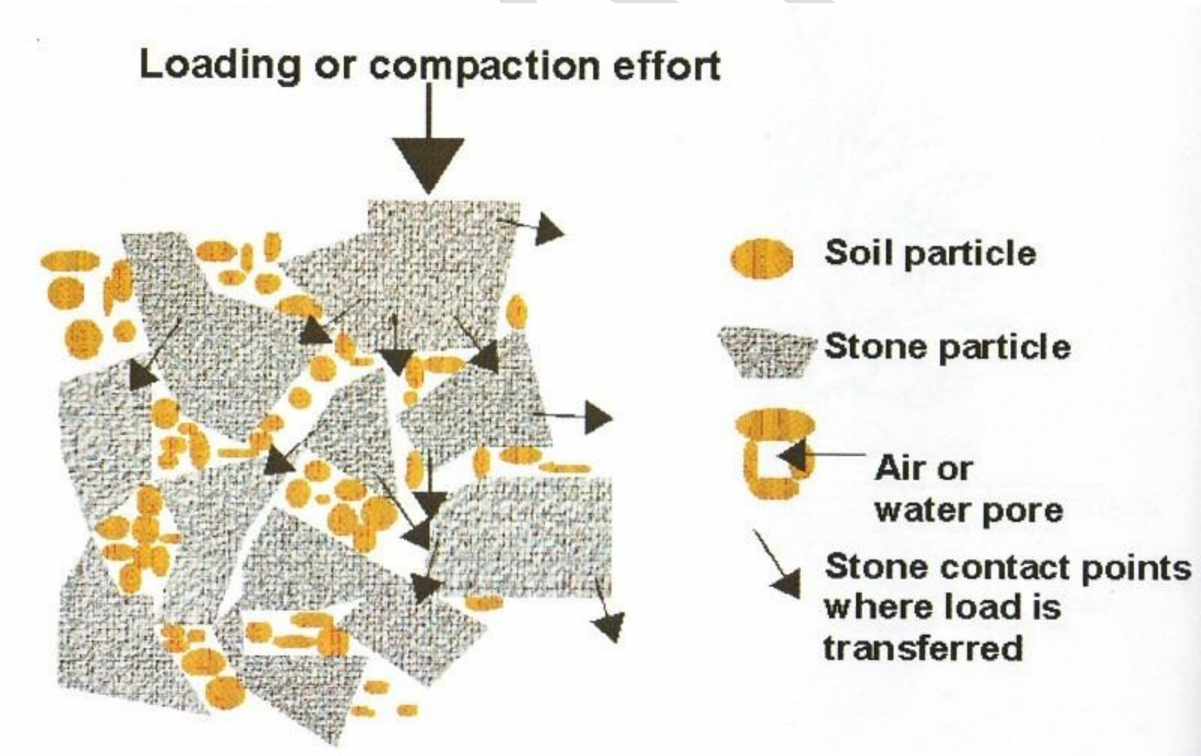

Figure 3: Skeletal Soil Concept. Source (Roberts, Jackson et al. 2006)

The soil comprises: a stone component of 20-35 mm angular crushed stone (80%); a soil component of preferably clay loam soil, with 2-5% organic matter, occupying the voids between the stones (20%);

and a small amount of hydrophilic gel to help bind the stones during transportation. An appropriate ratio of stone to soil (approximately 13-22% soil by weight) is critical to success, as excess soil will prevent the formation of a stable soil skeleton after compaction, as the stones must physically touch and interlock, transferring loads at the contact points (Grabosky, Bassuk et al. 1998a). Soil and stones are mixed prior to installation in a rotary mixer. During installation the stone matrix is compacted to within 95% of peak bulk density and a CBR greater than 50.

The tree-lined entrance to Stadium Australia at the Sydney 2000 Olympics site was an early high profile application of structural soils, in conjunction with permeable paving (Horne 1988; Selvey 1998; Ferguson 2005). The soil was based on the CU-Soil mix, but used smaller (45mm) gravel stones premixed with filler soil (Leake 2003). Care was taken to add only enough filler soil to occupy 50% of the void space. The premixed soil is available in several blends through Benedict Soil and Gravel Pty Ltd in Sydney and has since been used in a number of city centre projects in Sydney.

A rock-based structural soil developed by Jeffries soils is similar to the CU Soil, using aggregate and heavy loam. Jeffries does not currently use a tackifier in the production of this product, but mix to order and deliver in a slurry form.

