CONTINUING EDUCATION CENTER ARCHITECTURE + CONSTRUCTION

Trees Need Dirt

How soil cells can provide a sustainable environment for urban trees

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Use the following learning objectives to focus your study while reading this month's Continuing Education article.

Learning Objectives - After reading this article, you will be able to:

1. Identify the current problems with urban forests and discuss why current planting techniques are not adequate in providing a healthy and sustainable environment for urban trees.
2. Recognize the key environmental, economic and cultural benefits of urban arboriculture to both private development and public infrastructure projects.
3. Discuss the techniques that enable expansion of healthy tree cover within the urban infrastructure and identify how urban tree cover assists in overall project sustainability.
4. Describe which LEED® and the Sustainable Sites Initiative™ credits may be obtained through the use of a suspended pavement or soil cell system, and how the suspended pavement or soil cell system provides for a healthier ecosystem for trees within the constraints of most urban environments.

According to the National Wildlife Federation and American Forests, both non-profit conservation organizations, "There are over 600 million spaces along city streets where trees could be planted. This translates to the potential to absorb 33 million more tons of CO_2 every year, and saving $4 billion in energy costs. A well-maintained urban forest will save a community millions of dollars in storm water runoff expenses, remove millions of pounds of air pollutants and reduce energy costs by millions of dollars." (1)

The challenge in most urban environments is providing adequate soil conditions for trees to grow and survive. Trees need dirt and this article will outline all the ways that urban forests can be healthier, more sustainable and have greater longevity if provided with adequate growing conditions.

New “green design” and sustainability standards are being developed by communities throughout the US, Canada and Europe. These standards look to improve urban environments by requiring that new development meet sustainable design criteria. Many communities require compliance with the International Green Construction Code (IgCC), LEED® criteria, and Sustainable Sites Initiative™ criteria in addition to meeting the community's newer sustainability codes and standards.

Urban environments present many challenges in meeting these newer sustainability standards and one of the biggest challenges involves the design of sustainable growing conditions. This article will highlight an innovation that helps increase the longevity of urban trees, by providing a more sustainable environment for them. This information is of value to the building architect as well as site design professionals in that a healthy tree canopy adds value to the environmental credentials of a project. A site with a more sustainable urban tree canopy presents environmental benefits to the site and the building, economic benefits to the project, and the client and cultural benefits to the community.

Why Trees Need Dirt in Urban Environments

“Trees need dirt” is a quote from a lecture given by James Urban, FASLA, ISA at a Tree Symposium: Healthy Trees for a Healthy City held in 2004 in Toronto, Canada. (2. -Urban, 2004)

Trees need adequate amounts of dirt or soil to survive and grow, and soil volume and quality have a direct relationship to tree health and sustainability. Adequate soil volume and quality soil content (1) provide a more stable structural base for the tree, (2) increase water availability to the tree, and (3) provide more room for growth and tree longevity. According to James Urban FASLA, ISA, our cities fail in providing environments that are conducive to sustaining urban forests. Generally urban environments provide tree-planting areas that are confined, cluttered with utility lines and filled with compacted, poor quality soils. These challenging conditions have limited tree species diversity in urban areas, compromised tree growth and health, and generally reduced the quality of urban tree cover. These conditions are also presenting challenges for architects and design professionals as they look to meet new sustainability standards for storm water management and meet zoning and planning codes that require denser tree coverage to address heat island effect as well as challenges to communities as they seek environmental, economic and cultural enhancements.

Challenging urban conditions affect the growth and health of urban forests.

Photo courtesy of DeepRoot Green Infrastructure

The Ways in which Urban Forests Enhance a Project

The benefits of urban forests to the entire project can be measured not just environmentally, but also economically, and socially. (3- Sustainable Cities Institute)

Environmental Benefits of Urban Tree Planting

The environmental benefits of trees are generally well known and are those benefits that are most directly addressed by sustainable design criteria. These benefits include the following:

- Trees assist with the improvement of air quality by mitigating air pollution and greenhouse gases. Trees use photosynthesis to convert carbon dioxide (CO_2) into nutrients and this process helps to reduce the amount of CO_2, which is a greenhouse gas. Reduction in greenhouse gases reduces smog and unhealthy air quality in urban environments. Trees also capture particulate matter on their leaves and trunks, preventing it from being breathed in by people.

