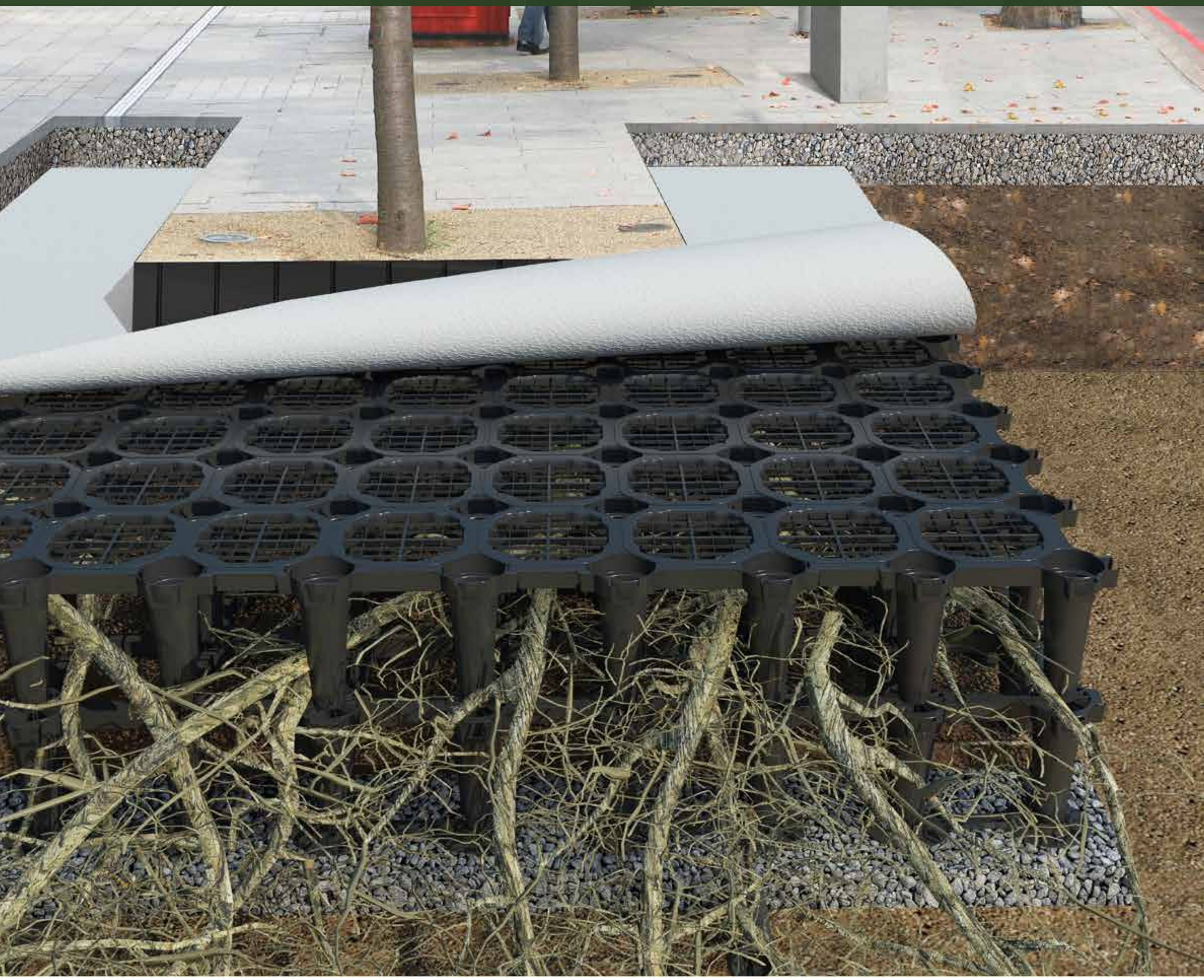
Citygreen Specifier Reference Manual

Soil Vault Systems for Healthy Trees

Solutions



Products

This booklet forms part of the Citygreen Specifier Reference Manual which aims to support the Citygreen mission – Transforming Quality of Life by Creating Innovative Solutions for Urban Spaces.

Designed to assist landscape architects, civil engineers and consulting arborists, each booklet addresses a key aspect of achieving healthy tree growth in urban contexts. Scientific and technical issues are outlined, then linked with available solutions and implementation. Scientific and technical concepts are outlined clearly in the Solutions section, then linked with best available products in the Products section.

citygreen®
URBAN LANDSCAPE SOLUTIONS


am - 6.30 pm
aturday
am - 1.30 pm
LIVEBAIT
Carlsberg

1. Soil Vault Systems for Healthy Trees

Key Issues

Trees require an adequate supply of loose, well aerated, moist and uncompacted soil in order to thrive. These conditions enable the tree's roots to obtain nutrients, oxygen and water – all essential for healthy tree growth.

Fig 2.1.1 & 2.1.2

Fig 2.1.1 & 2.1.2 - Trees are frequently observed in cities either failing in the face of hostile growing conditions, or surviving and causing damage to pavements.

The availability of space for tree roots to develop is crucial to the tree's ability to grow and stay healthy. In the natural environment, the roots of a growing tree will extend far into the surrounding soil to more than twice the width of the mature tree's canopy.

Fig 2.1.3 - The availability of space for tree roots to develop is crucial to the tree's ability to grow and stay healthy. In the natural environment, the roots of a growing tree will extend far into the surrounding soil to more than twice the width of the mature tree's canopy.

Via the roots, trees obtain nutrients from soil, but the roots also need the oxygen and water that occupy voids between soil particles. In uncompacted soil, voids are abundant.

For trees in hard surfaced areas, a fundamental conflict exists between maximising the soil volume available for tree rooting while also providing a stable base for roads and pavements. If soil is treated as a structural material and required to bear the load of pedestrians, building and roadways, it will be consolidated to the point that air and water are excluded and insufficient space is available for roots to grow. Fig 2.1.4

Tree roots are opportunistic, seeking out favorable growing conditions. To satisfy the needs of the tree, roots will explore the space below permeable pavements where moisture will be trapped, oxygenated sand layers, moist conditions in service trenches, cracks in road pavements and curbs.

Trees growing in typical urban 'tree boxes' are usually surrounded by compacted soil. This often leads to the roots seeking out the space between the compacted soil and the overlying pavement, where air and water are present, which then causes footpath heaving. Fig 2.1.5

If the tree roots cannot expand into the surrounding soil, they continue to grow until they have filled up the available space.

When the tree's needs for nutrients, air and water can no longer be met, the health of the tree will begin to decline and it will eventually die. Trees grown in these conditions rarely reach their full growth potential and cannot provide the wide range of benefits that mature, healthy trees have to offer.

Tree roots are opportunistic, seeking out favorable growing conditions. Moisture trapped beneath impermeable pavements, oxygenated sand layers, moist conditions in service trenches, cracks in road pavements and curbs- these are some areas that tree roots will explore to satisfy the life needs of the tree.

Wildlife and biodiversity—

"Urban forests help create and enhance animal and plant habitats and can act as "reservoirs" for endangered species (Howenstine 1993). Urban forest wildlife offer enjoyment to city dwellers (Shaw et al. 1985) and can serve as indicators of local environmental health."

(VanDruff et al. 1995).

Sustaining America's Urban Forest

Fig 2.1.4 - Pavement damage caused by shallow rooting.

Fig 2.1.5 - Insufficient soil volumes produce damaging, shallow roots.

How Much Soil Do Healthy Trees Need?

Resistance of soil to root penetration, or soil compaction, will affect tree root growth.

(Above) Fig 2.1.6 - Exposed tree root system showing shallow penetration due to heavy, compacted sub soils.

The old method of providing an area the size of the pavement opening is clearly insufficient and commits the tree to an untimely death or results in a life time of costly pavement repairs.

Careful assessment needs to be done of the above and below ground space required for each tree to reach its mature size. Various methods, described below, may be used to calculate the below ground space required for healthy root growth and thus the desirable soil volume.

As a general rule feeder roots grow in the top 150/6”-300mm/12” of the soil. This feeder zone can extend two to seven times the diameter of the canopy drip line. Major structural roots may penetrate to greater depths. All trees must be protected from compaction in the feeder zone.

Fig 2.1.6 & 2.1.7

Fig 2.1.7 - Tree root systems include sensitive root tips and minute root hairs, as well as structural roots.

Soil quality—

“Trees and other plants help remediate soils at landfills and other contaminated sites by absorbing, transforming, and containing a number of contaminants.”

(Westphal and Isebrands 2001).

Sustaining America’s Urban Forest

(Above) Fig 2.1.8 - Multiply Projected Mature Canopy Area x 0.6 meters for target soil volume.

"Nationally, urban forests in the United States are estimated to contain about 3.8 billion trees, with an estimated structural asset value of $2.4 trillion."

United States Department of Agriculture Forest Services

Mature Canopy Method

Probably the simplest method for calculating soil volume is to estimate the projected canopy area of the mature tree then multiply by a depth of 0.6 meters/2 feet.