As mentioned above, however, structural soils comprise a whole family of soils rather than a single rock-based soil. In Adelaide, South Australia, David Lawry has developed a structural soil utilizing recycled municipal water treatment residues. This colloidal based structural soil is known as SPACE (Structural Permeable Aerated Compacted Earth). Unique to Adelaide there are now a number of successful trial sites around the city where SPACE has been installed beneath pavements. SPACE soil was recently installed in a 60 m x 6 m, by 600-800 mm deep trench below paving at the Adelaide Central City Bus Terminal, to provide a growing medium for twelve Spotted Gums (*Corymbia maculata*) (Kelly and Stevens 2008). Attributes of SPACE soil include:

- Low Bulk Density (0.9 t/m^3 uncompacted, 1.0 t/m^3 at >95% compaction).
- Low penetration resistance for roots.
- High structural strength (CBR 15 -35).
- High Air Filled Porosity > 30% at field capacity.
- High Cation Exchange.

6. Critique of stone-based structural soils

Initial testing of CU-Soil at Cornell's Urban Horticulture Unit (UHI) indicated favourable results in terms of tree growth, vertical root distribution, and root and shoot elongation(Grabosky, Bassuck et al. 2001; Grabosky, Bassuck et al. 2002). In particular tree roots were observed to grow twice as deep in structural soils as in a standard soil (Grabosky, Bassuk et al. 1998a). In the last few years, however, a number of criticisms have been made of structural soils which are based on a stone matrix. One of the main criticisms is that they provide proportionally small volumes of growing medium, which is typically less than 20% of total volume (the remaining 80% comprising inert stones) (Connery 2009).

The primary reason for using structural soils is to increase available soil volume. Stone based structural soils are limited in the amount of soil that can be provided due to the large amount of rock in the mix required to meet the structural requirements. Trees generally grow well until the amount of soil in the mix is exhausted, the trees must then either find a way out of the soil provided or they will begin to decline. When calculating the volume of stone based structural soil to use for each tree, and making predictions on the effect of the material on tree growth, only the amount of soil in the mix, (approximately 20% of the total mix volume) should be considered in the calculation (Urban 2011). 100 cubic metres of stone based structural soil will therefore provide only 20 cubic metres of available loam soil.

Other criticisms include the need for long term monitoring of tree growth in terms of possible limitations in terms of water, fertility and the ability of larger roots fitting through the voids in the stone matrix (Harris, Clark et al. 2004; Roberts, Jackson et al. 2006).

Figure 4: Stone based structural soil: 80% rock, 20% soil. Source (Urban 2011).

Figure 5: SPACE structural soil with 100% rootable soil.

In the first edition of their book *Sustainable Landscape Construction,* Thompson and Sorvig (2000) gave qualified support to stone based structural soils as an innovative tree planting practice. However in the 2008 edition they provide a detailed critique of structural soils, especially the Urban Horticulture Institute patented CU-Soil). Issues raised include handling and mixing, with the patented soil requiring licensed installers. Having a single specification however does not account for local conditions and one mix may not suit all conditions. Mixing off-site ensures quality control, however the mix may segregate during transportation. On the other hand, mixing on site may not achieve the required specification, and most specifications use weight rather than volume as a measure which is often impractical in the field (Connery 2009). Thompson and Sorvig (2008) also report criticisms by Philip Craul that sand-based mixes are horticulturally superior to, less costly than, and almost as good in structural terms as CU-Soil. While CU-Soil achieves about 95% Proctor density (the standard US highway base course requirement), other structural soil mixes can achieve 85-90%, which is widely accepted in Europe, 85% is also the accepted standard under porous pavements (Ferguson 2005).

7. Cost comparisons

Table 2 provides a comparison of the supply and installation costs for three methods of extending the rooting zones of urban trees: rock based structural soil, plastic root cells and SPACE structural soil. The costs estimates include excavation, supply of materials including filler soil, and installation in accordance with the specific requirements for each system. The cost estimates exclude the supply and installation of trees, pavements and substate, and other tree pit components. Costs per cubic metre are provided for installation of the complete system, and for available soil volume provided (20% for stone based structural soils, 94% for plastic root cells, and 100% for SPACE structural soil.

Table 2: Comparison of rock based structural soil, plastic root cells and SPACE structural soil.

