

An introduction to growing urban trees in structural soils

Large trees provide valuable ecosystem services and they are a key component of green infrastructure. Small trees provide only a tiny fraction of these benefits and so it is important that landscape designers provide suitable environments for trees to live long enough for them to deliver returns on the investment of planting and maintaining them in the early years of establishment.

A structural soil is a stone-based growing medium that can support pedestrian and vehicular traffic, and so their use allows tree pits to be extended beneath hard surfacing. This enables designers to provide enough soil for a tree to be healthy and reach maturity.

When designing tree pits with structural soils rainwater that has been collected from roofs, roads and paved surfaces is diverted into the tree pit. Trees grow extremely well in tree pits constructed in this way and the approach also contributes to stormwater management systems.

It's now possible to build tree pits with structural soils in the UK by using the products supplied by Stockholm Tree Pits and this practice note aims to explain how to do it.



Figure 1:
These trees are growing in a structural soil beneath a pavement. The long shoot extension and uniform growth of the avenue shows that all of these trees are very healthy.



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Tree pits beneath hard surfacing

Just as a potted plant can grow too large for the volume of soil in the pot, so can an urban tree reach a size where its growth becomes limited by the available root space. When the root system cannot increase in size any longer because the rooting space is filled to capacity, crown growth will slow and the tree will develop a stunted appearance. Water stress becomes more frequent and severe, which makes plants more susceptible to secondary disease and insect problems. When stress becomes severe, decline will begin. This is why it is common to see urban trees in poor health, and trees planted in hard landscaping often die young.

The typical street tree is situated in a narrow strip between the road and adjacent buildings and has to compete for underground space with a variety of utilities. Under these circumstances trees rarely have enough soil to allow them to grow to a size where they provide significant benefits. In order to solve this problem, there is a need to construct **submerged tree pits** that extend tree pits beneath areas that are used by pedestrians and cars. Specially engineered tree pits are required to create a functional rooting environment beneath a hard surface (see Figure 2).

- + *Allow tree pits to be extended beneath hard surfacing* - Tree pits can be made larger so that street trees are provided with enough soil to live long and healthy lives
- + *Uses rainwater to irrigate the urban trees* - Water is diverted from aboveground into the tree pit where it can be taken up by tree roots
- + *The approach allows oxygen to reach the soil* - Roots need oxygen to respire and structural soils provide pathways for gaseous exchange between the soil and the above ground atmosphere

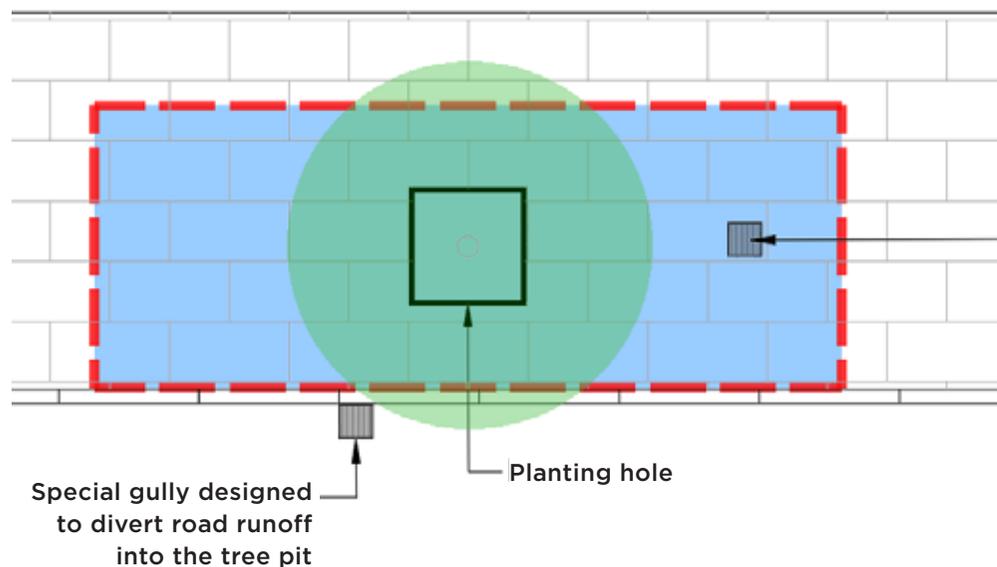
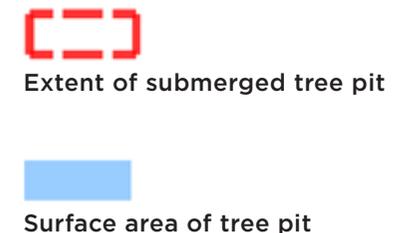