Fig 2.1.8

Mature Trunk Caliper Method

Trunk diameter is another predictor of root spread. For young trees [less than approximately 20cm/8 inches in diameter] the ratio of root radius to trunk diameter has been found to be about 38:1. Thus a 15cm/6 inches diameter tree at maturity can have a root system that extends nearly 6m out from the trunk.[1]

1. Susan D. Day and P. Eric Wiseman, At the Root of it, Arborist news 2004 www.isa-arbor.com

As a guide

- for large trees, allow 10 meters/33 feet for canopy development
- for medium trees, allow 6 meters/20 feet for canopy development
- for screens, shelter belts or park group planting, allow 3 meters/10 feet
- allow 2.5 meters/8 feet as an absolute minimum in intensive urban developments

Suggested soil volumes

Suggested soil volumes at a minimum are:

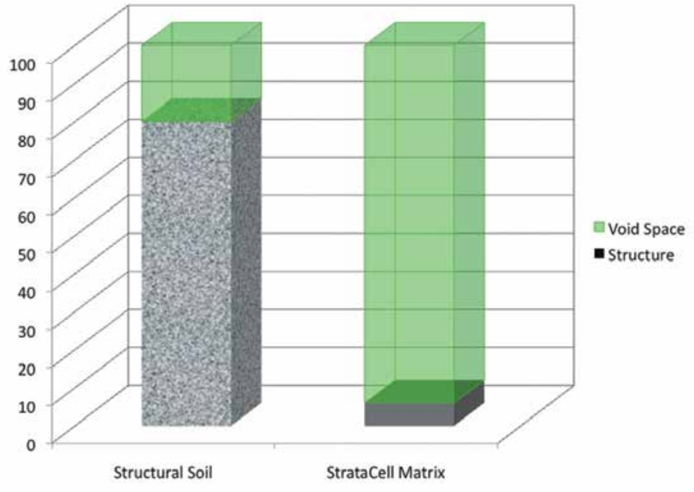
Small tree	5-15 m³/6.6 – 20 yd3
Medium tree	20-40 m³/26-52 yd3
Large tree	50-80 m³/65-104yd3

NOTE: For a comprehensive soil volume and treepit costing tool, visit https://citygreen.com/treepit-costing-tool/

Ultimately, tree size is relative to available soil volume, oxygen and nutrients in the soil and moisture holding capacity, besides genetic and environmental factors.

"There are over 6 million street trees in California and these trees are associated with approximately $70 million in expenditures to remedy conflicts between root growth and hardscape. This is a conservative estimate because it does not include repair costs for damage to irrigation and water meters, sewer lines, building foundations, parking lots, and pavement on private property. Although data are lacking, a full accounting of repair costs associated with trees on private lands as well as along streets in California would probably exceed $100 million."

Journal of Arboriculture 26(6): November 2000



Avoiding Soil Compaction

'Structural soil vaults', and before that 'structural soil', have been devised to address this dilemma of providing uncompacted soil for the trees while allowing durable roads and pavements to be built.

Early methods focused on a rock and soil mixture known as *structural soil* to provide pavement support, while permitting some root growth beneath the pavement. Since then, structural cells have moved this principle forward by replacing the rock (which had been 80% of total volume) with engineered modules (6 - 8% of volume).

Structural Soil

Structural soil comprises large gap graded gravel mixed with a horticultural soil, compacted to 95% of peak density. The gravel compacts to provide the weight bearing capability while the soil, occupying at most 40%, provides for the needs of the tree.

This method has been used with some success however there are extensive considerations to deal with including very specific requirements for the aggregate, precise calculations of voids, tree root diameters and compaction, consideration of climatic factors, choice of filler soil, mixing and compaction methods and measuring. A tendency to soil alkalinity over time limits the choice of tree that can be grown, while subsoil drainage, aeration and feeding are further requirements. Finally the level of compaction required to provide pavement support seriously restricts the development of mature, woody tree roots.

Fig 2.1.9 - High strength engineered soil cells permit large trees to be grown in road islands.

Structural Soil Vaults, Or Root Cells

Structural soil vaults, or root cells, are modular units that assemble to form a skeletal matrix, situated below pavement level, to support the pavement load while providing a large volume of uncompacted soil within the matrix structure for root growth.

Various designs are available on the market providing from 90% to over 94% of space for soil. Different designs address the need for strength while maximising available space for roots as well as for common conduits and service pipes.

Industry professionals are increasingly insisting on the use of structural vaults. They recognise that while structural vault technology builds upon the earlier structural soil concept, it is clearly superior in performance. Not only is vastly more soil made available to the tree, installation is straight forward and avoids the need for the extensive calculations and testing required for the use of structural soil.

Fig 2.2.0 - Soil volumes beneath urban roads can support healthy trees.

Trial Report

Fig 2.2.1 - Bartlett arboretum

Study Reveals The Fastest Way To Grow Larger, Healthier Urban Trees

At Citygreen, we love science. Since 2011, we've researched, developed and refined our range of sustainable urban landscape solutions to withstand rigorous testing – and produce outstanding results. So, when our Stratacell structural soil system became the subject of a study comparing the performance of soil treatments under concrete paving, we were keen to see the findings.

The study, entitled 'Comparison of Soil Treatments Under Concrete Pavement' was conducted by Thomas Smiley, James Urban and Kelby Fite at the Bartlett Tree Research Laboratory in Charlotte, North Carolina. It examined variations of the two main approaches that have been developed to provide rooting space for trees in urban areas – supported pavement and structural growing media.

Overall, the study found that structural load bearing modules (like Citygreen Stratacell™ and Stratavault™ systems) grow the largest, healthiest trees in the fastest time. It also highlighted the superior all-round performance of these systems compared to others.

Study Goals

The purpose of the study was to compare the growth of trees in different supported pavements and structural growing media. The aim was to determine which methodology would produce the largest, healthiest trees in the shortest time.

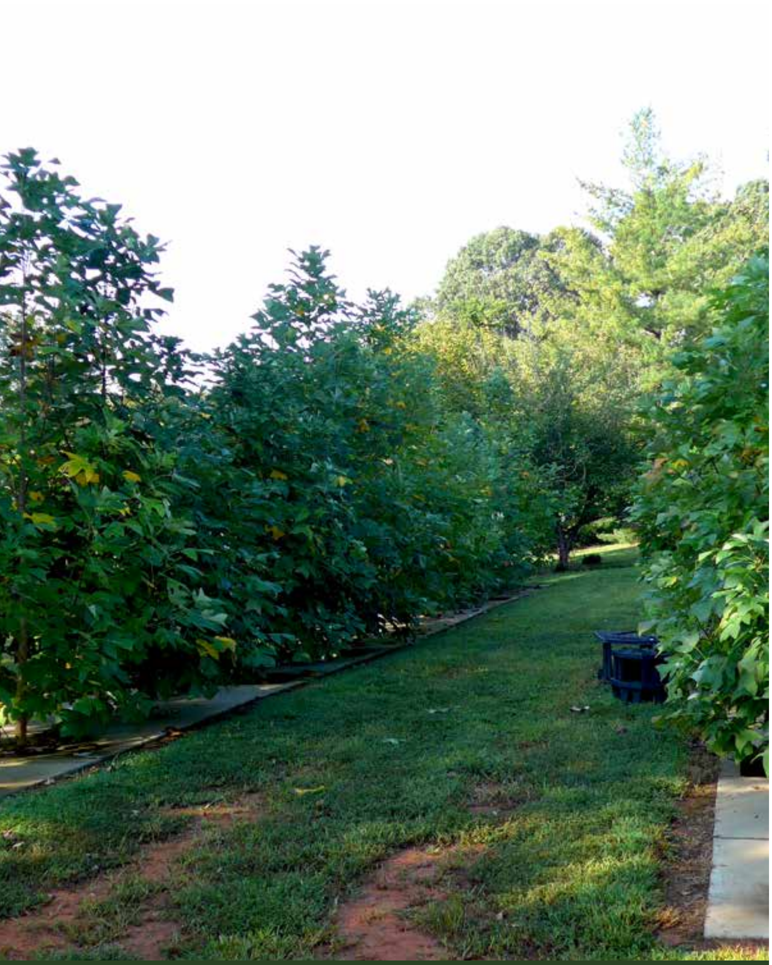
A key driver behind the research was canopy cover. Tree canopy provides a huge range of environmental, economic and health benefits, including:

- **Combats climate change by reducing greenhouse gas emissions**
- **Provides natural shade and cooling**
- **Conserves energy and reduces power costs**
- **Enables water filtration and retention**
- **Provides habitats for wildlife**
- **Increases property and area values**
- **Promotes health and wellbeing**
- **Contributes to a sense of place**
- **Encourages community interactions**

The faster tree canopies grow, the sooner the benefits can be enjoyed by cities, stakeholders and communities. Accordingly, the study sought to determine which system would produce the highest volume of canopy cover in the fastest time.

Methodology

To achieve the study goals, two plots were established at the Bartlett Tree Research Laboratory. The first plot was installed in 2004, exclusively for Study 1, which examined five variations of supported pavement systems. The second plot was established in 2014, specifically for Study 2, which examined six variations of structural media.