	Cost-supply/ m^3	Cost-Install/ m^3	Total cost/ m^3	Available soil volume (%)	Cost/ m^3 available soil	Notes
Rock based structural soil	$210.00	$400.00	$610.00	20%	$3,050.00	Supply includes stone/filler mix, 500mm depth. Installation in 150mm compacted layers. Source: City Green Tree Pit Cost Comparison Calculator.
Plastic root cell	$360.00	$100.00	$460.00	94%	$489.00	Assumes SC250-30 *StrataCell* Structural Soil Cell and filler soil 2 layer option 500 mm depth. Source: City Green Tree Pit Cost Comparison Calculator.
SPACE structural soil	$200.00	$50.00	$250.00	100%	$250.00	Source: David LawryTREENET.
Note: All calculations exclude tree, pavement, underdrainage and other tree pit components						

It is evident that stone based structural soils are the most costly when assessed on the basis of the actual volume of available soil provided, as opposed to the volume of the soil' rock matrix. Installation costs also appear to be high, given that the mix is prepared off-site. Plastic root cells compare favourably with stone based structural soils when considering available soil provided (94%). SPACE soil appears to be most cost effective with a low unit supply costs, 100% available soil and comparatively simple installation costs. Other factors for consideration not included in the matrix include system flexibility, quality control and long term viability of each system.

8. Summary and conclusions

Urban trees require an adequate volume of high quality soil to survive and grow to maturity, thereby maximizing the benefits they can deliver to the city. A number of methods have been developed for calculating required soil volumes of varying complexity. It is evident that these soil volumes are difficult to provide in confined urban settings surrounded by compacted soils. A number of techniques have been developed in recent years to extend tree rooting zones below paved surfaces, providing a favourable environment for tree root growth while still supporting required vehicle loads. Structural soils are one method of doing so, and comprises a family of soils, the best known being rock based soils which provide 20% by volume of loam soil within an 80% matrix of rocks which provide structural support. The viability of stone based structural soils however has recently been queried for a number of reasons including the low percentage of actual rootable soil provided. This is highlighted by cost comparisons based on the actual volume of useful soil provided. An alternative structural soil, SPACE composed of colloidal reservoir wastes, provides a 100% volume of rootable soil and would appear to provide a more cost effective alternative to stone based structural soils, while comparing favourably with recent plastic root cell systems.

References

Bassuk, N., J. Grabosky, et al. (1998). Structural Soil: An Innovative Medium Under Pavement That Improves Street Tree Vigor. ASLA (American Institute of Landscapoe Architects) Annual Meeting Proceedings.

Biddle, P. G. (1998). Tree Roots and Foundations. Farnham, UK.

Clark, R. (2003). Specifing Trees, NATSPEC.

Connery, K. (2009). "Soils under the city: New ideas take root." Landscapes.

Craul, P. J. (1992). Urban Soils in Landscape Design. New York, John Wiley & Sons, Inc.

Craul, T. A. and P. J. Craul (2006). Soil Design Protocols for Landscape Architects and Contractors. Hoboken, New Jersey, John Wiley & Sons Inc.

DeGaetano, A. (2000). "Specification of soil volume and irrigation frequency for urban tree containers using climatic data." Journal of Arboriculture **26**(3): 142-151.

Ferguson, B. K. (2005). Porous Pavements. Boca Raton, Florida, Taylor and Francis.

Frank, S. (2003). Planting site assessment leads to species selection. Urban Tree Planting Seminar, Melbourne, Treelogic.

Gilman, E. F. (1997). Trees for Urban and Suburban Landscapes, Delmar Publishers.

Grabosky, J., N. Bassuck, et al. (2001). "Shoot and root growth of three tree species in sidewalks." Journal of Environmental Horticulture **19**(4): 206-211.

Grabosky, J., N. Bassuck, et al. (2002). "Preliminary findings from measuring street tree shoot growth in two skeletal soil installations compared to tree lawn plantings." Journal of Arboriculture **28**: 106-108.

Grabosky, J. and N. Bassuk (1995). "A new urban tree soil to safely increase rooting volumes under sidewalks." Journal of Arboriculture **21**(4): 187-201.

Grabosky, J., N. L. Bassuk, et al. (1998a). Structural Soil Investigations at Cornell University. The Landscape Below Ground II:Proceedings of an International Workshop on Tree Root Development in Urban Soils, San Francisco ,CA, International Society of Arboriculture.