- Trees help to reduce stormwater runoff and improve water quality. Large amounts of impervious surfaces force excess storm water to accumulate on pavement surfaces faster than the sewer system can absorb. Trees are able to capture large amounts of rain through their canopies and root systems. In addition to absorbing storm water through their roots and canopies, trees also help to filter some of the pollutants carried with the storm water.
- Trees help to reduce the urban heat island effect. Large areas of pavement trap the heat of the sun and reflect it back into the environment, thus raising the temperature in surrounding areas. This process contributes to smog, global warming and higher energy costs associated with increased air conditioning in nearby buildings. Many community zoning codes now require the strategic placement of trees in and around parking lots and around buildings to provide shading and thus, limit the heat island effect.
- Urban trees and forests help to reduce, and even eliminate, erosion. Strong winds and storm water runoff can erode arable soil. The roots of trees bind to the soil and can prevent soil loss.
- Trees shelter wildlife and promote biodiversity. Trees provide a necessary habitat for a wide variety of urban wildlife. *A single oak tree can support up to 500 species of insects and invertebrate species.*
- Healthy urban forests contribute to the stabilization of watersheds. Trees absorb large quantities of water through their root systems, and their canopies intercept additional rain before it even hits the ground, and thus help to mitigate flooding. Soil absorbs and retains rainwater, which is then released slowly into the groundwater. Tree roots create air pockets within soil and the air pockets filter contaminants which would otherwise enter groundwater sources such as aquifers, streams, and lakes.

Economic Benefits of Urban Forests

The economic benefits of urban forests are less obvious than the environmental ones but these benefits have an impact on the short and long-term effects of a project. With enhanced property values and aesthetic qualities, building projects become easier to sell or lease as well as more economical to operate.

- Trees increase property values. The USDA Forest Service has found that mature trees add an average of 10 percent to a property's value. This fact is also realized by the US Association of Realtors.
- Businesses do better on tree lined streets. A 2004 study found that consumers overwhelmingly preferred business areas with well-planted canopy-covered streets and suggests a link to the amount of time that shoppers are willing to spend in stores.
- Trees can reduce heating and cooling costs for buildings. Trees can reduce cooling costs by 30 percent, and heating costs by 20-50 percent. Trees cool buildings during hot weather by providing shade, and limit snow accumulations during cold weather by providing a barrier to wind. This presents an economic benefit to a building project as it can reduce the fuel costs associated with heating and cooling.

- Crime rates tend to be lower in areas with trees. Research presented at the American Association for the Advancement of Science conference (AAAS) in Chicago showed that the presence of trees could cut crime by as much as 7 percent.

Healthy urban forests can enhance the environmental, economic and social conditions in urban areas.

Photo courtesy of DeepRoot Green Infrastructure

Social Benefits of Trees

Social benefits are difficult to quantify, but they contribute to the quality of life and the overall well-being in a community.

- Trees provide aesthetic benefits by creating more desirable landscapes and helping to define community character. Through size and color they soften the harsh urban landscape. Species type, placement, and even long-standing individual trees help to define regional history, culture, and community character.
- Trees and urban forests encourage community interaction. People tend to gather more when green spaces are available.
- Trees reduce noise pollution by blocking urban noise. Noise reduction has been shown to reduce stress for people living and working around trees.
- Urban forests provide opportunities for environmental educational programs for both children and adults. Many schools have “outdoor classrooms” with curricula designed for the natural sciences.