Citygreen's Stratacell system was part of Study 2, which also included an open control, compacted control, sand based structural soil (SBSS), gravel based structural soil (GBSS) and another structural load bearing module, similar to Stratacell. Fig 2.2.2

At the start of Study 2, on 19 August 2014, containerised 18mm caliper Liriodendron Chinense trees were installed in the centre of each plot. A 5cm thick layer of concrete was poured over the plot, with a 20cm hole centred on each tree. A soil moisture sensor was also fitted. Fig 2.2.4

Over the following three years, the trees were measured and assessed regularly against key performance indicators. On 23 October 2017, the trees were severed at the root for final measurements and findings. During the excavation, soil was removed from the roots, leaving the mass intact for examination. Fig 2.2.3 , Fig 2.2.5, Fig 2.2.6

(Above Left) Fig 2.2.2 - Trial plot. **(Below Left) Fig 2.2.3 -** Weighing all root systems. **(Below Right in Order) Fig 2.2.4 -** Stratacell samples growing in plot. **Fig 2.2.5 -** Airspade removing soil from roots. **Fig 2.2.6 -** Pressure wash and hydrovac removing tree stumps intact.

(Top) Fig 2.2.7 - Root distortion/restriction from structural soil
(Middle.) Fig 2.2.8 - Gravel based structural soil.
(Below) Fig 2.2.9 - Control tree.

Key Findings

Overall, the study found that soil treatments that provided a low density growing media (such as Citygreen StratacellTM and StratavaultTM) resulted in the largest, healthiest trees in the shortest time. These findings were consistent across Study 1 and Study 2. However, in Study 2, the tree growth differences between the systems were more pronounced than in Study 1.

The structural load bearing systems, including Stratacell, performed extremely well in Study 2. Compared to the compacted soil, SBSS and GBSS, these systems consistently achieved the highest scores across multiple measures of tree health and growth, including:

› **Tree trunk diameter**
› **Tree height**
› **Foliar color**
› **Number of roots > 1.2cm diameter**
› **Maximum root spread**
› **Maximum root depth**
› **Weight of tree parts**
› **Moisture content of soil**

Stratacell outperformed all other systems in terms of maximum root depth, moisture content and foliar colour. Like the other structural load bearing module, it also produced significantly larger trees with more large roots than other treatments, including compacted soil, SBSS and GBSS.

The final findings were consistent with observations throughout the study, which reported that the trees in structural load bearing modules began to diverge from other treatments by the end of 2015. Similarly, in 2016 and 2017, they were significantly larger than most other treatments.

Conclusion

The study concluded that structural load bearing modules (such as Citygreen Stratacell™ and Stratavault™) are superior for growing large, healthy trees in the fastest times when compared to other systems, such as compacted soil, SBSS and GBSS.

While the study was not intended to point to a 'best product', it proved the methods that support the load on a pavement and keep that load off the growing media work better than those that don't.

This is good news for urban planners, landscape gardeners, architects and developers. It means that, simply by choosing a structural load bearing soil system, they can achieve the canopy cover they require years sooner than they might with other systems.

Similarly, cities, communities and individuals can enjoy the environmental, economic and health benefits of tree canopies faster and for longer.

Download The Full Report

To download the full 'Comparisons of Soil Treatments Under Concrete Pavement' study, visit: ***https://citygreen.com/bartlett_soil_vault_comparison***

2. Soil Types

Key Issues

Soil is the uppermost layer of the Earth's crust and is the medium in which trees grow and spread their roots. Soil is comprised of finely ground rock particles of materials such as sand, clay, silt and gravel, with voids between particles containing water and air. Soil may be mixed with larger aggregate, such as pebbles or gravel. Not all types of soil are permeable, such as pure clay.

Soil type usually refers to the different sizes of mineral particles in a particular sample. Each size plays a significantly different role. For example, the largest particles, sand, determine aeration and drainage characteristics, while the tiniest, sub-microscopic clay particles, are chemically active binding with water and plant nutrients. The ratio of these particle sizes determines soil type: clay, loam, clay-loam, silt-loam, and so on.

Sandy soils have very large particles allowing water, air and plant roots to move freely. At the other end of the spectrum Clay particles are so small that they pack together tightly and leave little room for water, air or roots.

(Above) Fig 2.3.0 - Proposed Filler Soils should be specified and approved by a competent soil scientist.

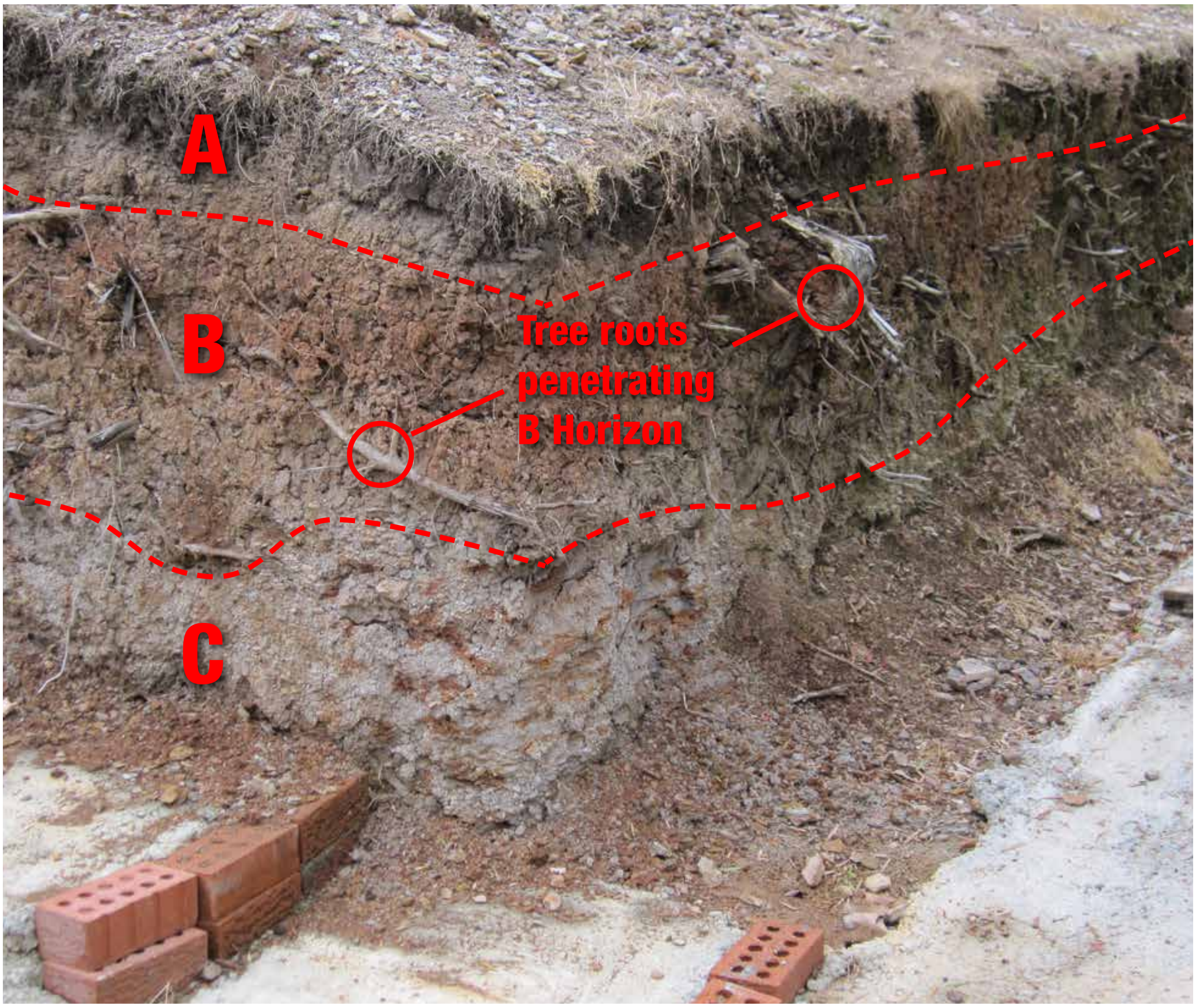
Nutrients

Seventeen essential plant nutrients have been identified.[1] Carbon and oxygen are absorbed from the air while the other nutrients including water are obtained from the soil, absorbed by the tree's roots. The primary nutrients are:

- **nitrogen (for healthy leaf and stem growth),**
- **phosphorus (for root growth) and**
- **potassium (overall plant health, especially the immune system)**

Secondary nutrients are calcium, sulphur and magnesium, while a range of other trace elements are also needed for healthy growth.

1. Allen V. Barker and D. J. Pilbeam, Handbook of plant nutrition, CRC Press (2007) p.4



(Above) Fig 2.3.1 - Soil profile.

Organic Matter

In addition to the mineral composition of soil, humus (organic material) also plays a crucial role in soil characteristics and fertility for plant life. Organic matter is dead plant or animal material. Organic matter improves sandy soil by retaining water and corrects clay soil by making it looser so that air, water and roots can penetrate. In all soils, it encourages beneficial microbial activity and provides nutritional benefits.

Soils change in composition and appearance with depth, creating what is known as a soil profile. A typical soil profile has a top layer of decaying organic matter formed by fallen leaves and debris that have been deposited by plants – this layer, if present is sometimes called the O horizon. Below the humus is topsoil, or A horizon, which can range in depth from a few inches to several feet and this is where most tree roots are concentrated. This layer has minerals, decomposed organic matter, and is generally dark brown or red brown in colour.

Under the topsoil is the subsoil, or B horizon, which generally lacks humus and therefore has poorer nutritional value for plants. If oxygen levels are sufficient, and drainage is adequate, tree roots can penetrate into this layer. Fig 2.3.1.

