Trees in Hard Landscapes

A Guide for Delivery

Consultation draft

Trees & Design Action Group

The Chartered Institution of Highways & Transportation

CIBSE

Institute of Chartered Foresters

ice Institution of Civil Engineers

Trees and Design Action Group

The Trees & Design Action Group (TDAG) is a pioneering group of individuals, professionals and organisations from both the public and the private sectors who have come together to increase awareness of the role of trees in the built environment throughout the United Kingdom.

The group shares the collective vision that the location of trees, and all the benefits they bring, can be secured for future generations by influencing the planning, design, construction and management of our urban infrastructure and spaces.

Now a registered charity, TDAG was established in 2007. It is not-for-profit and apolitical. Its membership, online publications and information are free. This approach enables TDAG to assimilate ideas and knowledge independently of organisational hierarchy, profit or commercial interests.

More information found at:
www.tdag.org.uk

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Foreword

Urban trees can make a significant contribution to a sustainable, integrated infrastructure approach, promoting value and economic development, climate change adaptation and human health and wellbeing. However, changes are taking place which need to be understood and incorporated in decision-making.

Firstly, there is more competition for the space beneath our streets, with an ever-expanding network of pipes and cables. This, of course, must be taken into account by those planning trees.

Secondly, there is a significant change in the way in which streets are used, designed and managed. They are no longer just for getting from A to B, they are the places where people live and work and street designers are increasingly aware of the need to ensure they meet the requirements of all of those who use them, be they motorist, cyclist, bus-user or pedestrian.

Thirdly, changes in weather patterns, particularly more frequent extreme rainfall, mean that we need to take a new approach to managing surface water in towns or cities, with a greater emphasis on water-sensitive urban design.

Finally, there needs to be an understanding of the factors to take into account in order to choose the right tree for the right place.

Trees in Hard Landscapes has been developed to help highway engineers, developers, tree officers and all those designing our urban spaces to make the right decisions at the right time in order to include urban trees in their designs. It provides principles on how to select, plant and maintain trees in our urban hard landscapes – our streets, civic spaces and surface car parks.

I congratulate the Trees and Design Action Group and the team which made publication of Trees in Hard Landscapes possible and I commend the document to all those involved in designing the public realm.

The challenge now is for everyone charged with the design and delivery of sustainable and inclusive public spaces to think how the “humble” tree can make a difference in the schemes they are developing.

Baroness Kramer
Minister of State for Transport
[Date]

Overview

Starting from the point where the decision to include or retain trees in a new development or retrofit scheme has been made, this guide explores the key building blocks for success.

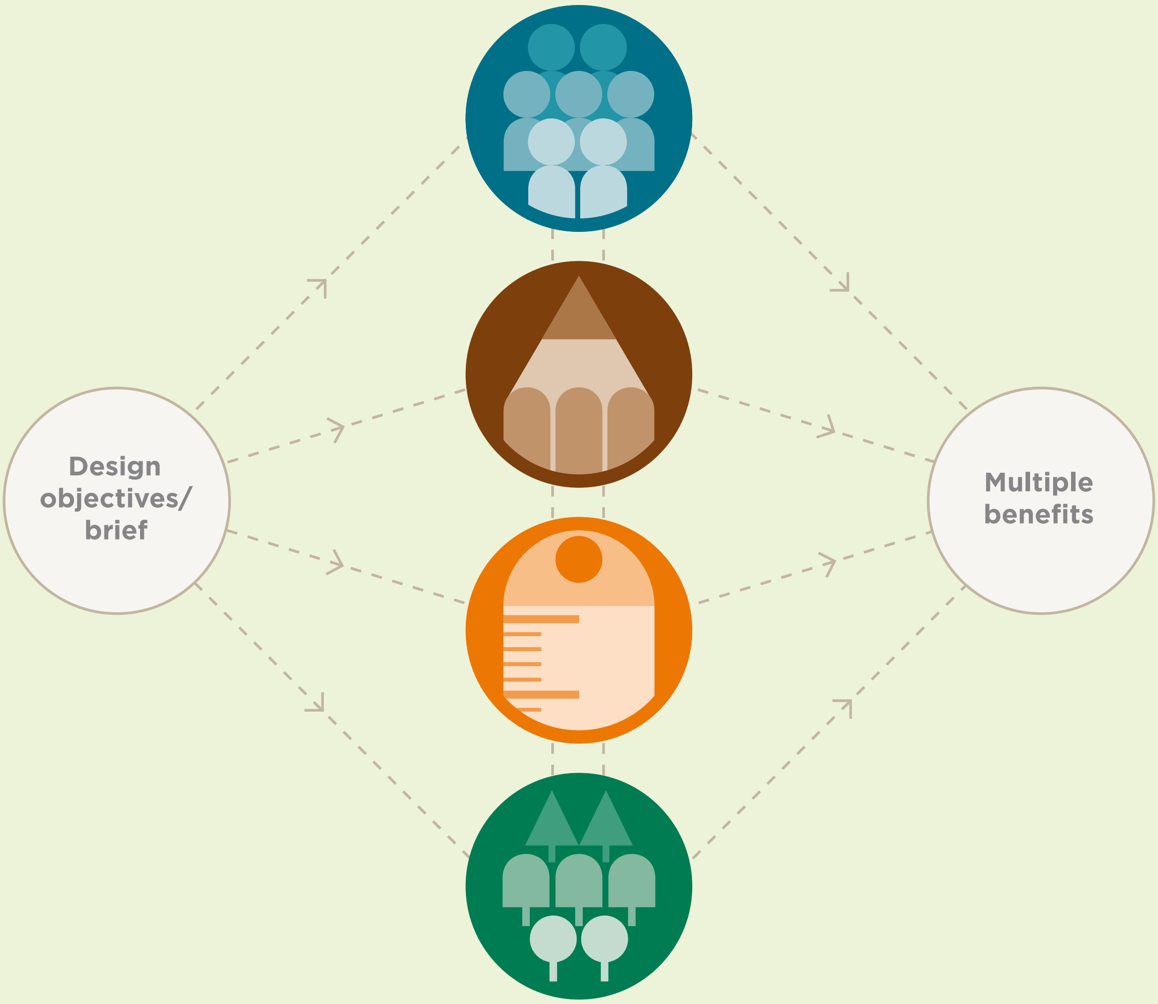
Maintenance and sustainability considerations are included throughout as they are key to ensuring that the early concept and vision produce the intended outcome over the long-term.

Collaborative Process
From project initiation to maintenance and monitoring, when, how and with whom joined-up working needs to happen.

Designing with Trees
Practical strategies to ensure trees best contribute to the delivery of the design objectives of a project.

Technical Design Solutions
The available technical design solutions to build-in success, rather than failure.

Species Selection Criteria
The frame of reference to use as a basis for tree selection.



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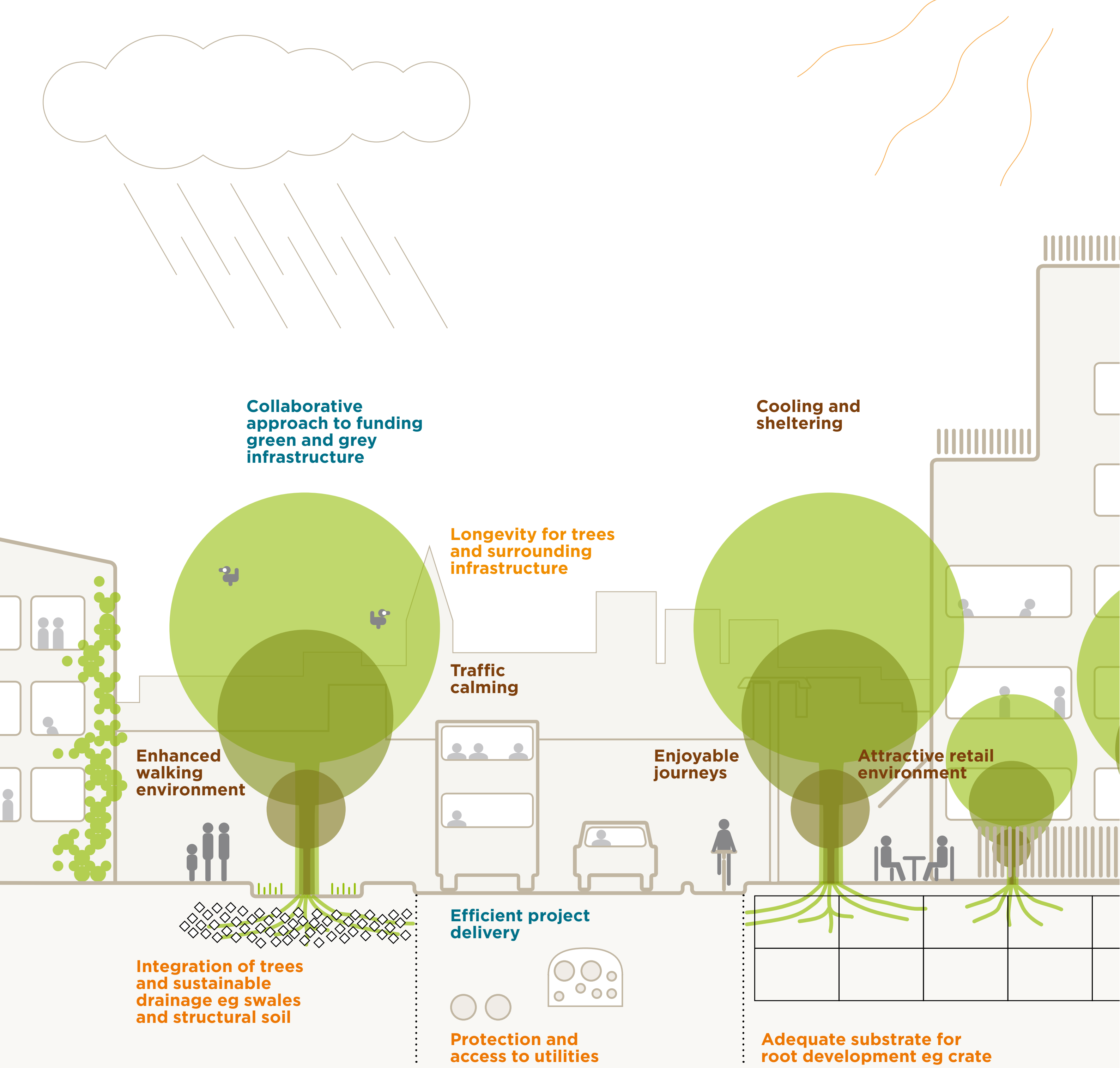
21st century opportunities and challenges



Collaborative Process

Weaving natural resources, especially trees, into the built environment requires a cross-disciplinary collaborative approach from project initiation through to design, implementation, maintenance and monitoring. This guide looks at when, how and with whom joined-up working needs to happen.

Designing with Trees

The inclusion or retention of trees is best approached as a means to an end rather than as an end in itself. Achieving long-term benefits and value from trees requires a concerted strategy. This guide explores current evidence on the enabling factors that turn trees into functional components of the hard landscapes in which they grow.