Figure 2:
The key elements of a submerged tree pit





What are structural soils?

A durable road or pavement needs a solid base. The traditional method to constructing a reliable surface is to dig down to nearly a metre and install a sub-base with aggregate ranging in particle size from about 100mm down to dust. These aggregates are highly compacted to meet load-bearing requirements and engineering standards. This often stops roots from growing, causing them to be contained within a very small usable volume of soil without adequate water, nutrients or oxygen. A typical tree used for street planting needs a root volume of at least 20m³ (and preferably a lot more) at maturity (say 50 years) but often the hole dug in the pavement to form a tree pit less than 2m³. Trees planted this way will suffer from ill health and won't make it to maturity. Furthermore, because the roots can't enter the hard-packed base they often grow into the thin layer of coarse sand beneath the surface and cause trip hazards by lifting the pavement.

This new approach, which has been evolving in Europe and the USA for some years, is now rapidly gaining ground in the UK. It involves the creation of a stone-based 'structural soil' which can be compacted to provide a solid base for surfacing while allowing large voids to remain for water movement, air diffusion and tree root growth. Structural soils can meet engineering standards for supporting pedestrian and vehicular traffic whilst at the same time providing enough soil for a tree to be healthy and reach maturity. The design encourages roots to grow deep underground and so they don't lift the pavement. The tree planting programme carried out by the City of Stockholm has demonstrated that exceptionally healthy trees can be cultivated when using structural soils.



Figure 3:
Most of a structural soil is made up of clean stone. After the stone has been compacted, and a soil mix added, there remains a network of interconnected voids between the stones. These void spaces provide opportunities for root growth, air diffusion, and water movement.

+ Provides a solid foundation - The compacted stone that makes up the structural soil meets the necessary engineering requirements to support a load-bearing surface

+ Prevents surface rooting - The design ensures root growth happens deep below the surface and so footpath disturbance is avoided, and future surface maintenance requirements are minimised

+ Easy to install - The components of structural soils are easily available and can be installed using standard construction machinery

+ Tried and tested - Structural soils have been proven to be a cost-effective way to provide for the needs of both engineers and trees

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The Stockholm system (structural soil with biochar)