Below the soil layers lies the parent material or C horizon, which is the main source of soil. This material can be a transitional or soft stone layer, or heavy clay. Organic activity and weathering do not affect this layer, unless it is exposed through heavy erosion or construction activity.

The makeup of natural soil is constantly changing as organic material from trees and other plants are added and eroded by wind and water. Many soils are teeming with animal and insect life as well as bacteria and fungi. Earth worms feed on organic matter and break it down whilst creating small tunnels and tracks through the soil helping oxygen to be transmitted.

Cation Exchange

Nutrient uptake in the soil is achieved by cation (positively charged ion) exchange. Root hairs pump hydrogen ions (H+) into the soil which displace cations attached to negatively charged soil particles, making the cations available for uptake by the root.

The root and in particular the root hair, is the most important organ for the uptake of nutrients.

3. Engineering and Pavement Design

Key Issues

Pavement has several key purposes:

To support loads without excessive cracking or deforming	To provide a smooth surface for vehicles to improve comfort and efficiency	To eliminate drainage problems such as mud and ponding

Pavement Types - Flexible, Rigid And Composite

Pavements typically consist of a number of layers, placed over the in situ material, which work together to withstand traffic and environmental conditions. The surface layer may be made of concrete, asphalt, aggregate, geocells, grids or blocks. Concrete provides a rigid pavement structure while almost all other pavements are flexible. Composite pavements, often the result of pavement rehabilitation, also exist comprising both flexible and rigid elements.

Fig 2.3.2

Fig 2.3.3

(Above) Road pavements are designed to support National Wheel Load Standards, for all pavement types, both rigid **Fig 2.3.2** and flexible **Fig 2.3.3.**

Soil texture is the amount of sand, silt and clay (large particle size to small particle size) in any soil. This affects water infiltration and retention, aeration, nutrient capacity and retention, and root and plant growth.

"Trees take up large amounts of water from the soil during the growing season. For example, measurements from a fully grown lime tree (crown diameter approximately 14m) in Malmo, Sweden, in summer 2006 showed that that particular tree consumed around 670 litres of water per day during the month of July. Therefore trees have a huge capacity to handle stormwater."

City of Stockholm

Pavement Types - Porous And Non-Porous

Whether rigid or flexible, paving materials may also be porous or non-porous. Porous (or permeable) materials have open voids between their particles or units allowing the movement of water and air around the paving material. While some porous paving materials are almost indistinguishable from non-porous materials, their environmental effects are quite different.

Porous paving materials include the following: pervious concrete, asphalt and turf; single sized aggregate; open-jointed blocks, resin bound paving, bound recycled glass porous paving.

The overwhelming benefit of porous paving is its contribution to growing healthy urban trees through the admission of vital air and water to their rooting zones. Porous pavements behave almost like a healthy natural soil surface enabling the soil moisture to fluctuate with rapid wetting followed by drying and re-aeration. Other advantages of porous paving include better management of urban runoff, resulting in less erosion and siltation, and control of pollutants particularly heavy metals and oil through capture and breakdown in the subgrade.

Disadvantages include: the inability of porous pavements to handle large storm events alone; possible soil and ground water contamination; climatic limitations for example road salt and sand cannot be used on porous pavement surfaces; cost, longevity and maintenance. These issues can usually be managed through integrating porous pavements with standard stormwater facilities and careful siting of porous areas.

Load Dispersion With Depth

Rigid and flexible pavements distribute traffic load differently to the layers below, necessitating careful attention to design and construction of the layers and the thickness of the surface layer. Protection of the base layer, the structural layer nearest to the surface, and the sub-base layer below this, is essential for the longevity of the road.

Because the rigid surface structure does not bend, a point load is spread rapidly over a wide bearing area. By comparison a flexible structure, for example asphalt, flexes to accommodate traffic load. A flexible surface laid over an aggregate base spreads the traffic load gradually to the layers beneath. In this case a thicker pavement structure is required to protect these layers to the same degree.[1]

1. Bruce K. Ferguson, Porous Pavements, Boca Raton, Fla., London CRC, 2005

Fig 2.3.4

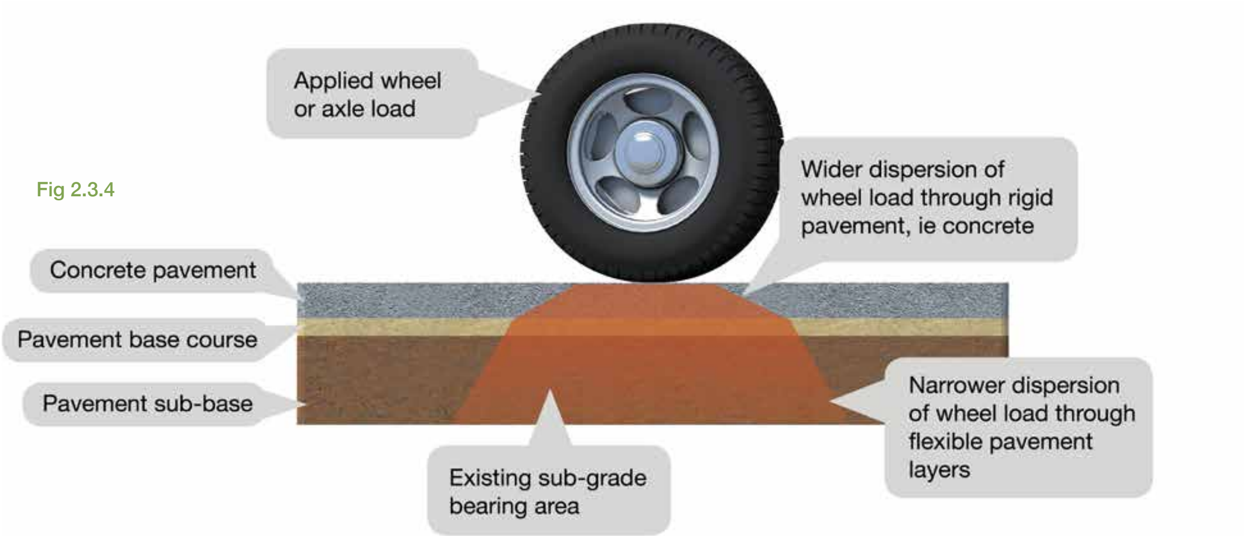
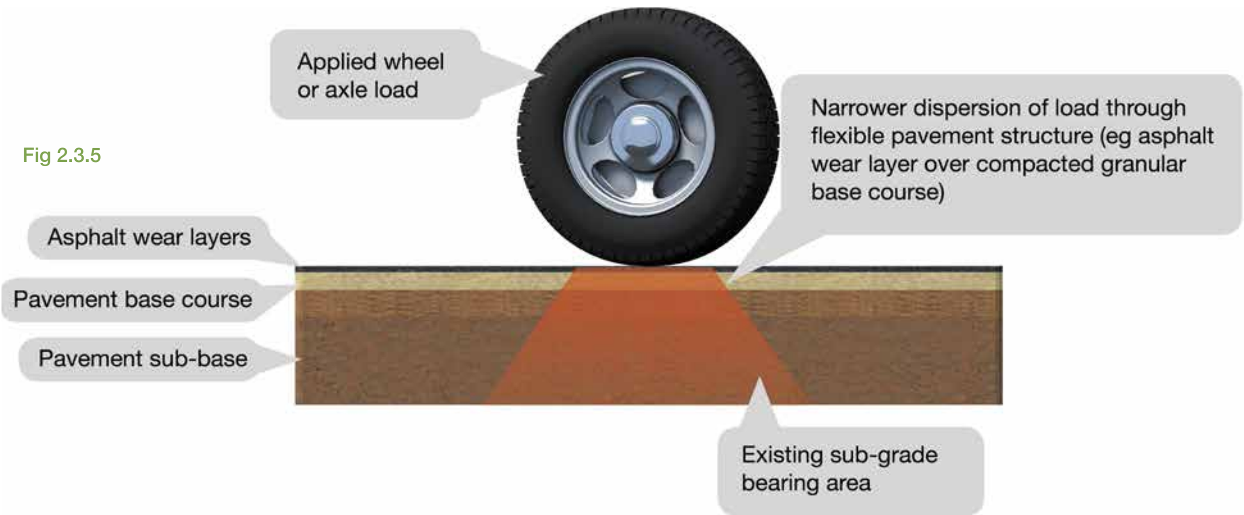


Fig 2.3.5



(Above) Traffic loads are dispersed differently through rigid pavement layers **Fig 2.3.4,** to flexible pavement layers - **Fig 2.3.5.**

Soil structure refers to the arrangement or aggregation of the soil particles. Good soil structure allows for water and air infiltration and movement, besides root growth.

Infiltration rates for soil media in rainwater harvesting treepit designs is critical. Many experts recommend a range of 100mm (4”) to 200mm (8”) per hour.

Sub Grade Strength

The subgrade is the soil underneath any pavement structure which bears the load of the pavement and the traffic. Subgrade may comprise naturally occurring earth, previously disturbed soil or fill brought from elsewhere. While subgrade provides the ultimate support for the pavement, structurally it is usually the weakest component in or around a pavement. For a pavement structure to be durable, it must protect the subgrade from deforming and it does this by spreading the load over the subgrade.

Because natural soils vary, the site subgrade characteristics are an important consideration in pavement design for that site. Typically subgrade is composed of clay, silt, sand and gravel, each of which has different particle sizes and chemical properties.