Issues and Challenges to Urban Tree Health

A healthy urban forest can meet or exceed most if not all of these benefits but a healthy urban forest requires sufficient soil quantities and adequate soil conditions. Some of the issues and challenges in providing proper urban tree health and growing conditions are as follows:

1. Urban pavements need adequately compacted subsurface material. Compacted subsurface material is not an appropriate growing medium for trees and compacted soils cannot provide the sufficient air and water spaces that trees need to maintain health and mature.

2. Many species of urban trees cause heaving of pavements because the roots have inadequate room under the pavement for tree growth and root expansion.

3. Existing utilities present impediments to the placement of urban trees. Tree roots sometimes wrap around utility lines.

4. Net soil volume is essential to long-term growth of a tree. According to studies, (Urban 2010) a typical large canopy tree needs in excess of 1,000 cubic feet of loam soil to reach a large enough size that provides significant environmental benefits.

5. Designers must understand existing soil conditions. In many instances the existing soil under pavements may actually be suitable for tree growth. The question is whether the soil volume is sufficient.

6. Managing storm water at the point source is critical to meeting many newer codes as well as sustainability criteria. Impermeable pavements and underlying compacted soils prevent proper storm water management.

Providing Urban Trees with Enhanced Soil Volume

There are two methodologies for providing urban trees with enhanced soil volume and a better quality soil base. One methodology known as structural soil is comprised of a mixture of soil and stone aggregate mixed together with a polymer gel for adhesion. The second methodology is a soil cell system, which is a modular system comprised of a recycled plastic frame and deck that is filled with soil.

The Attributes of Structural Soil

Structural soil was developed by a research team at Cornell University to provide load-bearing soils under pavements so that the soil could be compacted to the required density to bear the load of the pavement while still allowing trees roots to grow in it. Structural soil is a mixture of stone aggregate (crushed gravel) and soil, with a small amount of polymer gel used to prevent the soil and stone aggregate from separating during the mixing and installation process. This soil mix can be compacted to 95% of dry density so it supports paving while still allowing for tree root growth. The mix takes advantage of the fact that there are about 20% to 25% void spaces between pieces of compacted gravel, which is where the tree roots will grow. The type of soil needed to make structural soil is a loam to clay-loam containing at least 20% clay which maximizes the soil's water and nutrient holding capacity. Structural soil should also have 3-5% organic matter. The ratio of soil to stone aggregate is approximately 80% stone to 20% soil by dry weight. This proportion ensures that there is sufficient bearing capacity in the mix and each stone touches another stone producing a rigid stone skeleton.

Observations have shown that trees growing in structural soil do exhibit drought stress symptoms. The clay-loam soil in the structural soil mixture is a low percentage (20%) of the total volume and this limits the water holding capacity of structural soil. Because of the large percentage of stone aggregate, structural soil is a very rapidly draining material with a percolation rate of approximately 24 inches per hour. Consequently structural soil does not effectively retain significant amounts of water in a meaningful period of time. This rapid percolation rate and ineffective ability to retain water inhibits the ability of structural soil to filter and remove pollutants. In a 2008 study (Xioa and McPherson 2008), structural soil was found to filter an average of 53% of the nutrient pollutants.