Harris, R. W., J. R. Clark, et al. (2004). Arboriculture: Integrated Management of Landscape Trees, Shrubs and Vines. Upper Saddle River, NJ, Prentice Hall.

Helliwell, D. R. (1986). "The extent of tree roots." Arboricultural Journal **10**: 341-347.

Horne, M. (1988). Green on red: eco paving and structural soils for the plaza figs. Re: Making Landscape. The Australian Institute of Landscape Architects 1988 National Conference., Sydney, The Australian Institute of Landscape Architects.

Kelly, J. and D. Stevens (2008). Central City Bus Terminal Tree Planting Project. Adelaide, Arris Pty. Ltd.

Kopinga, J. (1985). Site preparation practices in the Netherlands. METRIA:5, Proceedings of the Fifth Conference of the Metropolitan Tree Improvement Alliance., The Pennsylvania State Univ. Press,University Park.

Kopinga, J. (1991). "The Effects of Restricted Volumes on Soil on the Growth and Development of Street Trees." Journal of Arboriculture **17**(3): 57-63.

Kristoffersen, P. (1999). "Growing trees in road foundation materials." Arboricultural Journal **23**(1): 57-76.

Krizek, D. T. and S. P. Dubik (1987). "Influence of water stress and restricted root volume on growth and development of urban trees." Journal of Arboriculture **13**: 47-55.

Landcom (2008). Street Tree Design Guidelines. NSW, Landcom.

Leake, S. W. (2003). "Structural soils:some technical aspects." The Australian Arbor Age **7**(5): 6-10.

Lindsey, P. and N. Bassuck (1991). "Specifying soil volumes to meet the water needs of mature urban street trees and trees in containers." Journal of Arboriculture **17**(6): 141-149.

Lindsey, P. and N. Bassuk (1992). "Redesigning the urban forest from the ground below:a new approach to specifying adequate soil volumes for street trees." Arboricultural Journal **16**(1): 25-39.

Marritz, L. (2012) Municipalities With Soil Volume Minimums for Trees. DeepRoot Blog

Perry, T. O. (1982). "The Ecology of Tree Roots and Practical Significance Thereof." Journal of Arboriculture **8**(8): 197-211.

Perry, T. O. (1985). Planting site with a 3 inch caliper tree with room to grow. METRIA:5, Proceedings of the Fifth Conference of the Metropolitan Tree Improvement Alliance.

Roberts, J., N. Jackson, et al. (2006). Tree Roots in the Built Environment. Norwich, The Stationary Office.

Schwets, T. L. and R. D. Brown (2000). "Form and structure of maple trees in urban environments." Landscape and Urban Planning **46**: 191-202.

Selvey, J. (1998). Structural soils: a technical perspective. Re-making Landscape,The Australian Institute of Landscape Architects 1988 National Conference, Sydney, The Australian Institute of Landscape Architects.

Thompson, I. H. and K. Sorvig (2008). Sustainable Landscape Construction: A guide to green building outdoors. Washington D.C., Island Press.

Thompson, J. W. and K. Sorvig (2000). Sustainable Landscape Construction:A guide to green building outdoors. Washington D.C., Island Press.

Urban, J. (1989). "New Techniques in Urban Tree Planting." Journal of Arboriculture **15**(11): 281-284.

Urban, J. (1990). Evaluation of tree planting practices in the urban landscape. Proceedings Fourth Urban Forestry Conference, Washington D.C., American Forests.

Urban, J. (1992). "Bringing Order to the Technical Dysfunction within the Urban Forest." Journal of Arboriculture **18**(2): 85-90.

Urban, J. (1996). "Room to grow." Landscape Architecture **86**(3): 74-79.

Urban, J. (2007). Tree planting in urban areas. Landscape Architecture Graphic Standards. L. J. Hooper. Hoboken, New Jersey, John Wiley & Sons, Inc.: 361-363.

Urban, J. (2008). Up by Roots. Champaign, ILL., International Society of Arboriculture.

Urban, J. (2011) Comparing Silva Cells and Structural Soil. DeepRoot Blog

Watson, G. W. and E. B. Himelick (1997). Principles and Practice of Planting Tree and Shrubs. Savoy, Illinois, International Society of Arboriculture.