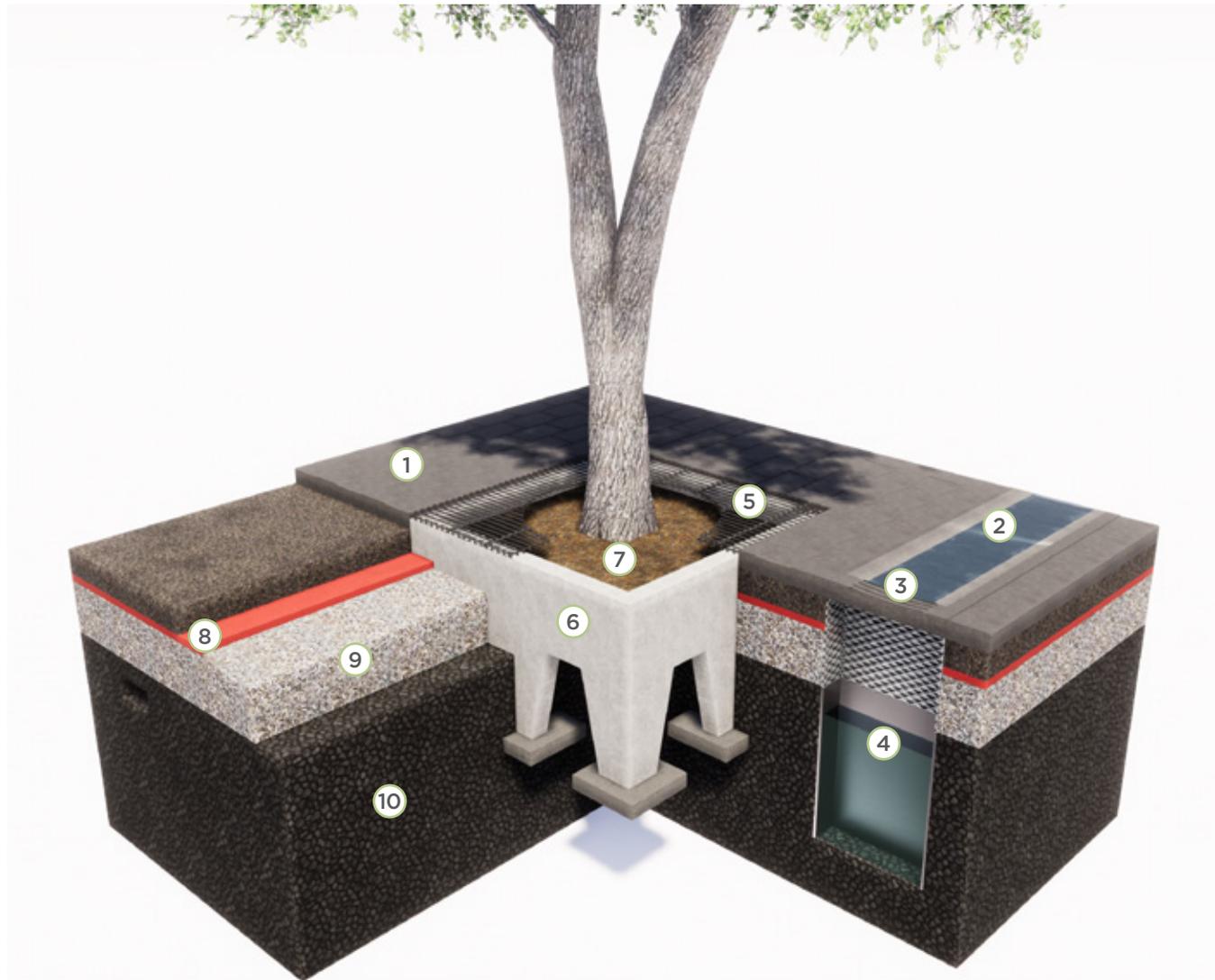


Diagram notes:

- 1 Standard paved surface with base course (this does not need to be permeable)
- 2 Channel to divert rainwater into the tree pit
- 3 Inlet/gully grate for water ingress and gaseous exchange
- 4 Aeration well with silt trap (available from www.stockholmtrepits.co.uk)
- 5 Tree grille
- 6 Concrete frame (available from www.stockholmtrepits.co.uk)
- 7 The concrete frame is filled with topsoil
- 8 Separation geotextile
- 9 Aeration layer, this is a 200mm layer of 20-40mm clean stone. Water from the inlet(s) is also distributed through this layer.
- 10 Structural soil is made up of 32-63mm clean stone combined with a 1:1 mix of enriched biochar and compost (15% volume)

[Image courtesy of Davies Landscape Architects]



The SuDS benefits of structural soils

In most built-up areas rainwater is diverted away from the trees into storm attenuation systems, but this is a waste of an important resource because the local street trees would benefit from receiving that water. This Stockholm system collects rainwater from roofs, roads and paved surfaces and diverts it into the tree pit. This type of tree pit design serves the soil's need for oxygen by incorporating large inlets that provide pathways for gaseous exchange and water ingress. An aeration layer of clean stone is included between the paved surface and the structural soil, this aeration layer is linked to the inlets to allow air and water to reach the whole of the tree pit. The inlets are deliberately designed to be at the low point of hard surfaced areas so that they receive as much rainwater as possible. Runoff from the roads can also be diverted into the tree pits using roadside drains (see Figure 4). Therefore, trees planted in this way contribute to Sustainable Drainage Systems (SuDS). Urban trees provide all the functions associated with SuDS, including the interception and storage of rainfall at source, the filtration of pollutants, the provision of amenity, and supporting local wildlife. Studies have found that access to stormwater increases the growth rates of street trees during the establishment period compared to traditional street tree planting techniques. **In the modern age stormwater management and urban tree establishment should be part of one integrated design.**



Figure 4:
An example of a street where road runoff is being diverted into a submerged tree pit via a kerbside inlet.