Wheel Loads And Global Standards

Total traffic load on a pavement comprises the magnitude of individual load events such as pedestrians, cars and trucks, and the frequency of events over time. This range of loads is expressed in terms of a common unit of measurement, the standard reference vehicle. Any vehicle can be related to the reference vehicle by its equivalent wheel load (EWL) or equivalent single- axle load (ESAL).[1]

The deterioration of pavement over time is directly related to traffic load expressed as ESAL. When a pavement is designed, it’s predicted ESAL is taken into account and its lifetime in years is calculated. Once this time arrives, the pavement is assumed to require some rehabilitation.

Direct Load

Pavements in cities must be engineered to withstand static and cyclic loads in accordance with applicable standards. Fully loaded emergency vehicles such as fire trucks must be able to access properties without causing catastrophic pavement failure. Where below ground tree pits are used, they must be capable of supporting applied loads while providing large volumes of uncompacted soil for root growth.

Lateral Load

In addition to direct vertical loads, pavements are subjected to significant lateral force. Frequent heavy traffic may cause the road pavement to fail adjacent to a tree pit and unless prevented, the base course may be displaced laterally into the tree pit void space. It is important that engineered space for tree root systems must be capable of withstanding this lateral force.

Engineering Support - Citygreen has invested heavily in comprehensive laboratory testing and advanced computer modelling, to provide answers for engineers and specifiers who seek to integrate green infrastructure into their cities. Ask a Citygreen technician to assist with design calculations, or provide the appropriate design report for your region and situation.

1. Bruce K. Ferguson, p70.

Fig 2.3.6

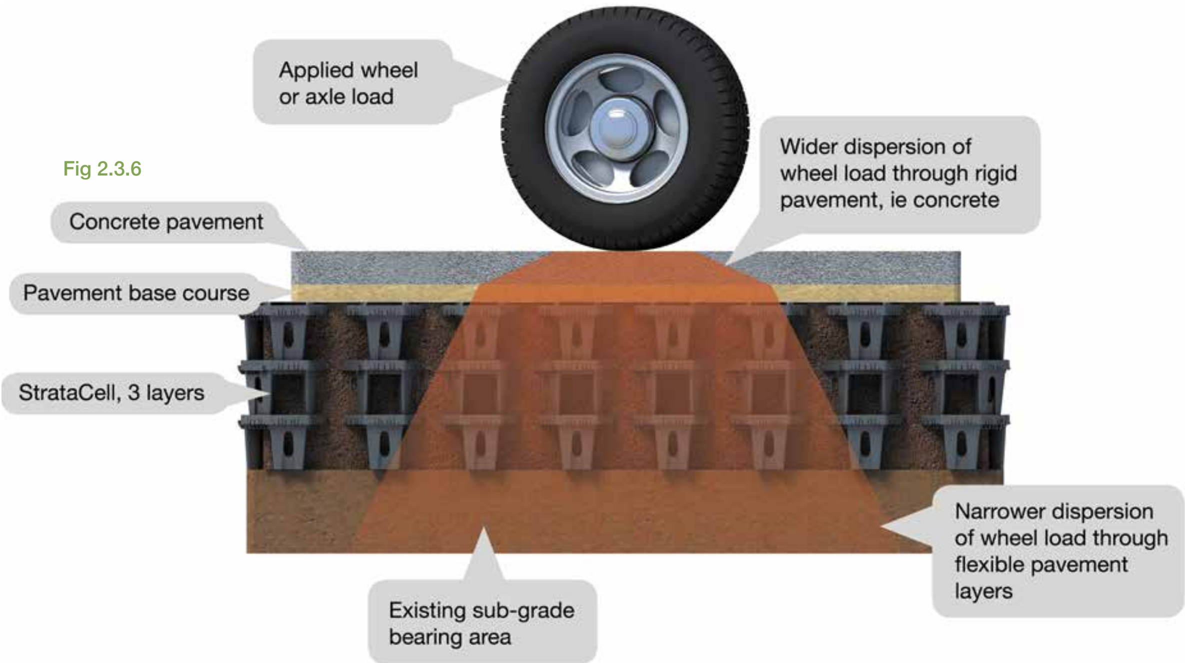
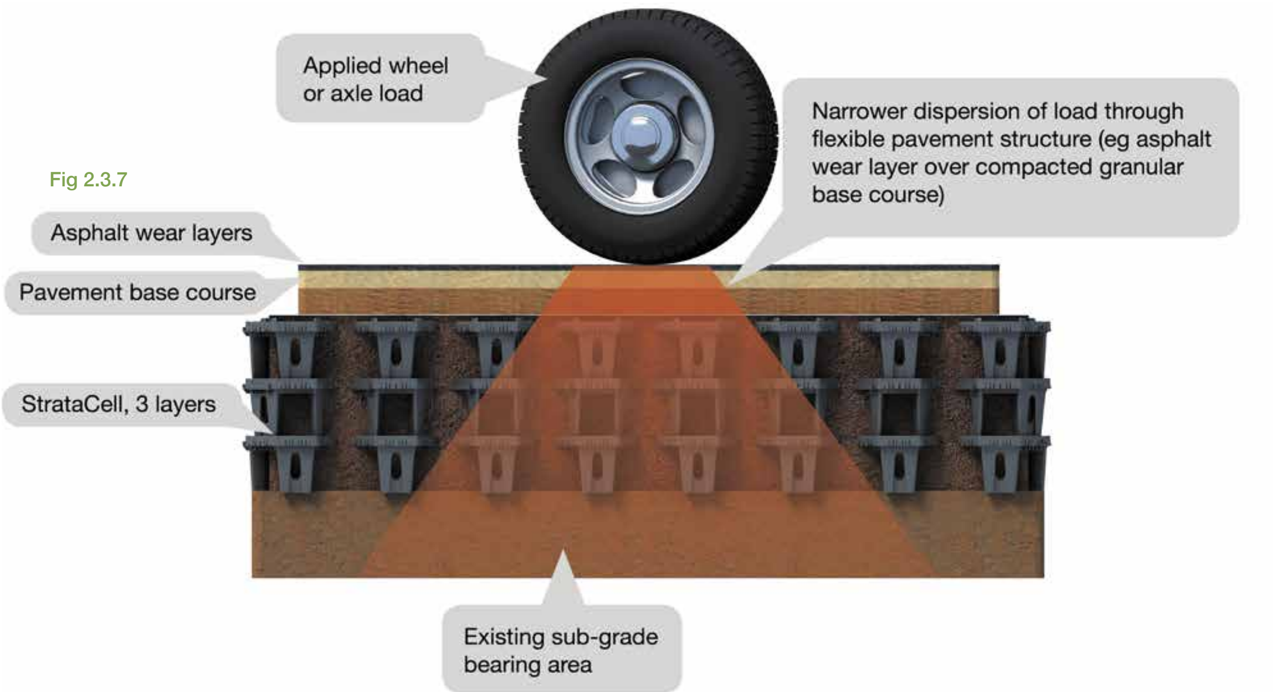


Fig 2.3.7



(Above) Interlocking Structural Soil Cells support pavement loads, with pressure being dispersed throughout the matrix in the same manner as engineered base course. Rigid pavements, **Fig 2.3.6** transfer load over a larger area than flexible pavements, **Fig 2.3.7.**

Approaches To Ensuring Subgrade Strength

Interlocking structural soil vaults are increasingly being adopted to ensure pavements and their subgrades are maintained despite the loads placed on them. These cells have been designed to support enormous vertical loads while providing uncompacted soil for tree roots and ensuring tree root systems can be brought closer to the pavement surface.

Structural soil vault units lock together to form a monolithic structure with excellent modular strength, both vertically and laterally. An assembled Stratacell™ matrix has been FEA tested to 550kPa vertical load. Engineers have calculated that with only 300mm/12” of granular pavement depth the base model Citygreen soil vault matrices can support maximum traffic loads.