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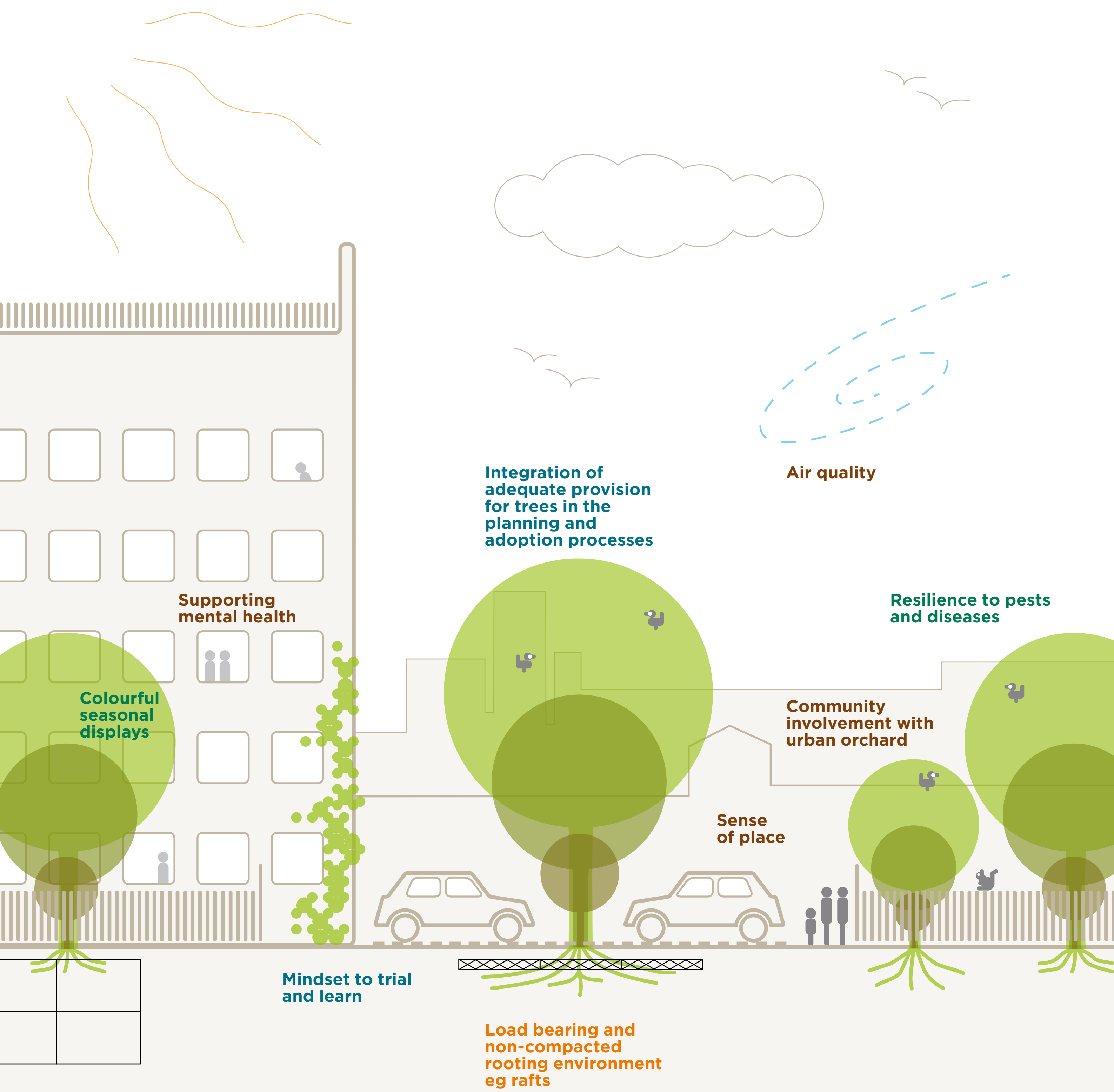

Technical Design Solutions

Design of the below-ground environment is key to achieving long-term compatibility between trees and the built infrastructure that surrounds them in towns and cities. This guide examines innovative and available technical solutions to help build lasting success from investing in trees.

Species Selection Criteria

While tree species selection alone cannot make up for a poor design strategy or inadequate underground growing conditions, choosing the right tree for the right place is an essential final ingredient for success. This guide offers a five-step process for making the best shortlist of available options and achieving resilient and successful tree choices.

Introduction
The need for sustainable integrated infrastructure

The purpose of this guide

Trees in Hard Landscapes: A Guide for Delivery explores the practical challenges and solutions to integrating trees in 21st century streets, civic spaces and surface car parks. It builds on the principles offered in *Trees in the Townscape: A Guide for Decision Makers* to provide practitioners with advice and examples for project delivery, detailing process, design and technical options.

Investments in infrastructure are driven by wide-ranging agendas including economic development, health and wellbeing, housing, flood and water quality protection, climate adaptation and mitigation. In a context in which public resources may be limited and sustainable outcomes a priority, wise infrastructure investment will seek to satisfy more than one objective at a time. Research and practice demonstrate that, with care and understanding, integrating trees with other infrastructure can often help to achieve such a range of benefits.

However, the track record for achieving successful and lasting integration of trees in hard landscapes in the early 21st century has been poor. A comprehensive survey from 2004, published in the 2008 DCLG report *Trees in Towns II*, found a 25% failure rate for new urban tree planting and an average life of 12 years for street trees[1]. This is disconcerting considering that it is only through growth over time that trees can fulfil their potential to deliver returns on investment. The figures have not been updated in the past decade but the DEFRA commissioned draft report *Barriers and Drivers to Planting and Retaining Urban Trees* (March 2013) also voices strong concerns[2].

1 Department for Communities and Local Government (2008). *Trees in Towns II: A New Survey of Urban Trees in England and Their Condition and Management.* London: Department for Communities and Local Government

2 Found at: www.tdag.org.uk/uploads/4/2/8/0/4280686/btp_barriers_and_drivers_final_report_march_2013.pdf

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The context in which trees can thrive in hard landscapes is in a state of flux, offering new challenges and opportunities for success. With the advent of cable television and the internet, there is increased crowding beneath our streets. Utility records, where they exist, often present an incomplete and inaccurate picture of these networks. The way we use our streets is changing, with heightened consideration for cyclists, pedestrians and public transport. Those who design and manage streets are increasingly looking to local solutions to accommodate the needs of all users. Finally, with changes to weather patterns, and especially more rainfall, surface water management needs more comprehensive approaches. There is evidence from innovative practices around the world that trees can be valuable and versatile additions to strategies designed to alleviate the pressures on traditional water management systems while also offering cooling and UV protection when needed.

Reflecting this context and associated challenges, *Trees in Hard Landscapes* shows how different approaches can enable greater long-term compatibility between trees and other infrastructure. It offers those directly involved in creating and managing hard landscapes the common language and tools they need to achieve better performance and reduce long-term maintenance costs.

Starting from the point where the decision has been made to include or retain trees in a new development or retrofit scheme, this guide explores the key building blocks to doing so successfully, including:

1. **The role and opportunities for collaboration to secure better outcomes and value throughout the project lifecycle.**
2. **Practical strategies to ensure trees best contribute to the delivery of the design objectives of a project.**
3. **Technical design solutions to build in success.**
4. **A frame of reference to use when selecting trees.**

Maintenance and sustainability considerations are included throughout as they are the key to ensuring that the early concept and vision produce a successful outcome.

The focus of this guide

Trees in Hard Landscapes focuses on hard surfaced areas in urban settings such as streets, civic spaces and surface car parks. These hard landscapes are arguably the most challenging environments for growing trees, but they are also the areas where much is to be gained from their inclusion.

This guide does not advocate that trees should be planted in every street or public square, but rather looks at situations where, following due consideration of townscape influences and the historic environment, a decision has been made to include trees. It does not cover trees planted over built structures such as basements, or trees on podiums and roof gardens, as these require very specific strategies for successful delivery.

The audience for this guide

Trees in Hard Landscapes is aimed primarily at highway engineers, designers and tree specialists. It will also be of value to developers, planners, elected representatives, local communities and anyone involved in hard landscape design, construction and management.

How this guide was developed

Trees in Hard Landscapes was developed by the Trees and Design Action Group (TDAG), in association with the Chartered Institution of Building Services Engineers (CIBSE), the Chartered Institution of Highways and Transportation (CIHT), the Institution of Civil Engineers (ICE), and the Institute of Chartered Foresters (ICF). The acknowledgements section provides more details about the wide range of individuals and organisations who gave their time to steer, review and inform the content of this guide. Such a rich cross-disciplinary, knowledge-sharing effort would not have been possible without the generous financial support of 37 sponsors as shown on page 125.

Collaborative Process

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Collaborative Process
Securing value throughout the project lifecycle

Weaving natural resources into the built environment requires a cross-disciplinary approach.

The Department for Transport's *Local Transport Note 1/08 Traffic Management and Streetscape* (LTN 1/08)[3] sets out a generic design and implementation process for highway schemes from project initiation through to design, implementation, and maintenance and monitoring. This four-step approach can be applied to all types of projects from new developments to changes to existing streets and squares.

Informed by the experiences shared by highway staff, design leads and tree specialists during interviews, this section offers suggestions about when, how and with whom joined-up working on trees can fit within and contribute to this existing framework. Success factors and potential benefits are also highlighted. Where relevant, issues related to planning consent and infrastructure adoption are discussed.