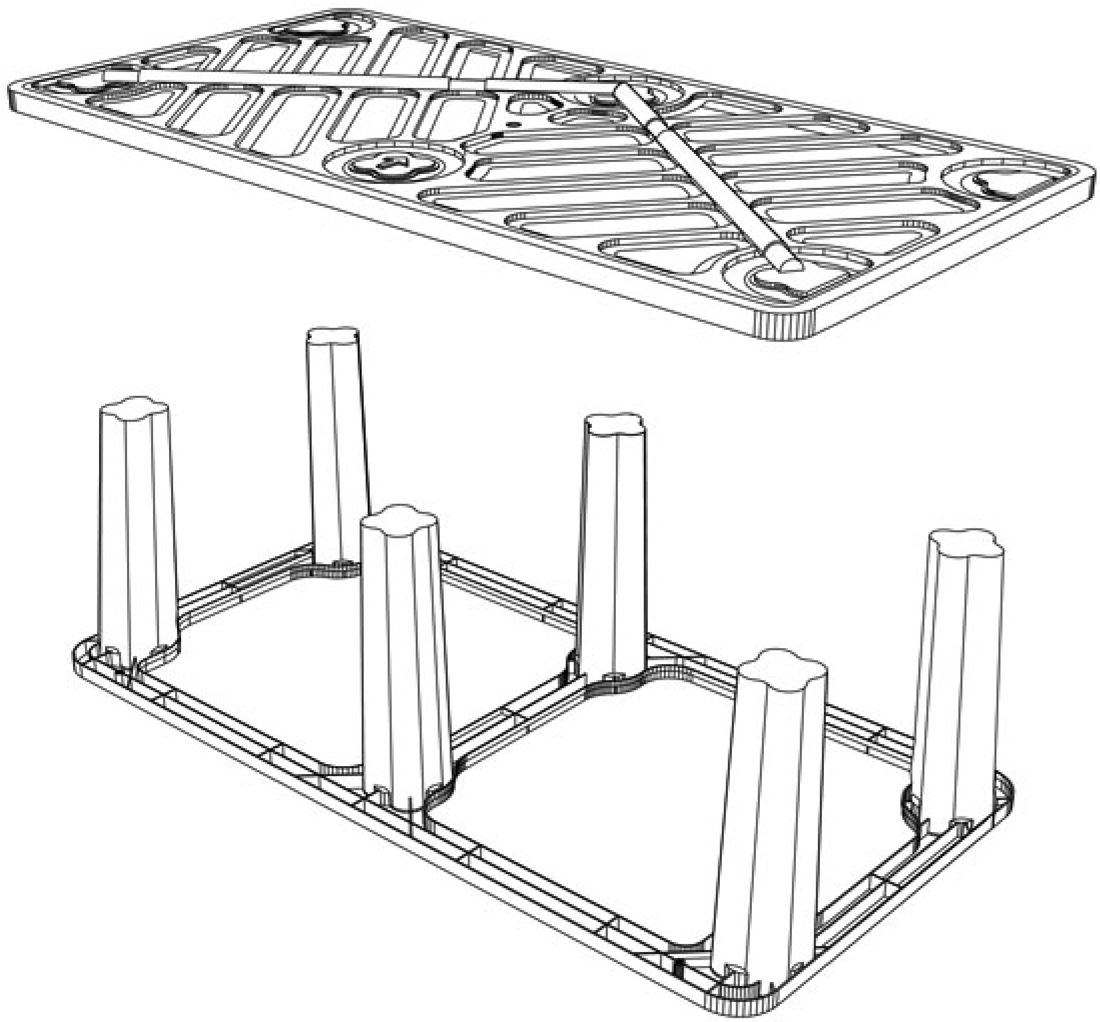
As structural soil is made from processed hard stone aggregates that require energy to mine, crush and ship, this may present issues with meeting sustainability criteria. Quarry activity can be damaging to local environments. Clay loam soil is often not available in many local project sites so it must be shipped to the site. Rock quarries are usually located a distance from urban areas and thus the stone aggregate must also be shipped. The stone and soil must be shipped to a site, processed and mixed and the reloaded for delivery to the project site. This can become a significant energy footprint.

The Attributes of a Soil Cell System

A soil cell system provides architects and site design professionals with a methodology that allows trees to be planted, maintained and matured in a variety of urban settings. The system provides room for the large volumes of soil that are necessary for tree growth and root expansion. The system allows for the installation of pavements over tree roots without causing damage to the roots or the health of the tree as the frame provides the necessary structural support for pavements without the need for soil compaction or the addition of large volumes of stone aggregate. The system also provides a means for tree installation around utilities as the modular frames can be installed around existing utility lines without requiring expensive re-routing.

The soil cell system is comprised of rectangular plastic modules filled with soil. This modular plastic structure supports pavements using a post-and-beam frame and a deck. The space below the deck and within the frame is filled with lightly compacted soils that can absorb and treat stormwater and that provide a large enough soil medium for the tree and the expansion of its root system.