- + Managing rainfall close to source** – *The leaves of the trees can intercept rainfall before it hits the ground, and the transpiration of the trees also removes water from the drainage system before it leaves the site*
- + Stormwater attenuation** – *Allows the water retention capacity of a new development to be increased and so reducing volumes of runoff discharged to receiving waterbodies and sewers*
- + Source control** – *Tree pits function as a source control for water-borne pollutants by degrading or immobilising contaminants that pass through them*
- + Amenity benefits** – *Large urban trees provide significant public amenity, they bring obvious visual appeal to many urban landscapes and their leaves can intercept airborne particulates that are harmful to human health*
- + Habitats for wildlife** – *Urban trees bring wildlife benefits by providing habitats for a wide range of other organisms*
- + Increased growth rate** – *Trees that have access to stormwater grow more quickly and are less likely to suffer from drought stress*

Advantages of structural soils over crate systems

Modular plastic structures (crate systems) or structural soils can be used to support surfacing above tree pits. Both systems are a good way of growing healthy urban trees but structural soils are more versatile because they can be installed around existing underground structures whereas crate systems need to be installed in a rigid geometric shape. Also, crate systems are difficult to dismantle and reassemble if they ever need to be moved but structural soils can easily be dug up and reinstalled if any underground maintenance works are required.

The biggest advantage that structural soils have over crate systems is that they are much cheaper to install. Structural soils also accommodate more water than loam soils and so they can contribute more to SuDS schemes by reducing peak flows and the volume of runoff. There are additional environmental benefits because crate systems involve the use of large quantities of plastic, and their use risks spreading micro plastics into the environment downstream. Furthermore, the materials used for structural soils are more sustainable than plastic crates because the stone, biochar and compost can all be made of recycled material.

When comparing the two approaches the manufacturers of the plastic crate systems will cite old studies where trees planted in crates performed better than structural soil mixes. However, there have recently been significant innovations in the design of tree pits for structural soils. One important new design feature is the introduction of the aeration layer. Soil aeration is an important factor in tree growth and tree pits designed for structural soils now cater for this need better than any other technique. The use of enriched biochar in the soil mix is another key innovation because it improves the water holding capacity of the soil and provides better nutrient availability.



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- + **Structural soils are cheaper to build than crate systems** – Allowing the landscaping budget to stretch further
 - + **Free from plastic** – Crate systems require lots of plastic material but structural soils do not
 - + **Sustainable** – Structural soils can be made of recycled materials
 - + **Ecological** – Biochar provides habitats for soil microbiota



Constructing tree pits with structural soils

A pre-cast concrete planting frame is used for the planting hole to house the rootball. This also functions as a root deflector by ensuring that roots can only grow deep beneath the surface. The concrete planting frame has rigidity which allows stone to be introduced and compacted around the planting hole during the construction of the tree pit. The frames are either 1m² or 1.2m² which means that a standard tree grille can be fitted above.

The similar-sized stones are installed in layers and once the material has been laid it is effectively a macadam¹ sub-base. The best results are being achieved by using clean stone combined with a 1:1 mix of enriched biochar and compost (15% volume). Specifiers should be aware that the stone fraction of the soil mix fills the tree pit and that the biochar/compost mix adds nothing to the overall volume of the soil because it fits into the void spaces between the stones.