Fig 2.3.8

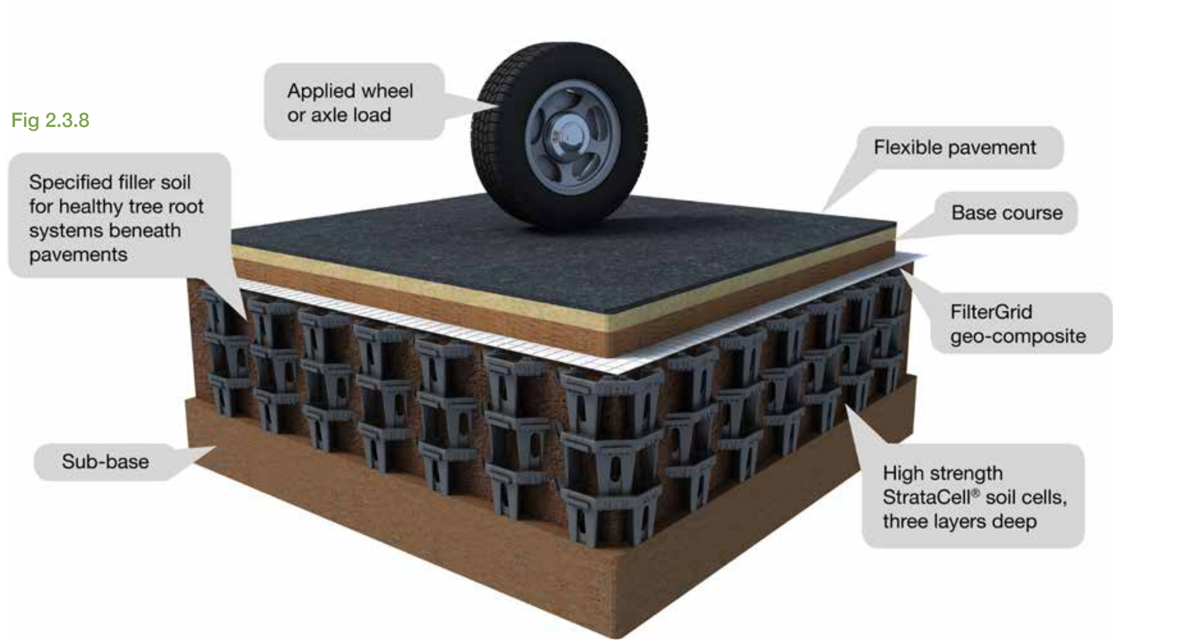
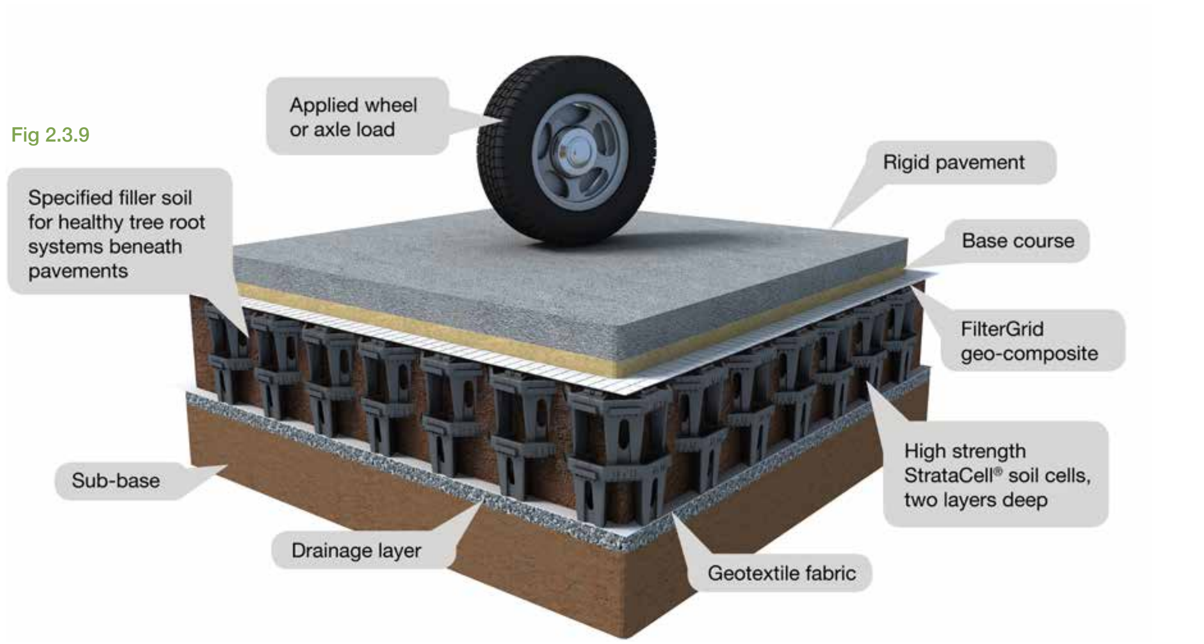


Fig 2.3.9



Interlocking structural soil cells form a fully engineered support for pavement loads while providing 94% void space for soil or bio-retention. **Fig 2.3.8 & 2.3.9.**

Compaction destroys soil structure by crushing the pore spaces. Compacted soils must be carefully worked and amended to restore optimal soil structure.

The Business Case for Water Harvesting Treepits

There is a very strong case for these new 'hybrid' treepits that function as a stormwater treatment device, while detaining and treating stormwater.

Stormwater flows can be controlled adequately.

Stormwater filtration can be performed and modeled.

Tree growth and performance an be enhanced, reaching canopy targets and higher asset values much faster.

All of this can be accomplished without sacrificing usable pavement area in parking lots, plazas, boulevards, waterfront developments and higher value residential development.

Water Harvesting And Soil Vault Systems

There are many sound reasons to support the incorporation of Water Sensitive Urban Design principles in structural soil vault treepits beneath pavements. Indeed, this is a very logical progression that has been extensively trialled in various regions globally. The design concepts for water harvesting treepits are explained in detail in the Citygreen ‘Harvesting Rain Water with Trees’ booklet.

Incorporating Services Within Soil Vaults

Utility services are often found to be in conflict with the requirements of trees in cities. This requirement needs to be considered at design stage, in view of a successful outcome for all parties.

Many services can be integrated within the Soil Vault matrix, due to the enlarged spaces between the load bearing columns.

For services that are over 230mm/10” in diameter, the structural soil vault matrix is segmented to provide sufficient clearance for the utility, and treated as a conventional service trench.

4. Stratacell™ Soil Vault System

The Development Of Soil Vaults

'Stratacell' represents the 4th and 5th generations of soil vault and have been developed by Citygreen Systems. Stratacell builds on the experience gained through trials, projects and collaborations with industry innovators. The main drivers have been the need for lower installation costs, higher strength, reduced transport costs and maintenance of large spaces for root growth.

Design Features

The fifth generation soil vault provides generous apertures for root growth without sacrificing the structural integrity of the matrix. Stratacell apertures are large enough to permit common conduits, service pipes and aeration systems to be incorporated within the structure.

The open skeletal structure of the Stratacell matrix provides an optimal growth zone for tree roots. Due to the advanced engineering design of these modern structural modules, more than 94%of the total volume of the soil vault is available for tree root growth. Stratacell structural modules are made from 100% recycled polymers.

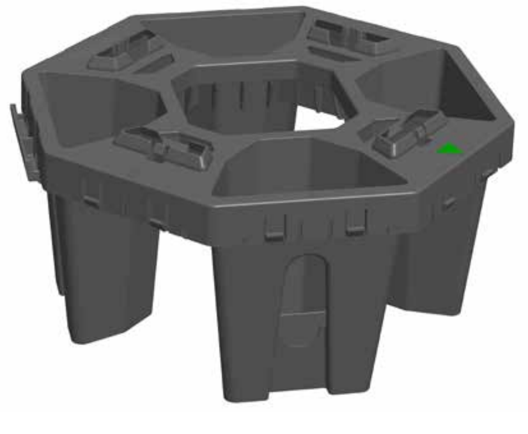
Assembly

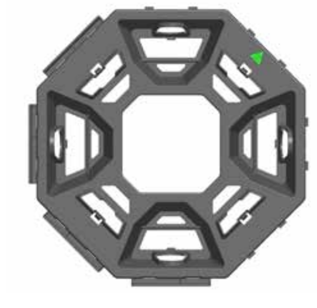
Stratacell has been designed to achieve major reductions in installation costs. Units snap together quickly and easily, with labour times being drastically reduced.

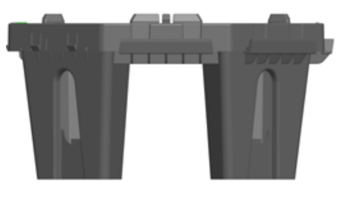
Positive and secure connectors are a feature of the Stratacell patented design both vertically and laterally. Stratacell modules are simple and fast to click together, producing an integrated matrix.

Volume Reduction For Freight

Another unique design feature of the Stratacell module is the significant volume reduction for freight. With increasing scrutiny placed on use of fossil fuels and shipping costs, it was decided that this unit must achieve major volume reductions for shipping. The innovative nesting design is protected by worldwide patents and design registration, as are all other design features.







(Above L-R) Fig 2.4.0 - Strata Cell module isometric,
Fig 2.4.1 - Strata Cell module top.

5. Stratavault™ Soil Vault System

Design Features

Apertures

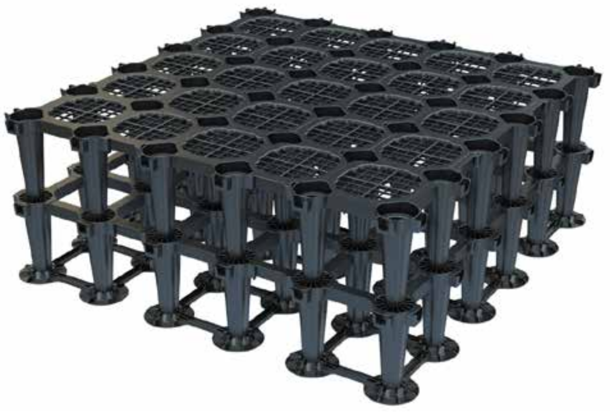
This sixth generation, large structural vault system has been designed with even greater apertures for root growth, without sacrificing the structural integrity of the matrix. Stratavault apertures are large enough to permit some common conduits, service pipes and aeration systems to be incorporated within the structure. Stratavault utilizes an evenly spaced columnar structure, with load spreading foot plates, to carry applied loads. Lateral connectors ensure that lateral forces are properly dispersed by a 'buried space truss' structure.