3 Found at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/3810/ltn-1-08.pdf

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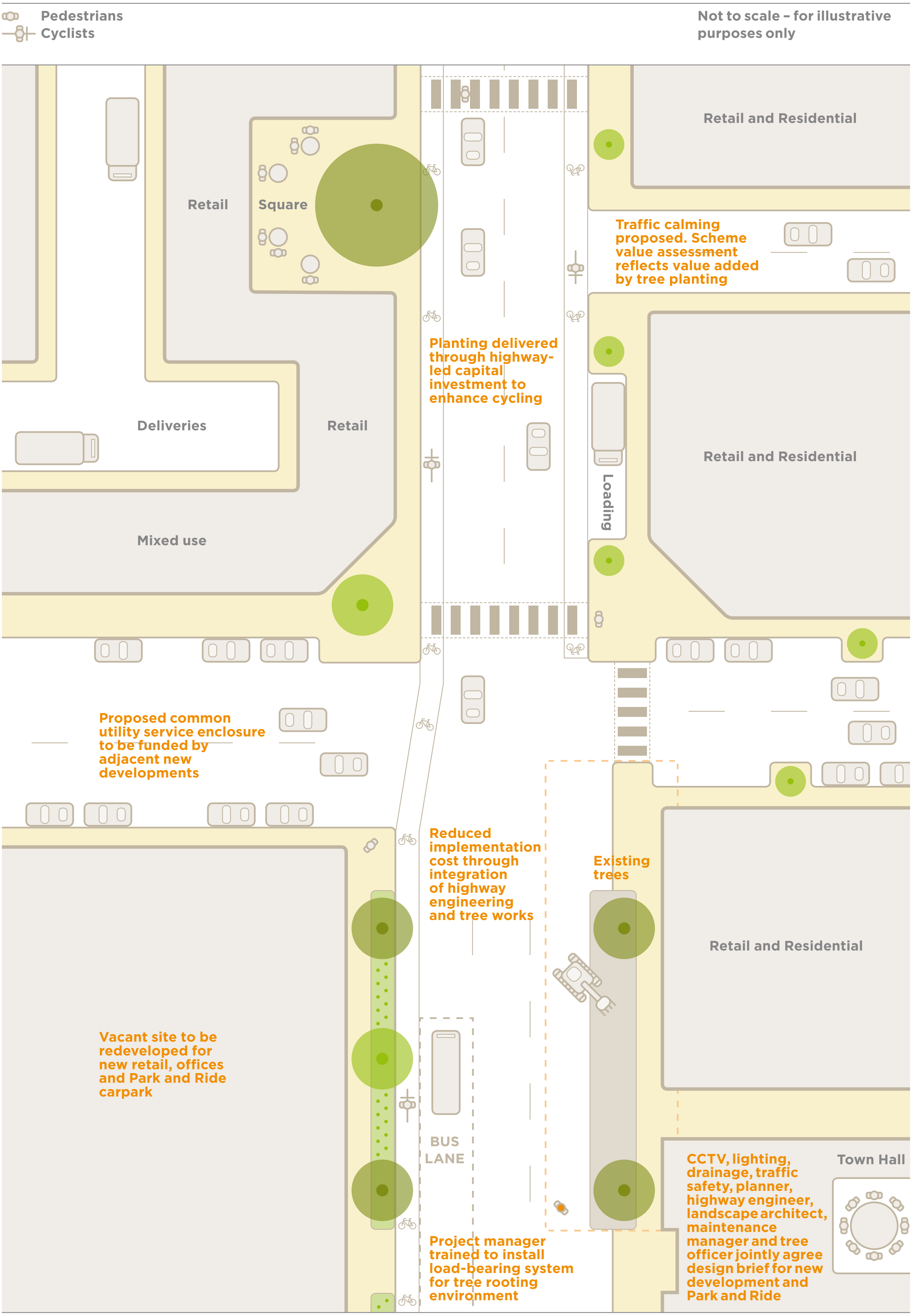
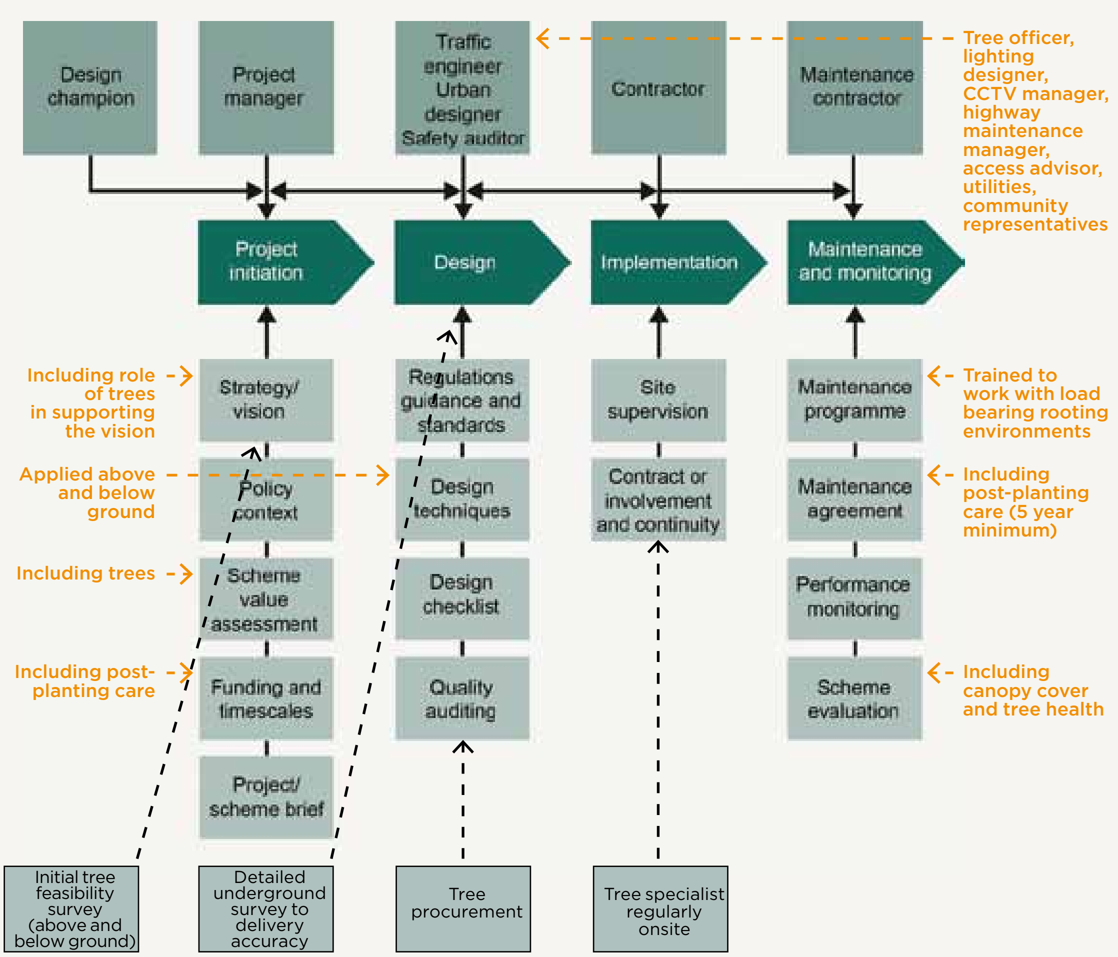

Pedestrians
Cyclists
Not to scale – for illustrative purposes only
Retail and Residential
Retail
Square
Traffic calming proposed. Scheme value assessment reflects value added by tree planting
Planting delivered through highway-led capital investment to enhance cycling
Deliveries
Retail
Retail and Residential
Loading
Mixed use
Proposed common utility service enclosure to be funded by adjacent new developments
Reduced implementation cost through integration of highway engineering and tree works
Existing trees
Retail and Residential
Vacant site to be redeveloped for new retail, offices and Park and Ride carpark
BUS LANE
Town Hall
CCTV, lighting, drainage, traffic safety, planner, highway engineer, landscape architect, maintenance manager and tree officer jointly agree design brief for new development and Park and Ride
Project manager trained to install load-bearing system for tree rooting environment

Integrating trees into the LTN1/08 design process, flow, inputs and outputs



1.1 A good start: leadership, project team and funding

1.1.1 The need for leadership

As *Trees in the Townscape* (Principle 9, pp56-61) highlighted, whether in local authorities or private organisations, leadership is required to create an environment of empowerment, mutual respect and trust, where there is pride in the inclusion of trees and a positive attitude towards resolving any conflicts their introduction may generate.

A strong message from the top is an enabling mechanism for empowering individuals to work as teams and successfully integrate trees in their projects. In practical terms, this requires:

- Clear standards for the protection, care and planting of trees in the local plan and/or other key policy documents, including local transport plans, highway design guides and supplementary planning documents addressing trees in new developments. Such standards may equally be set by private organisations in corporate policy documents (see the example of Land Securities on p23 and Tor Homes on p25 in *Trees in the Townscape*).
- Personal commitment from the elected and/or executive team to the policies and standards set.

The interviews conducted for this guide showed that success in integrating “green” (natural) and “grey” (engineered) infrastructure delivery also relies on leadership at staff level, including:

- Arboriculture or design staff who actively engage in policy work to articulate the relevance of trees within broader strategic policy or business agendas and place individual decisions within the wider framework of the overall management of the local tree population.
- Arboriculture and highway staff who feel confident in overseeing operational and construction work.
- Arboriculture and highway staff who share an interest in and appetite for innovation and learning. This is of particular importance when it comes to highways. It ensures that innovative approaches such as those designed to enhance the tree rooting environment

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beneath load-bearing hard surfaces can be examined and, potentially, trialled locally and embraced. Flexibility in the use of local standards to guide responses to proposed design is critical.

1.1.2 Integrating trees into the value argument and team composition

Building a shared vision for the tree project is highlighted in *LTN 1/08* (paragraph 2.3) and other guidance as an essential starting point.

For such a vision to provide a robust platform for later design stages, the role that trees and other "green" components are expected to play in supporting the delivery of agreed objectives needs to be articulated clearly.

This should be seen in:

- *The wording of the project brief*. The brief represents an opportunity to express the vision as well as describe the scheme's purpose and desired outputs. Existing policies on trees and the particular role trees may be able to play in the scheme should be made explicit, together with the capacity and

Case study 1
Melbourne's coordinated approach to streetscape projects

Location
Melbourne, Australia

Melbourne is aiming to double the canopy cover from its current 22.5% to 40% in 2040. To achieve this goal, the council's urban landscape department, which is leading the strategic planning, management and capital investment for the city's public open spaces (including parks, gardens and the "urban forest"), conducted a comprehensive survey of all the trees in Melbourne's streets. The survey looked at species, size and conditions to assess the useful life expectancy (ULE) of each tree. This database was then used to model how the canopy would evolve under different circumstances, including a "do nothing" scenario. The modelling showed that reaching the 40% canopy cover target would require planting an average of 3,000 trees a year for the next decade. The modelling did not focus exclusively on tree numbers but also considered how the tree planting conditions would affect canopy size. The process showed that achieving the target set would require moving trees on the other side of the kerb line, where there is more adequate below and above space to accommodate root and crown development, and where it is much easier to give the trees access to moisture. Extensive community consultation is underway to establish for each neighbourhood – or precincts as they are locally called – a ten-year urban forest plan identifying priority for tree planting and replacement, how the planting will support the local unique character of the area, and the benefits to be delivered through the planting. Delivery of such an ambitious urban forestry programme would not be possible without strong interdepartmental collaboration. To facilitate this, a streetscape coordination committee has been established bringing together, on a monthly basis, the traffic and parking, capital works and urban landscapes departments. The committee ensures that, wherever capital or refurbishment work is being planned in the highway, adequate green infrastructure provision is integrated into the projects, following the priorities and principles defined in the precinct plans. It also enables budgets and community engagement efforts to be shared across teams. Similar coordination takes place with the urban design team, when new developments make contributions to public realm improvements.

In its urban forest strategy, the City of Melbourne has committed to ensuring that future planting and management decisions will result in a dramatic increase of the diversity of the urban forest "with no more than 5% in any individual specie, 10% or any genus and 20% in any family". The strategy explains: "When managing financial assets, diversification is a basic rule for reducing risk. The same principle applies to urban forests, and tree managers around the world are investigating urban forest diversity. A greater range of species provides greater resilience and long-term stability for the forest as a whole.

Extract from the City of Melbourne's online urban forest map available at http://melbourneurbanforestvisual.com.au

resources available for long-term tree care.

- *The content of the scheme value assessment*. While the benefits brought by trees and other green elements are not always easy to quantify in monetary terms, the HM Treasury *Green Book*[4] recognises the importance of green infrastructure and emphasises that, "...material costs and benefits that cannot be valued in monetary terms should clearly be taken into account in the presentation of any appraisal or evaluation". A growing number of tools have become available to assess the replacement value of existing trees, as well as estimate the benefits associated with new trees.
- *The composition of the core and wider project team*. Input from tree specialists within the core team from the earliest stages will enhance the robustness of the work on the project brief and facilitate the value assessment recommended above. It will also help identify what level of site assessment might be required further down the line (soil test, tree safety audit, utilities mapping, etc), thus allowing for timely commissioning and delivery. It will help

Case study 2
South Shields' Ocean Road

Location
South Tyneside, England

One of the keys to building a sustainable future for South Shields in the North East of England is to strengthen the visitor and retail economy. Led by South Tyneside council's regeneration department, with strong input from the council's leadership team, the *South Shields 365 Town Centre Vision* changed the level of ambition for the borough's Ocean Road. This all-purpose urban A-road lined with restaurants and guest accommodation runs from the retail heart of South Shields's town centre to South Tyneside's sandy beach and parks – a natural asset that attracts 1.7 million visitors per year. The street, which carries an average daily traffic of 4,829 vehicles and high pedestrian footfall, had been scheduled for a simple refurbishment. It became a focal point for enhancing the distinctiveness of the public realm and the council's chief executive argued that the inclusion of trees would be one of the best ways to achieve this. Working as part of a multidisciplinary and cross-departmental project team, the asset management, infrastructure and design staff explored how to incorporate an avenue of 78 long-lasting trees in a shop front-lined street, delivering high accessibility standards for widened footways and new on-street parking. The design solution combined:

- A selection of hornbeams (Carpinus betulus), a tree that can withstand wind and saline content in the air. The cultivar chosen, called Frans Fontaine, has a column-shaped crown, which ensures that maximum visibility to restaurant frontages will be maintained. A trial planting of six trees was conducted in a nearby park to determine with business owners the best spacing for the trees. The council's landscape staff visited the supplying nursery soon after the project brief was finalised to select the tree specimen that would be planted over two years later.
- Use of below-ground engineered systems to provide a non-compacted rooting environment and good load-bearing capacity. The systems chosen were also designed to address utility constraints: a crate system (StrataCell) was preferred for the south side of the street where greater long-term access to utilities was desired while a raft system (Permavoid Sandwich Construction) was used on the north side of the street. Demonstration days were held with the product suppliers and the council engineering team to discuss the installation process and confirm that good access to utilities could be maintained where it was needed.