Biochar is produced through pyrolysis (burning at 350 to 800 under partial exclusion of oxygen). The resulting material is durable and its large surface area has a high affinity for nutrients. Adding biochar to soils directly sequesters carbon and produces soil that have a high carbon content. There are a variety of ways that biochars improve soils and these include reducing the bulk density, enhancing soil aggregation, improving the water retention capacity of the soil and reducing leaching of trace metals from the upper horizons of the soil profile. It also has excellent filtration properties which remove waterborne contaminants. Another benefit of biochar's structure is that it provides micro-habitats for soil organisms.

¹Macadam is a type of road construction in which single-sized layers of small angular stones are placed in shallow lifts and compacted thoroughly.

PRODUCTS AVAILABLE

Concrete planting frames and steel aeration wells and biochar are available to buy from www.stockholmtreepits.co.uk

Specifications for these products can also be downloaded from the website

MATERIALS CALCULATOR

Download the spreadsheet from the Stockholm Tree Pits website to calculate the materials that you require for your project. [stp-materials-calculator.xlsx](#)



Figure 5:
A structural soil tree pit in the process of construction. Here larger stones are being used so that the final surface will be able to support heavy traffic.

[Photograph courtesy of Björn Embrén]



Constructing tree pits with structural soils

The load bearing element of the structural soil needs to be a hard angular stone such as crushed granite, basalt or recycled concrete that has been screened to remove fines, for most installations this will be 32-63mm clean stone. Crushed limestone can be used in the structural soil mix but it influences the soil pH and so only alkaline tolerant species should be planted in this scenario. It is recommended that the stone is mixed with the biochar/compost mix before being installed. Larger stones (40-75mm) are used for roads because they can support heavier loads. When the larger stones are used the biochar/compost mix should be hosed into the void spaces after the stones have been compacted.

The top 200mm beneath the surface courses is clean stone (20-40mm), and this layer provides pathways for air and water to reach the whole of the extended tree pit via the aeration wells. The aeration wells are installed within the structural soil mix, they receive rainwater from the hard surfacing above; they also trap any silt and debris that is washed down with the water.

Impermeable tarmac or **any sort of paving can be laid on top of tree pits constructed using the Stockholm system.** A geotextile is laid over the entire tree pit followed by a base material for the pavement and the surface layer for the specific paving of the road, pavement, or cycle path to be installed. The membrane prevents the surface's base material from migrating down into the aeration layer and it also prevents roots from growing up into the base material. In this way the aeration layer ensures that root growth is well below the final surface and so problems caused by roots lifting pavements are avoided.

Standard machinery found on most building sites can be used to install structural soils. Also, the low-tech approach means that the surface can be dug up after the pavement has been laid if any future ground works are required, and shallow underground services can be installed in the gap between the pavement and the tree roots below.

Over 4000 projects using this approach have been completed in Stockholm, and after 10 years of monitoring tree pits created using structural soils the Swedish National Road and Transport Research Institute (VTI) now endorse the use of this tree planting technique.

Structural soils are an acceptable infill material for highway construction as defined by the Specification for Highways Works Volume 1, Series 600 - Earthworks. Structural soils fit the Class 6C specification and compaction requirements for such materials are provided in Table 6/1.

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Other types of structural soil

A stone-soil mix called CU-Structural Soil was developed at Cornell University in the early 1990s. Broadly speaking this mix is 80% stone and 20% soil by dry weight with a small amount of hydrogel to prevent the soil and stone from separating during the mixing and installation process. The stone component is highly angular crushed rock that ranges from 20mm to 40mm in size, with no fine materials. When this stone is compacted, friction between the stones at contact points locks them together. The compacted stone and soil mix has 26% void space for the storage and dispersal of air and water. The second component of the mixture is a clay loam soil that partially fills the void spaces between the stones. This mix is suitable for use below lightly trafficked areas such as cycle paths and car parks.

There is a large body of research that relates to CU-Soil and guidance for its use and installation is freely available. A particular advantage of using CU-Soil its precise composition allows designers to calculate how much water a tree pit will be able to hold.

Site specific structural soil mixes can also be made which may allow aggregate materials generated by demolition works to be recycled (e.g., crushed brick or concrete), provided that they are strong enough to support the required loading. Careful monitoring is required when recycled aggregates are being used to ensure that they meet the relevant specifications. Local soils can also potentially be used to provide the soil component of the mix, but these should be tested first because they may need to be amended before use. If a soil is not mixed properly it will not uniformly supply optimum growing conditions for the tree, and so quality management systems need to be put in place to ensure that the soils put into a tree pit have been mixed in accordance with the specification.