"I have installed over $2 million worth of soil cells, in the last 5 years. After the first day of using the Stratavault system I called my project manager to tell him I never wanted to use any other brand! Stratavault is far superior to its competitors."

Commercial Landscape Project Manager

"Stratavault is at least 3x faster than other soil cell systems. The ease of install and ability to adjust beats out other systems."

Commercial Landscape Project Manager



Growth Zone

The open, columnar structure of the Stratavault matrix provides an optimal growth zone for tree roots.

(Above Left) Fig 4.1.2 - Patented Stratavault system uses footplates to spread point load, lateral and vertical connectors for structural integrity, **(Above Right) Fig 4.1.3 -** Assembled Stratavault matrix with top grates in place, **(Below Left) Fig 4.1.4 -** Stratavault modules nest efficiently or freight volume reduction.

"The bridge connectors made a huge difference with the install. Keeping alignment was easier and we no longer needed 2x4's for spacers. Having the cells connected by bridges made it safe to walk on without filling, and I was able to fill quicker without risking shifting cells. The bridge connectors eliminate the need for base pins, which was another time saver. Having all the cells connected makes for a far simpler install."

Commercial Landscape Project Manager - Canada

Lower Cost Installation

Stratavault™ has been designed to achieve further reductions in installation costs. Units snap together quickly and easily, with labor times being drastically reduced.

Interlocks

Positive and secure connectors are a feature of the Stratavault patented design both vertically and laterally. Stratavault modules are simple and fast to click together, producing an integrated matrix with correct load sharing throughout the matrix, with the option of removing lateral connectors simply and quickly if required for deconstruction.

Volume Reduction For Freight

Another unique design feature of the new Stratavault module is the significant volume reduction for freight. With increasing scrutiny placed on use of fossil fuels and shipping costs, it was decided that this unit must achieve major volume reductions for shipping. The innovative nesting design is protected by worldwide patents and design registration, as are all other design features.

Free Soil Volume

The patented Citygreen Stratavault system has a very high void space volume for filler media for tree health and filtration, without compromising the high strength of the system.

6. Structural Integrity and Sustainability

Stratacell™ and Stratavault™ are very highly engineered modular systems, that owe much of their incredible strength to unique design (subject to numerous patents). So strong are these designs, that the base model Stratacell and Stratavault (Series 30) have an ultimate strength in excess of 300kPa/43.5psi without relying on any steel bars (subject to corrosion), or glass reinforcement, or virgin resins. This module is stronger than many comparable large soil vaults, and is made entirely from recycled polypropylene.

Stratacell and Stratavault modules are crush tested during manufacture as part of the rigorous quality control standards required by Citygreen. Whilst FEA (Finite Element Analysis) computer load testing was also conducted during the initial design stages to project the loading capacity laterally and vertically, physical laboratory tests were then used to clarify the cells actual loading capabilities. This physical load testing is part of an ongoing development and research program, and is the only true measure of structural integrity.

Fatigue Testing

Stratacell has been subjected to extraordinary laboratory tests, including fatigue testing. In one test a university applied a load of 8.6 tonnes to a Stratacell tower 10,000 times. The tower was then crushed to measure whether the ultimate load had been diminished by the cyclic loading. The high strength modules had lost no strength, verifying the design strength of this remarkable system.

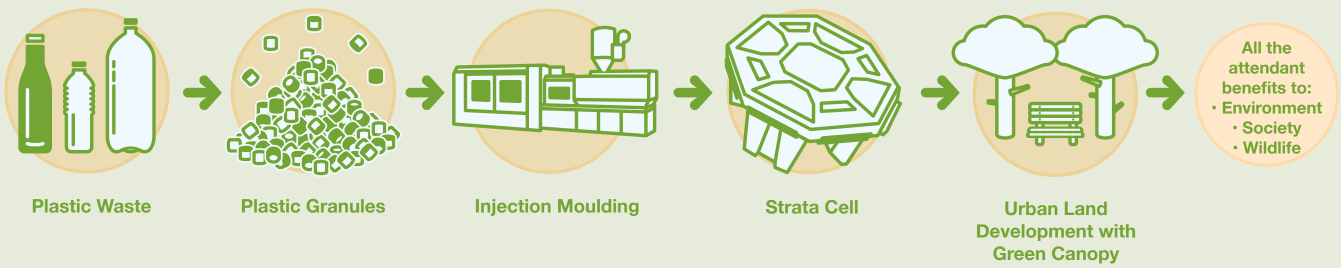
Sustainability

The use of virgin resins in a product for the Green Building Industry has never been a part of the Citygreen Soil Vault development program. Virgin plastics have an unacceptably high level of embodied energy, whereas recycled waste plastic into an engineering grade product starts with a clean sheet as recognized by industry and the Green Building Council. ***Due to the emphasis Citygreen places on environmentally sustainable systems, over 1,000,000 kg of plastic are recycled and reused for promoting healthy tree canopies, to offset climate change every year.***

California Assembly Bill 1080 was introduced into California's legislature in February. With no market for recycled plastic, even recyclers are forced to landfill or incinerate what they collect. Bottle deposit centers, where Californians could redeem a soda bottle in exchange for five cents, are closing throughout the state.

Now that bill, along with two others, are poised to dramatically re-imagine California's relationship to plastic, mostly by trying to prevent industries from producing new, virgin plastic in the first place.

Right now, the US produces 335 million tons of new plastic each year. If passed, the bills would ban the production or sale of any non-recyclable single-use packaging containers in the state by 2030. They would also require California to either recycle 75% of all single-use plastic packaging and products sold or distributed in California, or otherwise find a way for them not to end up in landfills. That would mean almost doubling the state's current rate. Right now, just 44% of waste is diverted from landfills, according to the Los Angeles Times.



Citygreen™ Stratacell™ Technical Sheet

The new Citygreen Stratacell is an extremely high strength module for support of pavements and traffic loads while providing large volumes of uncompacted soil for healthy tree root systems and water harvesting.

The high strength Citygreen Structural Module is the result of a team of talented design engineers working with Citygreen to produce the ultimate load bearing 'root cell' structure.

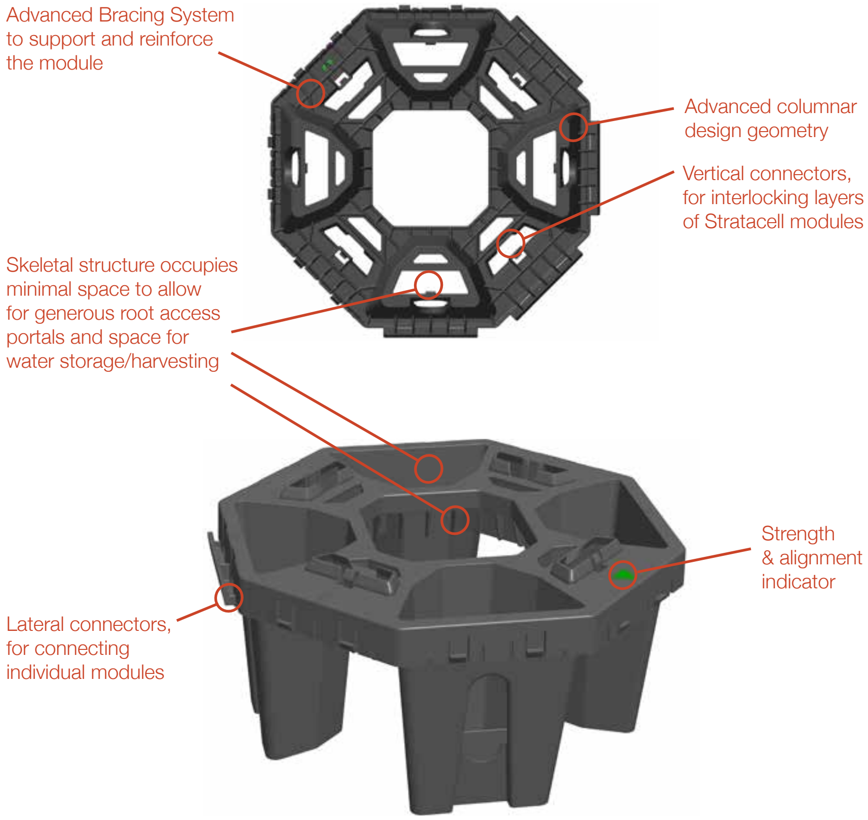
This patented design integrates an array of essential features, making it the most advanced structural module of its type globally.

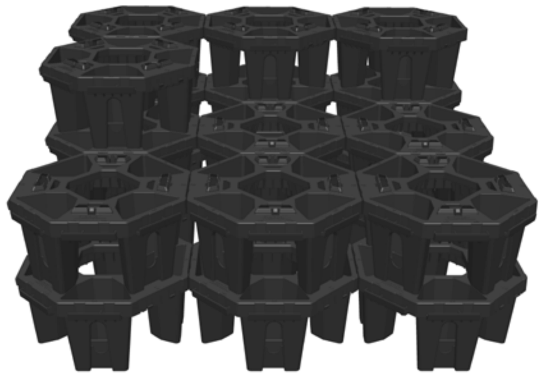
Immense compressive load bearing capacity is achieved by combining columnar design geometry with recycled, reinforced co-polymer materials.

Due to the positive lateral and vertical connectors, an assembled Stratacell matrix also has excellent lateral strength. The octagonal modules are placed and connected rapidly and simply, with minimum of skilled labour required.