The project was funded through council revenue budget and local sustainable transport funding and regeneration funds. Phase one was completed in April 2014 and phase two is expected to be completed in September 2015.

Ocean Road newly completed in March 2014; choice of trees with column-shaped crowns maintains good visibility to shop fronts.
Image: South Tyneside Council

4
The Green Book: appraisal and evaluation in central government. HM Treasury, April 2014 update. Found at: www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

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Case study 3
Exemplar partnership for Dortmund Square

Location
Leeds, England

Located off The Headrow, right in the heart of Leeds, Dortmund Square has the highest pedestrian footfall in the city centre. Refurbishment of the square was scheduled for winter 2012-13 to upgrade outdated urban furniture and address tripping hazards found around five whitebeam trees (Sorbus aria). Planted with inadequate rooting space, the trees had, over time, lifted the surrounding flagstones, creating uneven surfaces for pedestrians. When removal of the whitebeams was identified as the best way forward, the Leeds city centre management team assembled a multi-disciplinary team to take a coordinated approach to their replacement. The team included representatives from multiple departments including highways, street lighting, CCTV management, parks and countryside, as well input from the city's disability specialist, the local police and managers from St John, the shopping centre overlooking the square. Parks and countryside staff successfully argued that for such a high use and high profile site, aiming for quality with one tree would yield greater canopy cover and long-term, conflict-free benefits than a like for like approach to replacement.

To enable the new tree to reach over 100 feet in height (30 metres) and live well over 100 years, the proposed design aimed to provide 25 cubic metres of non-compacted rooting environment supported by a crate system (SylvaCell). Around the base of the tree, accessibility, aesthetic and water permeability requirements were met by specifying a large area of flexible permeable surfacing. The St John shopping centre sponsored a circular bench to provide protection and enhanced use value for the tree. CCTV cameras were realigned to account for the change in obstructions created by the new tree.

Once the design was agreed, the work had to be carefully planned to avoid causing disruption to the Christmas shopping season. Excavations revealed a thick concrete slab, a high-pressure water main, two other water pipes and Victorian-era cellars, which did not feature on any of the available records consulted during design in spite of due diligence having been exercised in compiling information on the below-ground conditions. The planting location was slightly altered to avoid any risk of breaking the high pressure main, and discussions with Yorkshire Water resulted in a suitable approach for integrating the smaller water pipes into the installation. A couple of months after planting, one of the most severe springtime droughts on record hit England. The watering programme agreed with the maintenance contractor (1000 litres every week) was supplemented by St John shopping centre security staff who used a 100-metre hosepipe to supply an additional 200 litres a week at the peak of the drought. This proved to be a life saver for the tree.

Terms defined in the Glossary found on page 124 are highlighted in green throughout the document

Top left: The vision for the square

Top right: The SilvaCell installation integrates existing services

Bottom left: Tree planted and fitted with aeration/irrigation tube

Bottom right: Summer 2013, following completion with circular seating.
All images: Leeds city council

identify key consultees who should be involved in order to pre-empt any potential conflicts (eg engagement with CCTV managers).

1.1.3
Setting the funding strategy on the right track

Establishing a robust strategy for funding the successful integration of trees in projects relies on two tenets:

- Ensuring that the first five years of post-planting care, essential to enable a newly planted tree to successfully reach independence in the landscape (as per BS 8545:2014[5], paragraph 11.2), are budgeted for as part of the capital investment sums.
- Taking a partnership approach to designing a funding strategy. While dedicated "tree budgets" are often very limited, the multiple benefits trees can deliver – if well articulated in the value assessment or project brief and fully realised through the project design – can justify access to funding and resources ranging far outside the green sector. An overview of possible leads to pursue is provided below.

Funding and resources within the highway team's reach

Sources available to highway/roads teams across Britain typically include maintenance fund allocations from central government as well as complementary centralised funding for safety improvements and alternative transport development.

Highway/roads maintenance funding can be allocated from capital or revenue sources:

- *Capital sources* will cover scheduled structural renewal of highway assets. This is one of the most effective ways to plan and deliver an incremental increase of tree planting sites. Highway maintenance funds might be able to cover the full planting costs. If not, a recognised alternative is for the highway fund to cover the excavation of the planting hole and surfacing up to the tree opening, while the green asset team finds complementary resources for post-planting care as well as soil, plant and tree opening surfacing materials and installation. This cost-splitting approach requires good coordination between the highway and arboriculture teams. Advance notice of the structural renewal work schedule needs to be given to the tree officer, allowing for match funding (such as developer contributions) and procurement of works to be arranged in a timely manner.
- *Revenue sources* cover the repair of worn or damaged roads and facilities, either short-term patching or a permanent replacement. In addition to maintenance of the road surface itself, it also includes the cost of lighting, footway repair and cyclical maintenance of verges, which should include the safety inspection and pruning of street assets such as trees.

Complementary centralised transport funds are subject to rapid changes and are structured differently across Britain. These funds often allow the financing of new planting, including materials and installation costs. However, in most instances, the budget allocated under this type of grant funding has to be spent within the project timeframe. If trees are planted in the last year of a project, this leaves no resources for post-planting care, which must be covered by other means. Current examples of complementary centralised transport funds for England include:

- *Integrated transport block funding*. This funding covers all expenditure on new infrastructure such as improvements at bus interchanges and rail stations, local safety schemes, pedestrian crossings, footways, traffic management, route and junction improvements, and cycle facilities. Given the role trees can play in facilitating traffic calming and enhancing walking and cycling as well as improving junction legibility (see paragraph 2.2), integrated transport block funding is particularly well suited to providing capital funding for new planting.
- *Local Sustainable Transport Fund (LSTF)*. The LSTF is a £600 million DfT fund running until March 2015. The aim is to support the local economy and reduce carbon emissions through promoting greater use of sustainable and low carbon travel choices. The fund will continue in 2015/16 through the Local Growth Fund (£100m capital) and via a bidding competition directly managed by the Department for Transport (£78.5m revenue).
- *Cycle Safety Fund (CSF)*. The CSF is a £20 million DfT one-off grant scheme launched in 2013 and covering financial years 2012/13 and 2013/14. It has provided funding for over 80 local projects that are improving routes and junctions to enhance both cyclist safety

5 *British Standard 8545: 2014, Trees: from nursery to independence in the landscape.* Recommendations. London: BSI

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and the perception of safety for cyclists, which can be a real barrier to travel. As highlighted in paragraph 2.2.3, and demonstrated in several examples in this guide, trees can provide an effective asset under this agenda.

Through the planning process, highway or roads authorities can secure payments from new developments to create or improve existing highways. These are covered below together with mechanisms available to ensure new developments also include trees in car parks and other non-adopted hard landscapes.

Funding and resources within the planning team's reach
English, Scottish and Welsh legislation all contain provisions to allow local planning authorities and highway/roads authorities to secure payments from new developments to create or improve existing highway infrastructure and ensure that, where appropriate, trees are incorporated in newly developed or refurbished hard landscapes. In England, this includes:

- *Direct provision on new developments*. The most effective mechanism available to planning authorities to secure trees in streets and other public areas is to require planting to be carried out as part of the landscape design scheme associated with new development. Local authorities have a duty, under Section 197 of the 1990 Planning Act, to ensure the preservation or planting of trees wherever appropriate when granting planning permission. This would generally be practised through the use of planning conditions and Tree Preservation Orders. If a new development incorporates new roads or public spaces, including car parks, there is a very significant opportunity to integrate new tree planting with other elements, such as services, lighting, carriageways, surface treatments and adjacent structures. A robust landscape design scheme should ensure that all these elements are harmonised and trees selected to meet long-term objectives (see Sections 2 and 3 of this guide). The use of planning conditions should also ensure that the quality of materials, planting and aftercare meet acceptable standards, as recommended in this guide. It is vital in these cases to ensure that adopting bodies, such as a highway authority, are fully consulted on any planting proposals and are committed to the ongoing management responsibilities.
- *Section 278 Agreements*. A Section 278 (S278) Agreement (of the Highways Act 1980) is an agreement between the local planning authority and a developer which describes proposed modifications to the existing highway network to facilitate or service a proposed development (ie typically the scope of any off-site works that are required to mitigate the impact of the development on the existing road network). The S278 Agreement provides a legal basis for the responsibilities (financial and otherwise) of parties involved in constructing works on the public highway, typically including the agreed highway works design, payments associated with the works and possible claims, land provision and dedication.
- *Section 106 Agreements*. Section 106 (S106) of the Town and Country Planning Act 1990 is used to secure financial contributions from a developer, for example to fund improvements to the highway near to the development site. This might include tree planting or match funding for post-planting care as a complement to a central government capital investment package. Coordination between the local planning authority's tree and planning staff should ensure that appropriate policy and fund management measures are in place so that S106 money collected specifically as mitigation for tree losses or for treescape enhancements is ring fenced and can be only spent on tree planting.
- *Community Infrastructure Levy (CIL)*. CIL will increasingly replace the use of S106 Agreements as a source of funding for infrastructure related to new developments. Local planning authorities produce a CIL charging schedule, which must be approved by independent examination prior to adoption. Local authorities must include provision for tree planting and associated maintenance (or an appropriate umbrella category, such as highway or street landscape improvements or green infrastructure provision) within a Regulation 123 List (from the CIL Regulations 2010). Once this has been adopted, all development subject to CIL payments, which may vary both between and within authority areas, will contribute according to locally fixed tariffs. Section 106 contributions can then no longer be sought or applied for infrastructure included in the 123 List. The receiving authority must publish

annual reports indicating how the monies received have been spent. Some of the CIL receipts may also be passed on to parish or town councils or neighbourhood forums for local infrastructure provision, which could include tree planting and maintenance.

Funding and resources within the arboriculture team's reach

- *Its own tree budget*. There might be opportunities to optimise resource allocation between maintenance and planting and free up some resources for planting (see paragraph 3.1.2 of this guide). Long-term strategic planning is required to realise such opportunities.
- *Community sponsorship scheme*. Fundraising for popular local schemes through street parties and similar events not only helps with the budget, it also builds up strong community support and commitment for post-planting aftercare. In Bristol, one of the street parties held in 2012 as part of TreeBristol, the local planning authority's community engagement programme around trees, raised £3000 for trees in the adopted highway. In Leeds, the in-kind contribution provided by the local shopping centre in watering the newly planted plane tree in Dortmund Square proved essential to the survival of the tree during the 2013 spring drought (see Case study 3, pXX).
- *One-off national/local tree planting fund*. From time to time, national or local governments issue one-off tree planting campaigns associated with a grant programme. Often focused on achieving target numbers, these programmes typically do not provide resources for post-planting care or for addressing the more challenging hard landscapes situation.
- *Compensation claims resulting from damage to or loss of council trees*. A case study in Trees in the Townscape (p67) provides a good example of how, in the context of planned works by Wessex Water, Bristol City Council used the evaluation tool CAVAT[6] to retain mature trees and obtain monetary compensation for replacement planting where tree retention was not possible. Like Bristol City Council, the London Borough of Islington has embedded into its tree policy the principle of valuation and compensatory claim when loss or reduction of council tree value occurs: "The council will seek compensation from any external organisation responsible for significant damage to or removal of any council owned tree(s) to the value as calculated by CAVAT". For 2013-14, the London Borough of Islington estimates income brought from compensation claims to be in excess of £45,000.