All of the materials required to create structural soil mixes are readily available, however mixing them and installing them requires careful oversight. Porosity is an integral property of structural growing media and so it is important not to completely fill the pore spaces with the soil component, i.e., it's better to add too little soil than too much.

Structural soils are a low-impact solution for creating shared surfaces that allowing the long-term survival of trees in streets, car parks, and plazas.

FURTHER READING

Embrén, B. (2009).
Planting Beds in the City of Stockholm, A Handbook.
 City of Stockholm.

Construction Industry Research and Information Association (2015).
CIRIA 753: The SuDS Manual.
 CIRIA, London.

Trees and Design Action Group (2014).
Trees in Hard Landscapes: A Guide for Delivery.
 TDAG, London.
[.tdag-trees-in-hard-landscapes](https://www.tdag-trees-in-hard-landscapes.com)



Installing structural soils

The structural soil ingredients should be mixed on a flat surface using an excavator with a spreading bucket. Care must be taken to ensure that the soil mix retains moisture and consistency from the mixing point to its installation. In order to maintain a consistent mix the material should be covered if it is stored for any length of time to prevent any surface washing of the outer layer during a rain event.

The structural soil should be laid in lifts of no more than 250mm and spread with the excavator bucket. At each stage the fill should be compacted by a vibrating compactor plate.

Structural soils can be placed around underground services. The services can be protected from root ingress by wrapping them in a suitable geotextile or by installing them inside plastic ducting. Fragile pipes or infrastructure can be protected in the standard way by surrounding them with a pipe-bed gravel mix (4-10mm clean stone).

New tree pits can be created in existing streets by excavating a hole and then filling it with structural soil, and growing conditions can be improved around existing street trees by removing existing soil with a vacuum and replacing the soil around the root system with the stone/biochar/compost mix.

RESOURCES

The compost and the biochar fit into the void spaces between the stone and so they add nothing to the overall volume of the mix; so, for example 20m³ of structural soil would require 20m³ of clean stone and 3m³ of the biochar/compost mix. An easy-to-use spreadsheet to calculate the components required is available at [stp-materials-calculator.xlsx](#)

Designs for water inlets and aeration wells and PDF files of key reference texts are also available for download.

Mature Size of Tree

	Very Small (<5m)	Small (5-10m)	Medium (10-15m)	Large (15-25m)	Massive (>25m)
Recommended volume of structural soil	8m³ (6m ³ if shared)	15m³ (12m ³ if shared)	26m³ (20m ³ if shared)	36m³ (28m ³ if shared)	45m³ (35m ³ if shared)
Recommended number of air/water inlets	1 (0.5 if shared)	1 (0.5 if shared)	1	2 (1.5 if shared)	2

SOIL VOLUME GUIDANCE

Detailed guidance on the size of tree pits for different species is available from www.stockholmtrepits.co.uk



Drainage

Designers need to ensure that tree pits have adequate pathways for water ingress and to allow gaseous exchange between the soil and the above-ground atmosphere. This could be provided by installing a permeable surface over the whole of the tree pit or by using a non-permeable surface with specially designed inlets. Permeable surfacing allows rainwater and air to reach the soil directly from above but supplementary inlets to help them reach the lower levels of the tree pit are recommended. Suitable inlets would be substantially larger than an irrigation tube and service the whole of the tree pit. The surface should be designed to have inlets at local low points so that the tree pits receive as much rainwater as possible, the planting hole can sometimes be used to collect surface water if it is designed to be highly permeable and lower than the surrounding surfacing.

Unless there is good drainage in the surrounding soil engineered tree pits need drainage included as part of the design in order to prevent the tree pit from becoming waterlogged. The tree pit drainage should be designed in such a way that the rainwater passes through the soil before it is drained out of the tree pit.