The frames and decks are made of recycled polymer and can be stacked up to three modules high and can be spread out laterally to any required width. Because they are modular, they can be adjusted to fit irregular urban conditions. The open frame module has about 92% void space, thus making it easy fit in and around utilities. Modular underground soil cell systems are designed to meet AASHTO H-20 loading standards.

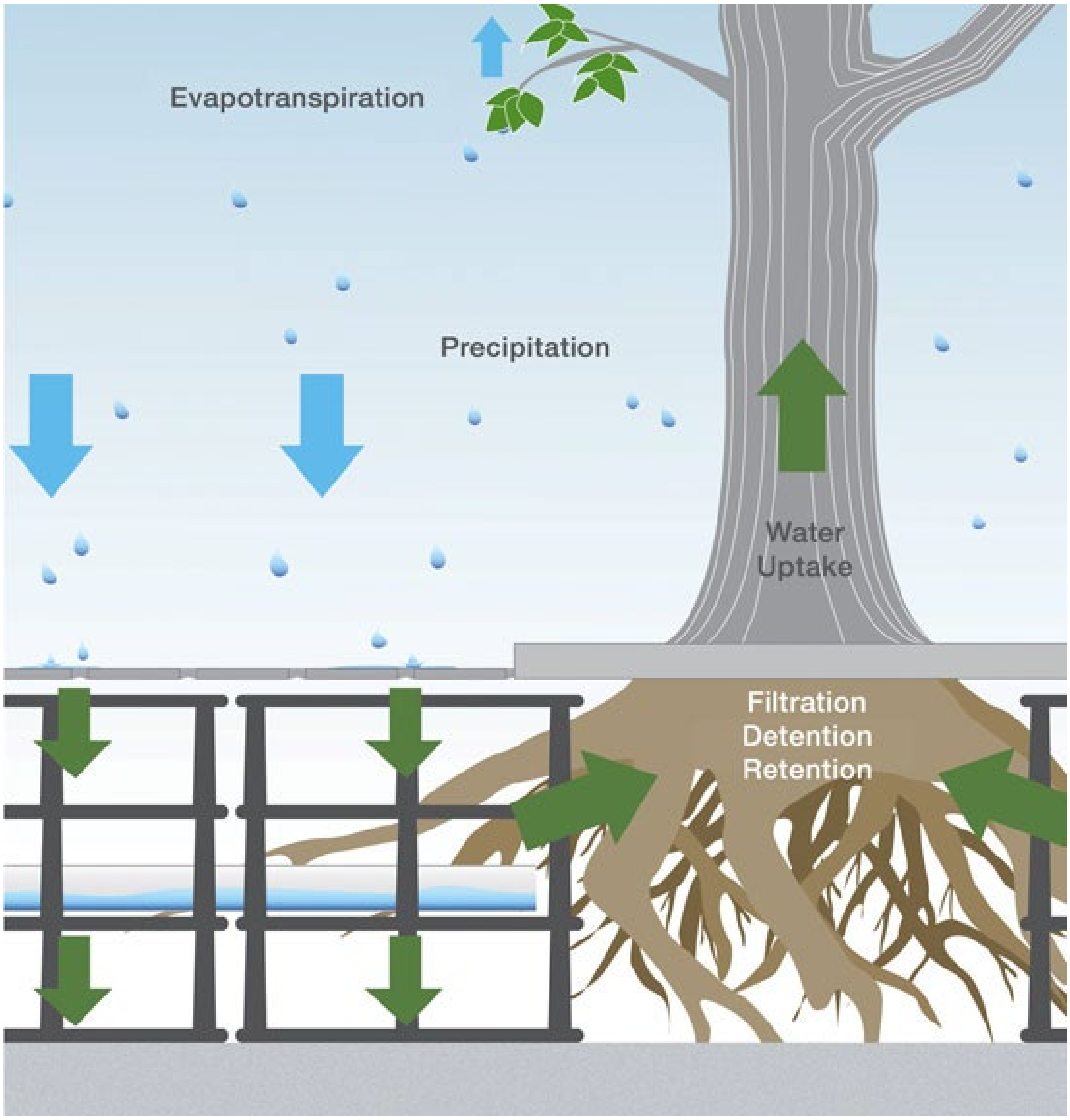


The modular frame of the soil cell system provides a structural support for pavements as well as space for increased soil volume.