Large spaces between the columns provide generous avenues for root growth in all directions, and volume within the columns is open and readily accessible for feeder and structural tree roots.

The environmentally-critical design parameters have resulted in an extremely strong module made from recycled material, which leaves over 94% of its total volume for root growth and storm water harvesting.





Material Specifications	Dimensions	Capacity	Ultimate Load Strength (tested)
30 Series - 100% recycled polypropylene **60 Series -** 100% glass reinforced recycled polypropylene	**Length -** 510mm/20inch **Width -** 510mm/20inch **Height -** 250mm/10inch	**Free Volume -** Above 94% **Soil Capacity (ea) -** 0.062m³/2.189ft3	**30 Series -** 300kpa/43.51psi **60 Series -** 600kpa/87.02psi

Citygreen™ Stratavault™ Technical Sheet

The new Citygreen Stratavault is an extremely high strength module for support of pavements and traffic loads while providing large volumes of uncompacted soil for healthy tree root systems and water harvesting.

The high strength Citygreen Structural Module is the result of a team of talented design engineers working with Citygreen to produce the ultimate load bearing 'root cell' structure.

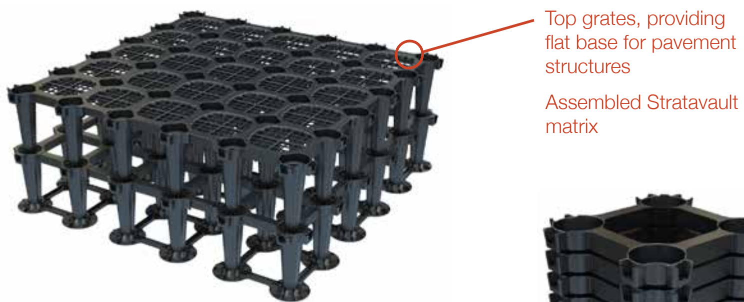
This patented design integrates an array of essential features, making it the most advanced structural module of its type globally.

Immense compressive load bearing capacity is achieved by combining columnar design geometry with recycled, reinforced co-polymer materials.

Due to the positive lateral and vertical connectors, an assembled Stratavault matrix also has excellent lateral strength. The octagonal modules are placed and connected rapidly and simply, with minimum of skilled labour required.

Large spaces between the columns provide generous avenues for root growth in all directions, and volume within the columns is open and readily accessible for feeder and structural tree roots.

The environmentally-critical design parameters have resulted in an extremely strong module made from recycled material, which leaves a huge proportion of its total volume for root growth and storm water harvesting.



Assembled Stratavault matrix

Stratavault modules nest for shipping ›

Material Specifications	Dimensions	Capacity	Important Note	Ultimate Load Strength (single cell & lab tested)
30 Series - 100% recycled polypropylene **45 Series -** 100% recycled ABS	**Length -** 600mm/24inch nom **Width -** 600mm/24inch nom **Height -** 404mm/16inch *Note: Product dimensions may change without notice. Please confirm with Citygreen at time of order placement	**Free Volume -** Assembled Matrix>92%	Request Stratavault Construction Details for matrix dimensions in plan and elevation Submit plans and pavement details to Citygreen for comment. All installers to complete online training certification	**30 Series -** 300kpa/43.51psi **45 Series -** 450kPa/65.3psi

Case Study

Amazon Leverages Cutting-Edge Stratacell Solution In New Seattle Headquarters

Amazon leveraged Citygreen's cutting-edge Stratacell tree-growth system for its multi-million-dollar Seattle headquarters.

Feature trees require large planting areas

Feature trees require large planting areas.

Purpose-built to accommodate 20,000 employees, the headquarters consists of multiple buildings surrounded by mingling areas and plazas.

One plaza, located between two buildings on 6th Avenue, had been constructed above a parking structure. It's home to several feature trees (Cercidiphyllum japonicum and Magnolia laevifolia) that require large planting areas.

Engineering plans provided enough soil volume beneath the plaza to house the trees, but a significant challenge emerged — how to provide sufficient structural support for the weight of heavy maintenance vehicles such as a boom lift. Engineers identified soil cells as an ideal solution, but many options were rejected because they lacked the necessary structural strength.

Case Study

Inverell's Town Centre Transformed With Healthy Street Trees And Sustainable Infrastructure

The town of Inverell is nestled in a picturesque valley near the Macintyre River in northern New South Wales. Renowned for its proud pioneering history, beautiful restored buildings, boutique shopping and cultural endeavours, it's also the centre of the Inverell Shire.

In 2014, Inverell Shire Council adopted an ambitious plan to rejuvenate the town centre. As well as making it more attractive, more functional and more profitable for local businesses, the plan sought to replace the old London Plane Trees that had been inappropriately planted along Otho Street.

In this case study, we explore how Citygreen collaborated with Inverell Shire Council, design consultants King & Campbell and other key stakeholders to revive this site, which is now home to large, healthy trees – and is much loved by the community.

Project Goals

As well as creating a first-class public space for people to live, work, shop and visit, a primary goal of the renewal project was to repair infrastructure on Otho Street. The existing London Plane Trees were poorly planted in concrete pipes, resulting in significant damage.

As Justin Pay, Civil Engineering Manager from Inverell Shire Council, explained, "Our main goals were to repair damaged infrastructure, replace trees to provide a functional and aesthetically pleasing town centre, and to improve road safety and access for pedestrians."

"It was important to substitute the old Plane Trees with a suitable new species that would deliver high and immediate impact on the street."

Case Study

Revitalizing Las Vegas' Main Street

In 2015, the City of Las Vegas performed a major overhaul of its downtown streetscapes, widening curbs and gutters, repaving and putting in stormwater drains, as well as adding new street lights, benches and trees.

A need to protect utilities

"This is a very old area of Las Vegas, with lots of old utilities," City of Las Vegas Program Manager Jeremy Leavitt said.

"In one area, there was a particularly significant energy duct bank underground. Given its size, age, and the fact that many of the surrounding casinos rely on it, we didn't want to move it."

The City needed a solution to protect those utilities while providing room for new trees to grow.

Using Citygreen Stratacells, the City planted twenty Chinese Pistachios (Pistachia X 'Red Push') around the energy duct bank.

The Citygreen Story

Citygreen was established to provide engineered green building solutions based on sound research into urban sustainability. Our solutions have proved to be current best practice in their field, endorsed by professional organizations around the globe.

Our Name

Our name reflects our passion – to help make our cities more sustainable. From our dedication to research and development and hands-on experience in the field has come a firm belief that there are ways of successfully integrating 'green utilities' – trees, soil and water – into urban design to make our cities greener and more liveable.

Our Vision

Our company vision embraces a world where sustainable green space is within reach of every person, every day – and natural resources are utilized (not wasted) for the benefit of mankind.

Local authorities, arboriculturists, landscape architects, civil engineers and other related professionals increasingly collaborate with Citygreen in implementing current best practice in green technology. As the industry market leader in specialist green building products, we are able to offer the results of 18 years of frontline experience in the field, exhaustive research, product development and field trials. Our support service, unrivalled in the tree planting world, can help you to achieve your vision.

Research and Development

Ongoing research and development is a key to the growth of Citygreen, with knowledge gained in laboratories and field collaboration construction sites being shared with industry partners. As a company, Citygreen pursues the current boundaries of design relentlessly to bring proven engineered green building systems that provide optimum solutions for urban planners to the market.

Training and Accreditation

Long term success of engineered green building systems is directly impacted by the quality of installation. Not only is the health of trees and shrubs but also pavement integrity and storm water function in danger of compromise, with potentially dire consequences, if installers are not competent in best practice installation.

For this reason, Citygreen has developed a unique accredited e-learning program. Installers may complete this comprehensive training course online to gain accreditation. This accreditation status is part of the prerequisite package for product warranty recognition and is further evidence of Citygreen's dedication to the Green Building Industry.

Technical Support

Citygreen strives to provide world class support for designers and installers of the various green building systems available. Complete suites of drawing files in CAD format and PDF are available to designers, free of charge, with a growing library of BIM or Revit files.

Detailed product and installation specifications are available for inclusion in project designs, many of which are fully editable. Citygreen consultants are also able to obtain independent engineering advice on behalf of clients, utilizing qualified engineers with key experience in the use of Citygreen green building systems.

Citygreen Grants Programme

Citygreen is inviting municipalities and developers to apply for grants to develop and implement pilot projects that use our canopy growth systems within their jurisdiction.

This is an open, competitive, grant opportunity, aimed at helping cities and developers to foster sustainable urban canopies at reduced risk and cost.

Project grants of between $5,000 and $50,000 are available, co-funded on a 1:1 basis with the applicant municipality. The total, maximum value of any one project is $50,000.

Citygreen Australasia
821 Pacific Highway
Sydney, NSW 2067
Phone: (+61) 1300 066 949
Email: info@citygreen.com

Citygreen USA

5450 West 83rd Street
Los Angeles, California 90045
Phone: (+1) 888 999-3990
Email: info@citygreen.com

Citygreen Canada
720 - 999 West Broadway,
Vancouver, BC V5Z 1K5
Phone: (+1) 888 999-3990
Email: info@citygreen.com

citygreen
URBAN LANDSCAPE SOLUTIONS

Worldwide Patents & Designs
Reg. and Pend.© Citygreen Systems