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Alternatively send an email to enquiries@stockholmtrepits.co.uk

RESOURCES

CAD diagrams for the design of tree pits with structural soils are available from www.stockholmtrepits.co.uk

Designs for water inlets and aeration wells and PDF files of key reference texts are also available for download.

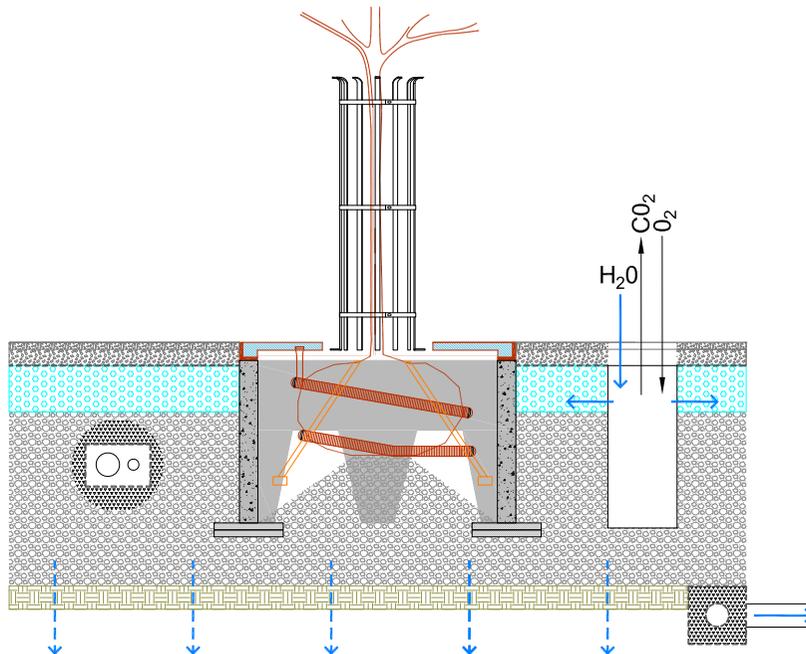


Figure 6:
Design for a submerged tree pit with structural soil.

Summary

Typical urban soils are very unlike natural soils and so tree planting sites need careful design in order to support healthy and long-lived trees. In the past the lack of understanding of the tree's requirements has led to them being planted with inadequate soil volumes; ultimately this results in urban trees having short lives and only providing a small fraction of the benefits that they could potentially be bringing to towns and cities.

With competing demands for space in the modern street we need to be creating submerged tree pits that can support pavements whilst allowing tree root growth beneath. Structural soils are one of the simplest solutions to this problem because they can support heavy loads and simultaneously provide soils suitable for root growth. If structural soils are to be used they need to be installed in engineered tree pits and the tree pits have to be designed provide adequate water infiltration, drainage, air diffusion, soil, and nutrients to support the tree into maturity. By installing structural soils beneath pavements and car-parking spaces designers can provide enough soil for an urban tree to reach a degree of maturity that will deliver returns on investment by providing benefits to local communities.

Stockholm Tree Pits can supply the concrete planting frames and the aeration wells required to construct the tree pits. Stockholm Tree Pits can also supply Carbon Gold Tree Soil Improver biochar in bulk and at a discounted rate. This is an enriched biochar that improves soil structure and is proven to boost the health and vitality of trees.



There are three key factors that tree pit designs need to include:

Soil volume – Designers need to specify enough soil to support the tree at its mature size

Water – Trees need a continual supply of water if they are to thrive. In the urban environment a tree's water supply can be naturally sustained if rainwater is collected and diverted into the tree pit

Air – Roots respire in order to generate energy, and this process requires oxygen. Therefore, pathways need to be provided for gaseous exchange between the soil and the above ground atmosphere



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CONSULTANCY SERVICES

Stockholm Tree Pits specialises in the design of urban tree pits and offer this as a consultancy service. We can assist in all stages of a project, from initial masterplanning through to detailed design and the supervision of tree pit installations. Please get in contact if you have any questions about how to design or construct tree pits using structural soils.

We are here to help, call us now on 07872 609633
or email enquiries@stockholmtreepits.co.uk