Funding and resources accessible through other partnerships

Partnerships with other teams within the local authority, with other public bodies, third sector organisations, utility companies and other private organisations also offer significant opportunities to find resources for trees in hard landscapes. These may include:

- *Regeneration funding*, through partnerships with town centre associations and Business Improvement Districts as well as a local authority's regeneration team.
- *Health and wellbeing funding*, through engagement with the local clinical commissioning group and third sector organisations.
- *Housing monies*, through engagement with third sector organisations eligible to receive funds from responsible providers for greening housing estates.
- *Landfill tax credits funding*, through partnership with local voluntary organisations.
- *In-kind contributions* to conduct consultations, assist with planting and post-planting care through partnerships with local voluntary organisations, as achieved in Bristol (see Case study 13, pXX).
- *Partnership delivery with other infrastructure providers*. This might include water companies, where trees are integrated to local drainage solutions, as demonstrated in the Counters Creek example (see Case study 27, pXX). It is also not uncommon for energy companies and their alliances to fund tree planting as compensation for tree removal.

For updates and other examples, including funding sources available in Scotland and Wales, please visit the TDAG website at www.tdag.org.uk/trees in hard landscapes/funding for trees

1.2
Design: multi-discipline input and holistic above/below-ground response

1.2.1
Integrating trees into the site assessment process

For highway schemes, a quality audit is a process whereby a series of discrete

6
The Capital Asset Value Amenity Tree (CAVAT) method for evaluating trees takes into consideration both replacement costs and community value. More information can be found at: www.ltoa.org.uk/resources/cavat

7
Department of Transport (November 2011) *Traffic Advisory Leaflet TAL 5/11: Quality audit In the street design process.* Found at: www.gov.uk/government/publications/quality-audit

8
British Standard 5837: 2012. Trees in relation to design, demolition and construction. Recommendations. London: BSI

evaluations of design conditions and how the space operates are collected and given due consideration within the design process[7]. Other development projects equally require such an evaluation and trees are among the features that should be included in such assessments. This may include:

- An assessment of the safe and useful life expectancy of existing trees and their potential to be compatible with and of benefit to the future development and use of the site, as per the tree survey recommendations set out in BS 5837:2012[8]. This would consider species, location, current size, conditions of existing trees and their ultimate potential size. It would also assess the contribution of existing trees to the streetscape or overall quality of the site, and any potential conflicts or nuisance trees might cause.
- Wider context analysis of the treescape: types of trees in private properties, in adjacent streets, etc (see section 4.2 of this guide on the importance of tree diversity).

Some of the criteria applied for this initial tree survey should be kept in ongoing

Case study 4
Wirral Waters Green Streets project

Location
Birkenhead, England

Over the next 20 years, Peel Group's Wirral Waters regeneration scheme is expected to bring to Birkenhead's derelict docklands about 420,000 square feet of new office space and 13,000 new residential units alongside leisure and retail facilities. By April 2014, in advance of the scheme, over 600 trees across 8km had been planted in streets and green spaces within and around the Wirral Water area with another 600 due to be planted over the next two years. This ambitious scheme is part of Mersey Forest's Green Streets programme which combines extensive street tree planting with improvements to local parks to ensure that the setting for what is expected to be the largest regeneration scheme in the UK is as attractive as possible. The goal is to create green links between residential areas and places of employment and training so as to maximise the scheme's economic development and health impacts. Delivered in partnership with Wirral Council and Birkenhead Development Land Trust, the Wirral Waters Green Streets project is also designed to ensure that local people in the Wirral Peninsula feel a sense of ownership of the work that is happening in their area. Following consultation with local residents, the planting targets the main roads, including routes down to the Wirral Waters investment area, to Birkenhead, to the train station and to the Wirral Metropolitan College as well as routes to and through parks and social housing landscapes. Funding sources to meet the £1.46 million total cost are:

- The Local Sustainable Transport Fund (LSTF) through Merseytravel and the Department of Transport. The results of a door-to-door evaluation survey conducted in the project area played a key role in allowing the Green Streets project for Wirral to access LSTF: 25% of local residents suggested that Green Streets would encourage them to cycle to work more regularly and 15% said that they would walk more.
- The Forestry Commission's Setting the Scene for Growth programme supported by the Department of Business, Innovation and Skills (BIS). For Richard Mawdsley, development manager of Peel Group, there is no doubt that the green infrastructure investment underway in the Wirral Peninsula is critical to the future success of the Wirral Waters scheme: "Occupiers want a compelling place. It's more and more important to get the place right and give it an identity – a campus feel on the doorstep of a vibrant city. The green infrastructure will be at the forefront of the marketing".
- ForestClim, a European Interreg project on the role of trees and climate change adaptation.

The funding secured covers not only the planting costs but also the consultation and engagement process with local residents, as well as post-planting care for the first five years. Wirral Council will adopt the trees and take over management from that point onwards.

Before and after implementation of the Green Streets programme at the corner of Laird and Brassey Street in Birkenhead.
Before image: McCoy Wynne
After image: The Mersey Forest

monitoring of the performance of the scheme. This might include measurement of the increase in tree size and improvements to tree health (see 1.4.2).

Another essential dimension of the site assessment process is associated with the below-ground environment. Further details on this are in 1.2.2 below.

1.2.2 Proactively designing the below-ground environment

Understanding the below-ground conditions is particularly important when deciding if the inclusion of new trees is feasible.

Understanding the below-ground conditions is essential.
Image: Pr. Kai Bong, University of Birmingham

For all projects, early liaison with utilities is an essential first step in the feasibility assessment process. This should enable the project to:

- Compile utility asset data for the project area. With water companies it is important to explicitly request waste, surface water and clean water asset data because records for each of these tree elements are usually maintained in separate databases.
- Enquire about planned refurbishment or upgrades, and opportunities for joint-work scheduling, as was achieved along Hornsgatan in Stockholm (see Case study 25, pXX) and in Henley-on-Thames' public car park (see Case study 6, pXX), or joint problem solving, as underway in Counters Creek (see Case study 27, pXX).

Utility records often do not reflect accurately the layout and conditions of the subsurface. As a result further investigations will always be necessary to ascertain the availability of below-ground space for tree planting. The new *PAS 128: Specification for Underground Utility Detection, Verification and Location*, to be released by the Institution of Civil Engineers in the summer of 2014, differentiates between four different quality levels of underground survey ranging from the collection of utility records (quality level D) to exposing the pipes and cables using trial holes (quality level A). Each quality level is associated with different vertical and horizontal location accuracy levels. The detection of buried utilities is commonly done using geophysical techniques (such as cable avoidance tools and single or multiple frequency ground-penetrating radar) and the most appropriate technique(s) needs to be chosen depending on the expected pipe material, pipe size, depth and ground. It may be necessary to select more than one technique to achieve the highest detection quality level. Further guidance on utility surveys, including pros and cons of different techniques, is available at no charge from the Survey Association[9].

In the context of planning applications where trees are proposed, some local authorities, such as the London Borough of Southwark, are requiring survey proof that trees can be planted as shown on plan before permission is granted. When using such survey information in the context of planning application, it is important to understand the accuracy level of the survey data to be provided. Investment in information at this stage can provide significant savings later in the project.

Where new development or redevelopment occurs in conjunction with improvements to existing highways, opportunities to introduce the use of common utility service enclosures should be explored. In urban infill locations, the planning team has a critical role in proactively identifying locations where multiple redevelopments could jointly support such shared infrastructure. In larger new developments, the use of shared ducting site-wide should be a priority consideration. A holistic approach to the design and position of below-ground utility apparatus and above-ground landscaping – especially trees – is key to success. It is much easier to move a pipe or cable when it is only on paper than when it has already been installed. The lack of a joined-

9
See: *The Survey Association. Guidance Note – The Essential Guide to Utility Surveys*; and *The Survey Association. Guidance Note – Utility Survey method of measurement Issue 2*. Both found at: www.tsa-uk.org.uk/?page_id=24

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up approach to landscape (especially trees) and below-ground utility results in situations in which everyone loses:
- Trees might not be able to be planted where they would strongly enhanced the environment for those living or working near it or moving through it, as described in section 2 of this guide.
- Conflicts might easily arise if suitable tree choice and infrastructure design measures, as detailed in 3.4, are not taken, leading to the need for expensive remedial work.
- Opportunities to reduce the need for, or to downscale the size of, below-ground infrastructure might be missed: trees are of particular relevance to assist with the management of surface water runoffs and alleviate drainage networks (see 2.4 and 3.5).

Whether in the context of a private development or a highway scheme, design of the below-ground tree-rooting environment will be a determining factor of tree health and of successful long-term co-existence between trees and all surrounding infrastructure, including not only utilities but also hard surfaces and above-ground structure. Detailed advice on this is provided in section 3.

1.2.3
Securing early and substantial input from a tree specialist

Consulting a tree specialist on tree species selection and placement as well as sizing and design of the below-ground rooting environment is essential, not only when planting new trees, but also when refurbishing hard landscapes around existing trees. In the latter situation, lack of engagement with a tree specialist often results in missed opportunities to enhance the design of the rooting environment, and improve the longevity of both the tree and the surrounding infrastructure.

Depending on circumstances and project needs, such a tree specialist might be:
- A project advisor or consultant with adequate qualifications and experience in young tree establishment or remedial work on tree roots and tree rooting environments.
- The long-term tree manager/owner, such as the local authority tree officer.

The latter is particularly important as they know the resource limitations for long-term maintenance. However, refurbishing around an existing high value tree or planting in most challenging hard landscapes situations might require expert input from specialists in young tree establishment or root environment remedial work.

Involving the tree specialist(s) early in the design process will help to identify potential conflicts between trees and infrastructure, and allow the team to work out effective solutions collaboratively. This can be greatly facilitated by:
- A willingness to give and take: it is important for the tree specialist(s) to take a "whole urban forest" view, accepting that this may mean the loss, at times, of some trees as long as adequate provision for replacements is made (preferably using canopy cover or diameter at breast height as the point of reference – see *Trees in the Townscape* Principle 3).
- A readiness to consider proposed specifications that depart from local design standards and to take part in knowledge sharing sessions where technical issues can be discussed in the context of real life examples. For example, Norwich city council's tree officer invited the crate system manufacturer he wanted to use in the St George's scheme (see Case study 21, p XX) to facilitate a thorough in-situ discussion of the load spreading and installation issues that were of concern to his highway colleagues. The go-ahead for the project was agreed soon afterwards.

1.2.4
Designing with maintenance and adoption in mind

Post-planting care is important if longevity in the landscape is to be achieved. A full young tree maintenance programme with budgetary provision should be in place for all planting schemes. This maintenance programme should be in place for at least five years and include not just watering and re-staking but also formative pruning (see 1.4.1).

Beyond post-planting care, a tree should, for the most part, be healthy and self-sustaining. Future anticipated capacity for maintenance (in terms of technical skills, budget and time) should inform design choices. Seeking feedback on the proposed design from the maintenance team is essential to help determine whether the option being pursued is practical. Important topics to explore include:
- Ease of cleaning around the base of the tree.