Image courtesy of DeepRoot Green Infrastructure

A soil cell system provides not only for increased soil volume but allows for a less compacted, and thus, better quality of soil. Due to the plastic frame in the soil cell system, the infill soils do not require stone aggregate or densely compacted soils to provide structural support for overlying pavements. Minimally compacted soils are better quality soils. They provide the air and water spaces necessary for tree root expansion and tree growth. Also, soils with air and water spaces allow storm water to penetrate through to groundwater areas thus serving as a means of storm water management. Soils in the soil cell system are usually fine-grained loamy soils that are slow draining. Soil draining soils have good capillary capability and this attribute provides a wider, more even distribution of water. Slow draining soils also hold the water for a longer period and, thus, they are able to filter pollutants before the water enters the groundwater.

As a soil cell system can utilize most of the loamy soils that are found at project sites, and as there is no need for including stone aggregate in the soil layers, there is less of a need for processing, mixing and delivering the soil mixture to the project site and thus, there can be an energy savings. The recycled plastic modules along with the use of local soils can contribute points towards meeting sustainable design criteria.



A concept sketch showing how the soil cell system functions.

Image courtesy of DeepRoot Green Infrastructure

The following table provides a summary of the characteristics comparing a soil cell system and a structural soil system.

CHARACTERISTIC	STRUCTURAL SOIL	SOIL CELL
Best soil type for use with product	Specific clay loam soil texture	Variety of soil types many of which are existing at site
Efficiency of Loam-soil volume	20%	92%
Soil character	Clay—loam, rapidly draining	Fine grained loam, slow draining
Water harvesting availability	Good	Good
Capillary capability	Fair with water lost to vertical drainage	Good with wider, more even distribution of water
Rainwater retention effectiveness	Rapid draining (approx. 24 inches per hour) so waters is not effectively retained. Pollutants cannot be effectively filtered	Slow draining so water is retained. Pollutants can be effectively filtered.
Sustainability criteria	Made from process hard aggregates that require significant energy to mine, crush and ship. High energy footprint due to shipping and large volume of materials	Lower energy footprint due to lower volume of soil materials. Locally sourced soils and recycled plastic materials are used.

The following are some Case Studies illustrating the applications where a soil cell system has been used to meet sustainable design criteria by:

1. Containing and managing storm water

2. Augmenting the tree canopy and reducing heat island effects

3. Providing shelter for wildlife and promoting biodiversity and

4. Enhancing community aesthetics

Managing Storm Water via a Soil Cell System

Vandergrift, Pennsylvania has been at the forefront of developing design guidelines for urban forests as well as implementing projects to enhance their urban forests. The Vandergrift-streetscape project occurred in an old historic district. The project designers explored a number of options to help them minimize CSO and water quality problems while nourishing large tree growth within the streetscape. The project designers decided to use a soil cell system to manage storm water and CSO issues. Because this was an existing urban streetscape, the use of a soil cell system allowed the designers to provide a quality planting condition for trees with minimal change to the urban fabric. The designers were able to use the native soils at the site and underdrains were provided for future connections.

Use of modular underground bioretention cells around existing utilities was a factor considered by the designers at the Aurora Avenue Secret Rain Garden along Route 99 near Seattle Washington. A rain garden was designed along one side of a roadway to provide a separation for pedestrians. The designer, Curtis LaPierre of Otak, Inc. created a design that integrated permeable pavers, curb cuts and a modular underground bioretention cell system. These modular underground bioretention cells extended the rain garden underneath the pavement. Storm water from the road enters the rain gardens through the pavement and curb cuts and is absorbed into the soil, providing irrigation for the plantings as well as recharging of the groundwater. The project area had a limited right of way and large paved areas. The design solution provided additional traffic lanes, wider sidewalks, better storm water management and increased green space.