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- The maintenance record of the materials proposed for the surface opening at the base of the tree (eg aggregate, permeable pour-in rubber, tree grille/grate, etc), including cost, frequency and ease of repositioning, repair, refill or replacement.
- Inclusion and maintenance of an irrigation and/or aeration system.
- Inclusion and maintenance of a silt trap and drainage outlet.
- Formative pruning and crown lifting.
- Provision for access to underground utilities.

> *"The designer must ensure that maintenance is simple and if not followed through for whatever reason, the consequences will not compromise the tree. Far too many trees have died because of bad design eg steel cages, metal tree grilles."*
>
> Howard Booth, Transport for London

1.2.5
Capitalising on trees for community consultation and planning permission

With many highway schemes there will be a need for thorough public consultation and involvement.

Bristol city council's highway staff found that by working more closely with the green space team's arboriculturists, greater inclusion of tree planting in schemes often eased the consultation process.

In the minority of instances where trees raise concerns (see the Brislington Hill example in Case study 13, pXX), the ability to take community groups on a tour of similar projects delivered jointly by the highway and the arboriculture team made a decisive impact.

For projects requiring planning permission, a positive approach towards trees can help facilitate the approval process. Such an approach will be demonstrated through:
- The proactive adoption of protective measures towards existing on-site trees or adequate replacement measures where this is not possible (see *Trees in the Townscape* principle 3 and Case studies on pp23-24).
- The inclusion of new trees provided with sufficient space and sustainable growing conditions.
- Articulating the value added by the planting of new trees and the retention of existing trees through the use of tree valuation methods, and using graphics to help visualise the canopy cover enhancement.

1.3
Implementation: joined-up work sequence and site supervision

1.3.1
Defining contracts, qualifications and roles

After a well-designed scheme with a competent specification has been prepared, the next stage is to implement it.

For a public works scheme, implementation may be handled in a variety of ways. A local authority may have in-house staff responsible for managing the project and, in some cases, undertaking construction, or they may go through a tender process to award the contract externally.

For private developments, contracts are usually awarded through a tender process.

In all cases, responsibility for specific aspects needs to be well delineated, and the delivery programme must clearly identify the order in which the work is to be undertaken. This is particularly important where load-bearing systems are integrated into the design of the root-growing environment (see 3.2).

Where existing trees are present, tenders and statements of work for construction or maintenance around trees should be explicit on qualification levels:
- Contractors undertaking work on trees should provide evidence of adequate insurance and an arboriculture qualification accredited by the relevant professional body.
- Contractors conducting specialised installations of load-bearing systems for tree planting (such as crate systems – see 3.2.2) should have access to adequate engineering expertise.
- Contractors working near trees (which is almost anyone conducting work on streets) should also demonstrate adequate environmental awareness (eg ISO 9001 certification).

Tender documentation, which includes contracts as well as references to

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relevant corporate policy, should also communicate very clearly the expectations of best practices to be followed:

- All contractors working in the proximity of trees should be required to abide by the relevant recommendations of BS 5837:2012.
- Contractors working on highways should be required to work to the latest version of the National Joint Utilities Group (NJUG)'s *Volume 4 Guidelines for the Planning, Installation and Maintenance of Utility Apparatus in Proximity to Trees*.
- Contractors working directly on trees should follow the relevant recommendation of BS 3998:2010[10].

Corporate policy should also make it clear that compensation will be sought in the case of non-compliance and tree damage. The contract needs to state the scope and amount of damages to be applied in the case of certain events. If a value is to be placed on a tree or trees, there will need to be a clearly defined set of contractual terms set out in advance stating how a tree is to be valued and how and by whom the extent of damage might be assessed.

More importantly, if/when breaches occur, enforcement needs to take place. This requires budgetary provision for monitoring and enforcing tender specifications.

1.3.2
Optimising the work sequence

Significant efficiencies can be realised through better integration of the work sequence between tree-related interventions and other construction work, as demonstrated below in the Bristol Bath Road (Case study 5, pXX) and Henley Waitrose car park (Case study 6, pXX) case studies.

10
British Standard 3998: 2010. Tree Work. Recommendations. London: BSI

Case study 5
Bath Road's integrated delivery model

Location
Bristol, England

When elm trees (*Ulmus New Horizon*) were planted in a newly built central reservation on the Bath Road/A4 corridor, Bristol's highways and green space teams trialled a more integrated way of sequencing works. The highway contractors built a new central reservation, including planting holes, while the arboriculture team was responsible for planting the trees. Had the two teams worked according to the traditional silos, the work sequence would have been as follows: (1) put traffic management in place, (2) conduct demolition and preparation, (3) build the central reservation complete with planting holes, (4) resurface the road, and (5) turn to green team and say "here are your tree pits". Instead, the arboriculture team was geared-up to be ready to bring in soil and plant the trees immediately after the central reservation had been built and while only the first layer of tarmac had been laid on carriageway. The canopy of the planted trees was left tied up to ensure no damage would occur while the resurfacing of the road was completed. Only then did the green team came back to untie and prune the trees. For both teams this resulted in a win-win situation: the new road surface was not damaged by the machinery used to bring the trees in or clogged with dirt, the trees were kept protected from damage and the costs incurred for traffic management were significantly lower than initially budgeted. There were also benefits and efficiencies in terms of reduced disruption to the public and reduced officer time required to correspond and liaise with local residents and other stakeholders affected by the works.

Bath Road in summer 2012 following completion.
Images: Bristol city council

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Case study 6
Joint working with Waitrose to retrofit trees in public car park

Location
Henley-on-Thames, England

When the time came to refurbish a South Oxfordshire council-owned car park located adjacent to a large Waitrose in Henley-on-Thames, the council and the retailer decided to work together. Waitrose customers were extensive users of the public car park and it needed resurfacing due to a combination of normal wear and tear, drainage issues and root damage caused by mature plane trees that predated the car park's creation. The original planting scheme comprised some 14 trees, predominantly rowans (Sorbus spp.), that had been planted when the car park was established. Due to soil compaction and lack of adequate rooting environment, the rowan trees were either missing, dead or dying.

Having been notified by the council's property management team that the car park was to be resurfaced, the council's arboricultural lead approached Waitrose to seek their support in integrating a tree replacement strategy into the project. A few years earlier the council had secured a financial bond for tree works in relation to another Waitrose site and both parties agreed that the Henley car park provided a good opportunity to use this fund.

The agreed strategy relied on the use of permeable asphalt over the root zone of the existing mature planes and a load-bearing crate system (SylvaCell) to plant four new plane trees to replace the rowans. The design of the rooting environment for the new planes also featured aeration and irrigation pipes connected to vents integrated into the new surfacing. The choice of large canopy trees combined with good design of the below-ground environment would ensure that, although only four trees were being replanted, the impact, in terms of shading, aesthetics and longevity, would be much greater while parking space would be maximised.

The first phase of the scheme consisted of the installation of two of the four replacement trees plus the laying of the permeable asphalt near those existing mature plane trees that were to be retained. This went ahead as planned in combination with the car park resurfacing work, allowing significant cost savings to be made since the tree work could be conducted with equipment and ground teams already on site. However, the cross-departmental collaboration that had enabled the successful delivery of phase one was not sustained. Drainage upgrade works that affected the area where phase two was expected to take place went ahead without prior notice having been given to the arboricultural team. The opportunity to use the tree-rooting environment to assist with surface water attenuation or to simply share costs on machinery use and ground workers was lost. When priced in isolation, the planting of the two remaining replacement trees proved to be twice as expensive as phase one and could not be accommodated within the available budget.

Top left: Surface damage around mature plane prior to resurfacing. Image: Martin Gammie

Right: New replacement tree, one year after planting. Image: Martin Gammie

Bottom left: Surrounds of mature plane post-reinstatement, featuring permeable asphalt. Image: Martin Gammie

1.3.3
On-site presence and supervision

Simple things can make a big difference to effective implementation and to the team confidence. For example:

- The presence of the tree specialist on site can help identify tree protection zones for existing trees and also contribute to the resolution of day-to-day issues for both existing and new tree planting. See Case study 13 on how Bristol appointed a dedicated tree staff to a large capital improvement scheme.
- It is essential that where/when less familiar techniques are used to enhance the tree rooting environment (through the use, for example, of one of the load-bearing planting systems), the construction manager and the tree specialist build a shared understanding of the construction details, work sequence and quality of workmanship required. In Lyon in France and Stockholm in Sweden, two cities where skeleton soils have been extensively used, training sessions for construction managers and/or site controllers are regularly held to continuously improve sustainable integrated infrastructure delivery capacity.
- Alliances are built if, as excavations take place and reveal an opportunity for tree planting (eg if utility apparatus is not where expected), the construction manager takes note and puts an offer out to his landscape design or arboriculture colleagues to fit in an additional tree.

1.4
Maintenance and monitoring

1.4.1
Post-installation maintenance is key

As highlighted in Annex G of BS 8545: 2014, provision of five years of post-planting care is essential. This should at least involve:

- Watering. For four to five months after transplanting, a tree exclusively relies on the water found in the soil within the root ball. Frequency and regularity of irrigation at this early stage is essential. The period over which irrigation is required is likely to be at least two full growing seasons.
- Checking and adjustments of tree stakes and ties or below-ground root anchor systems.
- Removal of support and protective devices when they are no longer needed.
- Checking that grates, grilles and other furniture do not damage or compromise the tree, taking remedial action where appropriate.
- Replenishing mulch at the base of the tree.
- Formative pruning. Nursery pruning is an integral part of the production process of trees but the branch structure created is usually temporary. Trees without formative pruning are more prone to develop defects. These in turn can shorten the tree life and put people and property at risk. Remedial pruning once trees have grown more mature is much more expensive. Formative pruning is therefore an essential part of the post-planting management and maintenance of transplanted trees.

1.4.2
Monitoring and continuous learning

A formal assessment of young tree health and development should be carried out annually, as recommended in BS 8545: 2014, paragraph 11.5.1. Monitoring should also include qualitative dimensions, as recommended in *LTN1/08* paragraph 4.2.

Local authorities may have obligations to monitor the performance of some schemes. However, other competing obligations, such as scheme delivery or resource restrictions, may compromise the achievement of effective monitoring. In larger schemes, it might not be feasible to find the time and resources to monitor all trees but it is recommended that at least a representative sample is monitored. Indicators might include tree cover and tree health.

Monitoring can empower the project team through:

- Learning about what works well and what does not.
- Enhanced understanding of the contractor’s performance.
- Increased opportunities to undertake adjustments before failure – requiring significant expenditure – occurs.
- Evidence to build the case for future investment in good practice.

1.4.3
Innovative approaches to contracts

Many different types of contracts are available to local authorities and other organisations to procure maintenance and works.

It is essential to review contractual arrangements very regularly to ensure the best procurement route is secured for the services to be delivered.

Case study 7
Research and development in the Greater Lyon Authority

Location
Lyon, France

A few years ago, excavation of Lyon's Bellecour Square revealed a set of mid-19th century underpinned footways and porous irrigation pipes that made use of gravity to take in surface water runoff. The discovery revealed that over 150 years ago the knowledge existed to build sophisticated green-grey-blue infrastructure – solutions which are only being rediscovered today. This was one of the triggers that led the Greater Lyon Authority's arboriculture team to make research and learning an explicit objective of project delivery. As a result, inclusion of an element of research and development in each major highway project is one of the key commitments written in the "tree charter" agreed by the Greater Lyon Authority (GLA) and 65 local authorities and other local partners. This "innovation principle" and continuous improvement approach is focused primarily on three themes: soil, water management and climate change. The R&D work associated with the Garibaldi project (see Case study 15, pXX) explores the last two themes.