The Aurora Avenue streetscape project in Seattle, Washington during the installation of a soil cell system.

Photo courtesy of DeepRoot Green Infrastructure

As more municipalities update their codes and design guidelines for increased on-site storm water management and increased urban forest canopy, a modular underground soil cell system provides an option for achieving these criteria. In this case study, the modular underground soil cell system provides the structure to support the overlying pavement while creating an underground vault for containing soil and managing water. This integrated system of soils within a modular underground support frame provides a larger and better planting medium for urban trees, creates a simple and effective method of capturing and treating rain and storm water at the source, and allows designers to plan for more extensive, functional, and sustainable urban green space.

The Aurora Avenue streetscape project in Seattle Washington utilized a soil cell system to capture storm water into rain gardens.

Photo courtesy of DeepRoot Green Infrastructure

To Enhance Landscape Environments

The University of North Carolina campus in Chapel Hill used a soil cell system to expand the root volume for a large plaza of trees. The designers wanted the new trees to grow to similar sizes. The consistent amounts of shared soil volumes in this soil cell system allowed this to be possible. Over 700 modular frames were used throughout the entire plaza area with twelve trees sharing the space. This provided over 700 cubic feet of soil per tree. Bald cypress trees were used in the new plaza area because they are an underutilized native species that meets the new campus landscape standards.

Sand set pavers were used for the plaza pavement thus allowing the capture of some storm water and surface water at tree openings. These trees will provide a shady gathering space to enhance the campus landscape. These trees are also projected to have a longer life span and the project will be monitored by the university to determine the effectiveness of the soil cell system and it possible future use as a campus design standard.

At the University of North Carolina, Chapel Hill, a soil cell system was used to provide ample soil volumes for native bald cypress trees at a new campus plaza.

Photo courtesy of DeepRoot Green Infrastructure

Meeting Sustainability Requirements

Compliance with new sustainability regulations and criteria can be met through the use of a soil cell systems. In 2011, landscape architecture firm CMG designed a courtyard for a large technology company based in Menlo Park, California. The landscape architects proposed a design that caused the impervious surface area to increase from 40 percent to 60 percent. This increase necessitated that the design meet California's C3 requirements, which mandate that 85 percent of the storm water runoff over the lifetime of the treatment facility be captured and treated.

CMG landscape architects decided to use a soil cell system to provide a planting environment that was lightly compacted, provided ample amounts of soil for the trees, and provided underground bio-retention areas under the pedestrian pavements.

The primary considerations by the designers for these bio-retention areas were as follows:

1. Treatment of major pollutants in surface and rain water

2. Seasonal groundwater levels

3. Geotechnical concerns

4. Distribution of treatment flows to bio-retention areas

5. Overflow requirements

6. Pollutant removal rates

Geotechnical issues and seasonal groundwater levels were addressed through the engineering and design of a soil cell system that was developed based on a review of the site's existing soils and existing seasonal groundwater levels. The engineering evaluation was critical to ensuring that the paving section and adjacent buildings remained stable. This soil cell system included an under-drain to address groundwater levels and heavy soils with limited infiltration capacity. Treatment flows were directed to the bio-retention soils through slot drains and perforated distribution pipes. The distribution pipes ran the entire length of the treatment area and distributed treatment flows to the underlying bio-retention soil. The pollutant removals were centered around removing Total Suspended Solids (TSS) from the bio-retention areas.

A soil cell system was used to meet new storm water runoff requirements at a courtyard project in Menlo Park, California.

Photo courtesy of DeepRoot Green Infrastructure

Soil Cells Provide a Multi-Directional Approach to Urban Challenges

Toronto, Canada has been at the forefront for urban forestry initiatives. They have set minimum soil volumes for street trees of 30 cubic meters (1,059 cubic feet thus exceeding the 1,000 cubic feet recommended by James Urban) per tree, and they have also set a goal of increasing their overall tree canopy from 17 percent to 40 percent. A recent (2007) project for a six-block stretch of Bloor Street in the Bloor-Yorkville Business District involved the planting of 138 new London Plane trees. The trees were planted in the large volume (30 cubic meters) of soil to ensure their growth and health.

The project required the installation of trees within the existing utility framework. The new street design also included wider sidewalks and seasonal flowerbeds within a curbed planting island. Slot drains are used to capture rainwater on the sidewalk and direct it to small catch basins that remove debris and floatable materials. This captured rainwater is used to irrigate the soil volume underneath the sidewalks via a perforated pipe that extends throughout the Soil Cell system.

The soil cells in the Bloor Street project meet a number of new design criteria for urban forestry in that they provide the required amounts of soil, they capture rain water and help to manage storm water runoff, they use captured rain water to irrigate the newly planted trees, they satisfy engineering loading requirements for pavements and both new and existing utilities were integrated into the soil cell system.

The City of Toronto, Canada used a soil cell system to plant 138 London Plane trees and capture rain water along six blocks of Bloor Street in their downtown area.

Photo courtesy of DeepRoot Green Infrastructure

How Much Does it Cost?

Earlier in this article we briefly compared the soil cell system to structural soils. The soil cells system is initially be more expensive than the structural soil system and definitely more expensive that the initial cost of conventional planting of trees in a small tree pits. However, studies have shown that the soil cell system is comparable to the cost of using structural soil on a net soil volume basis. Long term costs have not been studied but there may be a definite long-term savings in cost over conventionally planted trees as a soil cell system provides a longer life span for the tree, reduces issues with tree root heaving of pavements and reduces issues with storm water flooding and management in urban areas.

Conclusion

Emerging Trends Relating to Urban Trees

Municipalities are implementing minimum soil volumes for tree plantings. The most ambitious of these tree-planting programs is in Toronto, Canada where there is a requirement for 30 cubic meters (1,056 cubic feet) of soil per tree. A soil cell system allows this large volume of soil to be provided without compromising the visual design of the project. With a soil cell system, pavements and other site elements can be installed with the required compaction densities without compromising the volume or quality of the underlying soil. A soil cell system can also be used in areas where bio-retention swales and rain gardens are inappropriate or cannot be used.

Municipalities are also implementing more stringent storm water management regulations and in some instances enacting storm water utility fees when a project is not able to adhere to these newer regulations. These new regulations incentivize developments that keep storm water on the site and manage it at the source. A soil cell system provides a means of managing storm water at the source where it hits the ground. The large volume of soil within a soil cell system has a high water absorption capacity and is able to filter pollutants through the fine-grained slow draining soil.

Sustainability standards and criteria that address heat island effect, storm water capture and management and treatment of polluted storm water can all be addressed through the use of a soil cell system which provides more supportive and sustainable growing conditions for urban trees.

The Advantages of a Soil Cell System in Urban Projects

A soil cell system provides designers with the ability to meet the challenges of urban environments and install trees in more locations, in better growing mediums and in a more sustainable manner. As a soil cell system provides larger volumes of soil, it provides trees more room for root expansion and also allows for a greater variety of tree species to be planted. In a soil cell system the soil is less compacted and more friable with extensive air and water spaces, thus creating a better growing medium for trees. The system also allows designer to use a broader range of soils in the tree planting medium and this can be a cost and energy savings as more local in-situ soils can be utilized without the need for transporting soils to the project site. The system with its modular frames allows trees to be installed within the existing framework of utilities, again providing another cost saving measure to the project as utilities need not be relocated. A soil cell system can help to meet sustainability criteria and new sustainable codes and guidelines as the system can absorb rain and surface water and assist in the management of storm water and the treatment of TSS pollutants.

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