As part of the Garibaldi Street refurbishment, an old underpass that had allowed cars to avoid ground level intersections is being converted to a rainwater collection cistern. Water from the cistern will be used for, among other things, the irrigation of the new planting areas. Trees will be integrated into the new streetscape created by the project. Beyond the first three growing seasons, irrigation will only take place during drought periods in the growing season. The objective is not only to ensure the vegetation survives, but also to maintain its ability to cool local temperature through evapotranspiration. One of the strategies trees use to manage water stress is to close the stomata on their leaves so as to limit water loss due to transpiration. Maintaining good water provision enables the tree to keep its stomata open for gas exchange and perspiration. Censors to be installed within and around the newly planted trees and vegetation strips, as well as around existing trees, will allow the team to quantify the cooling effect of vegetation at different stages of maturity and under different irrigation regimes. Censors are also being installed further down the street, where the refurbishment is to be completed in later phases, to provide control data. The cost of the censors installed are covered as part of the capital budget for the Garibaldi Street refurbishment while data analysis is being financed through the arboriculture team's own budget.

Garibaldi Street, after phase one refurbishment. Image: Frédéric Ségur

For further images see pXX and pXX

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Consideration should be given to:

- The impact of contractual choices on the quality of the work or services being procured and the diversity of a local pool of skilled contractors. The Greater Lyon Authority has embedded in its tree charter (see Case study 30, pXX) the principle of developing relationships with local nurseries so as to build a robust and traceable supply chain for its ambitious tree planting programme. It also requires the use of multiple local contractors for arboricultural work in order to build up local long-term capacity to deliver very high quality schemes economically.
- The sharing of contracts across council departments. Savings can be made in the delivery of routine maintenance activities through sharing contracts for services used by both highways and green space teams. The unit rates a client can secure will often vary according to the volume purchased. For example, within a local authority, a highway department may manage to secure a much lower car haulage rate than their green space colleagues. In Bristol city council, it is therefore common practice for the two teams to share contracts to procure services they both use. According to Russell Horsey, former arboricultural manager at Bristol city council, "There are two possible attitudes: 'I get you a budget to manage our highway trees and I don't want to hear from you' or 'let's work together and use each other's contracts to get better value'."
- The sharing of contracts across local councils. Some types of arboricultural work, such as planting and caring for young trees in hard landscapes, requires skilled labour. However, procuring such services on a single council basis might be too onerous or uncertain (in terms of the volume of works) to be practical. Yet resorting to the default contractor used for maintenance might not deliver the quality of services required. Procuring such specialised services on a cross-council scale offers a good alternative, allowing the spreading of the overall cost of the tendering process. The London Borough of Islington and other neighbouring councils are currently exploring this route for procuring tree planting services. The City of London is using the London Borough of Islington's contracts for tree works.

Whiteladies Road after completion of the GBBN scheme.
Image: City Design Group 2014, Bristol City Council

In Summary

Demonstrate leadership

- Ensure that there are clear policies for the protection, care and planting of trees in the Local Plan (for local authorities), Highway Management Plan and/or other relevant corporate policy documents.

- Demand and enable strong commitment to the implementation of adopted tree policies at all levels of the organisation through collaborative and cross-disciplinary working.

- Integrate the right range of tree skills and information (particularly on below-ground conditions) from the outset of projects.

Secure adequate resources

- Take a partnership approach to funding, capitalising on the multiple benefits designing with trees can deliver.

- Fund critical post-planting care from the capital investment budget.

- Explore community involvement in aftercare where appropriate.

Look after implementation and aftercare

- Secure competent implementation through a good specification and a delivery manager well briefed in or advised on technical solutions for trees in hard landscapes.

- Seek seamless integration of highway and treeworks – this will deliver better value for money.

- Explore innovative approaches to contractual arrangements, maximising opportunities for cross-department or cross-council sharing.

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References

Non-technical publications and resources

Professional publications and resources

Scholarly publications

British Standard 8545: 2014.
Trees: from nursery to independence in the landscape. Recommendations.
London: BSI.

British Standard 5837: 2012.
Trees in relation to design, demolition and construction. Recommendations.
London: BSI.

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Designing with Trees

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Designing with Trees
Using trees as positive assets

Principle 6 of *Trees in the Townscape: A Guide for Decision Makers* argues that "*the inclusion or retention of trees is best approached as a means to an end rather than as an end in itself*".

The guide further advises: "*When considering the aspirations for a neighbourhood, street or single site, the question should always be asked: how can trees support the vision for this place? How can trees provide solutions to the issues identified? [...] Designing with trees is a matter of trying to achieve a balance between securing the maximum required benefits with the least possible disadvantages*".

The list of benefits urban trees can deliver to their immediate surroundings is rich: quality of place, economic potential, health and wellbeing, nature conservation and habitat connectivity, local food and community links, traffic calming, surface water management, air pollution control, cooling and sheltering, noise abatement and more (see *Trees in the Townscape*, pp40-45).

Fully realising any of these benefits requires a concerted strategy that both exploits enabling factors and devises solutions to potential conflicts. This section explores the above-ground components of such a strategy.

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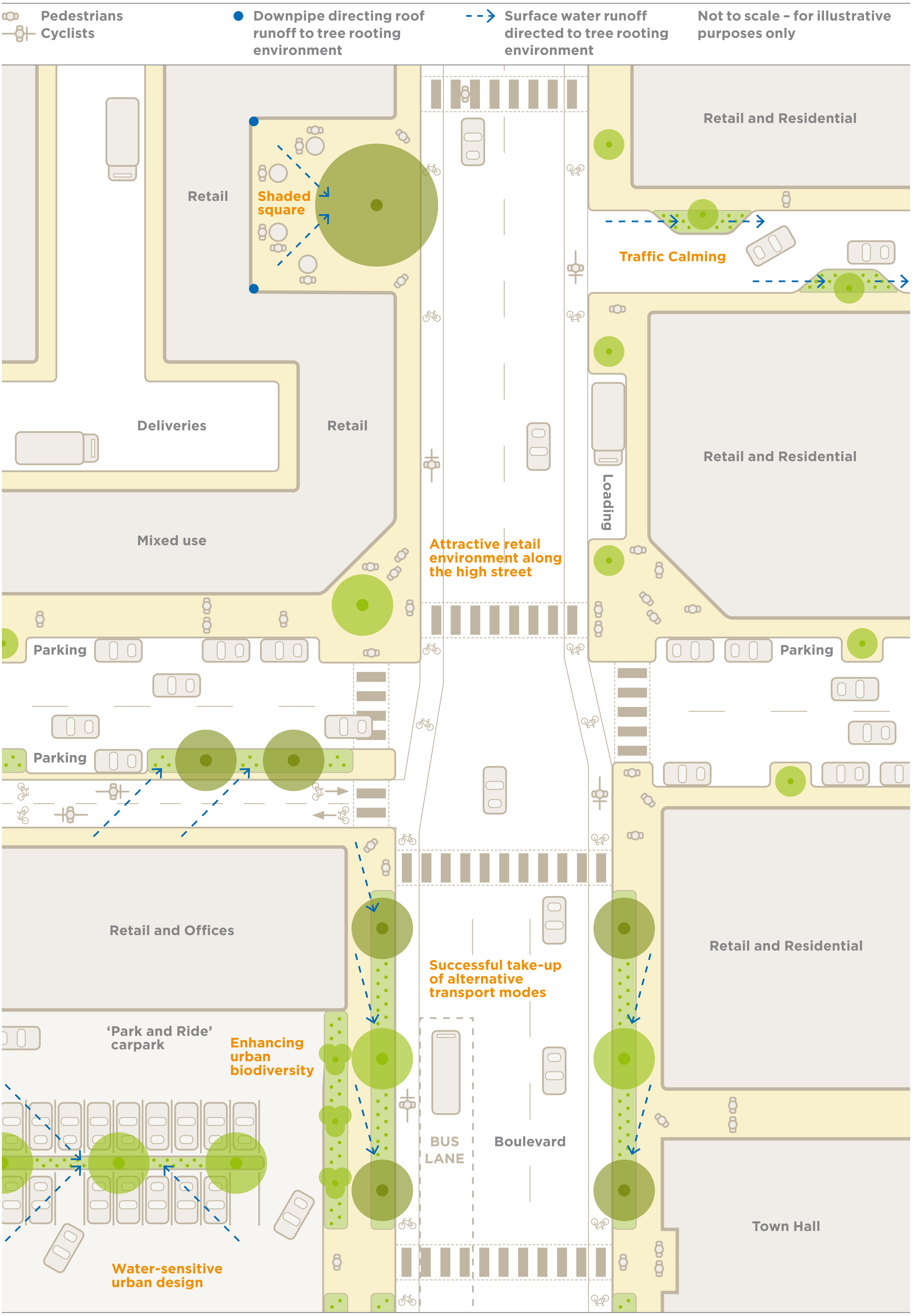

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2.1
Effective use of space and sense of place

2.1.1
Making space for trees: a shared responsibility

Principle 4 of *Trees in the Townscape: A Guide for Decision Makers* advocates creating places where trees can thrive and deliver their full range of benefits without causing harmful nuisance (*Trees in the Townscape*, pp30-33).

Exploring the oft-cited adage "right place, right tree", the guide emphasises that good tree design involves both adapting the selection of the tree to the context and ensuring the design of the surrounding infrastructure allows for trees to thrive. The guide argues that the latter ought to be considered first where possible because it largely predetermines the very possibility of having trees in the urban landscape.

Faced with an agreed design objective to plant trees but competing demands for space, design teams sometimes resort to planting trees in above- or below-ground containers with insufficient growing

Case study 8
Lyon and London reclaim road space for trees

Location
Lyon, France. London, England

In Lyon, the second largest metropolitan area in France, high quality public space is a strategic priority to secure and sustain economic growth. Local municipalities have therefore granted the Greater Lyon Authority (GLA) responsibility for highway and civic space design. When residents started chaining themselves to trees that were being removed to make way for urban motorways, a dramatic shift in both transport planning and public tree management ensued. Between 1990 and 2014, the GLA planted over 50,000 new trees and replaced about 18,000 existing older trees, all in public hard landscapes. This, explains Frédéric Ségur, the GLA arboricultural manager, was made possible by reclaiming space over vehicles: "*Our tree and alternative transport development strategies go hand in hand: the latter frees up space for the former, the former creates the attractive environment needed for the latter. There is no other way we could have succeeded.*"

In the UK, the City of London has pursued similar trade-offs, driven by heightened concern for security. Reducing vulnerability to terrorist attacks required limiting vehicular traffic. This, however, could not come at the cost of reduced accessibility for the UK's finance and insurance hub. The response was the "ring of steel", the security and surveillance cordon surrounding the City of London, which allowed the City to reclaim approximately six football pitches' worth of roadways for public space and extensive tree planting in what is probably the densest and most constrained urban centre in the country.

Below right: Tree and alternative transport strategies go hand in hand in Lyon.
Image: Anne Jaluzot

Bottom left and right: Before and after reclaiming road space at West Smithfield in the City of London.
Image: City of London

space for longevity. This often yields high financial and environmental costs for relatively little and benefit. Such an approach creates what is effectively a pot plant and should only be used as a last resort to meet specific objectives.

Better alternatives require forethought and joined-up working, as detailed in pp30-33 of *Trees in the Townscape*. Of particular importance in urban hard landscapes, whether existing or new, are the choices made concerning the space allocated to motorised vehicles. As demonstrated in Lyon, France and the City of London (see Case study 8, pXX), finding space for trees may mean relinquishing some road space. Although different locations will have their own set and level of ambitions, it is always within the reach of design teams to:

- Consider reallocating one or two parking spaces to allow a tree to be planted.
- Review carriageway dimensions in light of the desired operating speed – designs inherited from the 1970s and 1980s are often over-specified.

2.1.2 Adapting tree choices to local conditions

The importance of adapting the choice of tree to the context is explained in Principle 5 of *Trees in the Townscape*. Benefits include:

- Enhanced certainty of outcomes.
- Improved opportunities to achieve a mature working landscape.
- Avoided costs of remedial work.

One essential dimension of the context to take into consideration when making design choices involving trees is the local tree population. It is the population as a whole that delivers benefits, rather than individual trees considered in isolation. All new plantings, whether large or small, contribute to the local tree population and impact its long-term resilience. Effective tree design therefore requires a good understanding of the greater whole to which any scheme contributes.

Building on the advice provided in *Trees in the Townscape*, a detailed framework for making an informed tree selection is provided in Section 4.

2.1.3 Trees and local distinctiveness

Tree planting can transform the identity and feel of a place, enhancing the sense of scale, framing views of surrounding buildings and adding colour.

Using trees to improve the aesthetic and overall quality of a place requires particular attention to:

- *The type of tree being planted*: while the guiding rule is “right place, right tree”, if the “right” trees have a large final canopy size then they perform better than smaller types of trees (which may also be “right”) in delivering a wide range of benefits, including

Top and middle image: Winter and spring along the Cours de la Liberté’s avenue of trees in Lyon, France.
Image: Anne Jaluzot (winter) and Sophie Barthelet (spring)

Bottom image: Spring bloom on Oxford’s St George street landmark tree.
Image: Michael Murray

impact, in the townscape. A positive design aspiration is to aim for the inclusion of larger trees, even if this means planting a smaller number.

- *Arrangement of planting*: the possibilities are endless and will depend on the particular site and the design objectives. Choices should reflect the local setting: linear planting will support a strong urban frontage while individual accent planting might be more suited to market town settings and intimate public squares. Where widths allow, double rows of planting is possible.
- *Spacing*: unless otherwise agreed and supported through a long-term management programme (see 2.1.4), trees should be planted at their final spacing. Where issues with access to light arise from trees planted too close to building frontages, reducing planting density might be an appropriate response, along with careful choice of tree and leaf size.
- *Species*: this choice will determine shape, colour, density of foliage, etc. However, aesthetic considerations should not override other important criteria for long-term success when selecting tree species (see section 4).

On the River Saône embankment in Lyon, France, removing half the number of trees yields the same townscape impact but much improved access to light for residents. Images: Frédéric Ségur

2.1.4
Trees for immediate (and lasting) impact

Securing immediate impact is often a concern on high visibility civic squares or commercial projects. Addressing this legitimate concern commonly leads to:

- Planting trees at a higher density to compensate for the smaller size of the tree. This strategy, which is derived from forest management practices, can offer some advantages: trees compete and can attain height more quickly while protecting each other during vulnerable early years. Regular thinning of the weakest trees to make space for the strongest specimens is essential for such a strategy to yield good results. In urban settings such an approach might be applicable for trees planted in soft landscape areas, verges or large civic spaces with open ground planting. Failure to undertake selective felling as the trees mature can result in poor tree growth, increased maintenance costs and nuisance for neighbours (see the Saône embankment pictured on pXX). This planting strategy is unlikely to be suitable for trees in hard landscapes where competition for space is fierce, high investment in providing good quality rooting environment or load bearing is needed, and/or progressive felling of young trees to achieve adequate mature spacing is impractical and likely to generate public outcry.

BS 3936 – Part 1: Nursery stock specification for trees and shrubs		**Further guidance/description, as provided by Barcham Trees**	
Standardised classification	**Corresponding tree girth size**	**Description in common language**	**Anticipated tree height when planted**
Light Standard (LS)	6-8cm		
Standard (S)	8-10cm		7-9ft (2.1-2.7m)
Select Standard (SS)	10-12cm	Large tree	9-11ft (2.7-3.3m)
Heavy Standard (HS)	12-14cm	Instant impact tree	11-13ft (3.3m-4.0m)
Extra Heavy Standard (EHS)	14-16cm	Specimen tree	13-15ft (4.0m-4.6m)
Advanced Heavy Standard (AHS)	16-18cm		15-17ft (4.6m-5.2m)
Semi-mature	18-20cm+	Mature and semi-mature trees	17-19ft (5.2m-5.8m)

- Exclusively planting larger diameter or semi-mature trees. Older, semi-mature trees (as described in the table below on tree sizes) are less adaptive than their younger, smaller counterparts. When planting semi-mature specimen, higher quality of tree stock, tree handling and post-planting care are required to achieve success. This needs to be reflected in the budget and procurement process.

Alternative strategies to secure instant impact include:

Multi-stem trees marking the entrance of the new cinema created in converted shipyards in Lyon's Vaise neighbourhood (France). Image: Anne Jaluzot

- Securing good growing conditions for the trees as this will promote faster growth. The growth rates observed in Stockholm among new trees planted with excellent soil aeration provides a striking example (see Case study 19, pXX).
- Considering the use of multi-stem trees (if compatible with the design intent) as these could be planted alongside smaller diameter trees until they have grown sufficiently.
- Combining species that have different growth rates.
- Preserving and integrating existing trees into the scheme while combining trees of different diameters in new planting.

2.1.5
Tree strategies for year-round impact

Increasing the diversity of the species used not only supports better resistance to pests and diseases and improves resilience to climate change, it also helps ensure that the trees make a valuable contribution to the townscape throughout the seasons. Consider:

- Incorporating evergreens. Where uniformity is not required to maintain local character, the inclusion of some conifers or other types of evergreen trees can positively contribute to the landscape. They need to be positioned carefully as they will provide shade throughout the year.
- Mixing in species that shed their leaves later in the season. As pictured below in the new neighbourhood being

In the former Sathonay military base being redeveloped as an urban extension near Lyon, new streets have been planted with oaks (*Quercus frainetto*), alders (*Alnus glutinosa*) and willows (*Salix alba*). The fast growing willows will be removed within 20 to 25 years and the alders within 40 to 60 years. By then, the oaks will have grown to buffer these losses. Images: Anne Jaluzot (winter) and Frédéric Ségur (summer)

developed in the former Sathonay military base near Lyon, France, in the middle of January oaks still carry their dry leaves, making a pleasant contribution to what would otherwise be a barren new street.

2.2 Safe movement for all

"Where the car was king, now – according to Manual for Streets at least – people must come first."

Civilised Streets, CABE Space Briefing, 2008

While the *Design Manual for Roads and Bridges* (DMRB)[10] remains the design standard for trunk roads and motorways in England, Scotland, Wales and Northern Ireland, it is now widely accepted that "*the strict application of DMRB to non-trunk routes is rarely appropriate for highway design in built-up areas, regardless of traffic volume*"[11].

Whether in the *Manual for Streets* (MfS)[12] and *Manual for Streets 2* (MfS2)[12] in England and Wales or *Designing Streets* in Scotland[13], government-sponsored guides on urban highway design emphasise that:

- Streets are about **place** as well as movement.
- Streets must serve the **needs of all users**, rather than primarily shorter vehicular journey times.

Below left and right: The Greater Lyon Authority shifts new planting to the middle of the street to support its alternative transport strategy in tight, high-density, city centre locations such as Rue de La Part-Dieu. Image: Frédéric Ségur (top right), Sophie Barthelet (bottom)

Rebalancing streets to ensure that the needs of all users are adequately catered for often leads to traffic volume or speed control retrofit schemes. Increasingly, investment is also directed towards creating more attractive environments for active travel (walking and cycling). Tree planting can support both of these actions.

2.2.1 Are trees allowed on the highway?

Highway authorities in England and Wales have powers to plant and maintain trees on the highway under the Highways Act 1980 (S64 and 96 HA1980). In Scotland, roads authorities have similar powers under the Roads Scotland Act 1984. Highways/roads authorities may

10
The Highways Agency (1994 with quarterly amendments and additions) *Design Manual for Roads and Bridges (DMRB)*, London: Department for Transport. Found at: www.dft.gov.uk/ha/standards/dmrb/index.htm

11
Department for Transport (2010, p5), *Manual for Streets 2 – wider application of the principles*. London: CIHT. Found at: www.gov.uk/government/publications/manual-for-streets-2

12
Department for Transport (2007), *Manual for Streets. London*: Department of Transport. Found at: www.gov.uk/government/publications/manual-for-streets

13
The Scottish Government (2010), *Designing Streets. A Policy Statement for Scotland*. Edinburgh: The Scottish Government. Found at: www.scotland.gov.uk/Publications/2010/03/22120652/0

grant licences to adjacent property owners to plant, or maintain trees in the highway (S142 HA1980, S51 RSA). A property owner may only plant or maintain a tree in the highway if they have such a licence (S141 HA1980).

Legislation is subject to change. For full details and most recent editions, the respective acts of parliament are available at www.legislation.gov.uk.

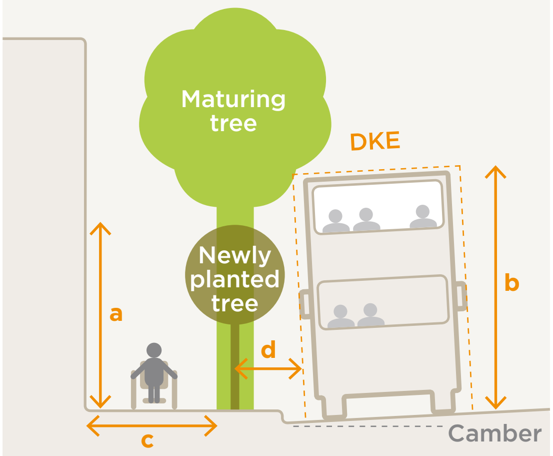
2.2.2
Trees and urban road safety

The inclusion of trees in central reservations or on footways sometimes gives rise to safety concerns. Comparative analysis of crash data in the United States shows a difference between urban and rural settings. Within built-up areas, the presence of trees is not associated with an increase in the probability that a "runoff-roadway crash" (a type of single-vehicle collision that occurs when a vehicle leaves the road, such as after misjudging a curve or striking a fixed object such as a tree) would occur[14].

Accident statistics for built-up areas are as follows: in 2012, one-vehicle accidents accounted for 26.6% of road user fatalities[15]. Of these, collisions with trees accounted for 6.2% and collisions with lampposts for 5.3%[16].

Paragraph 2.4.1 covers how to ensure trees do not obstruct sight lines and, usually, it is the minimum dimension from trunk to kerb face that is critical. To establish this criterion, the characteristics of the highway and the class of route should be considered. The dynamic kinetic envelope (DKE) of the largest normal vehicle can be determined by considering the vehicle height, the lateral overhang (caused by mirrors) and the carriageway camber. As shown in the diagram above, trees should be planted outside the DKE.

Dimensional criteria for locating trees



Not to scale: for illustrative purposes only

- **a.** Vertical clearance over footways for pedestrians (eg 2.5-3 metres)
- **b.** Vertical clearance over the carriageway for tall vehicles (eg 4.5 metres)
- **c.** Horizontal clearance on footways to accommodate a wheelchair or buggy
- **d.** Horizontal clearance to accommodate vehicle DKE: (eg 0.6 metres)

On shady or windy streets, additional allowances might be required. Exposed trees can lean due to prevailing wind; if this is towards the carriageway there is a higher risk of vehicles striking the tree (either branches or trunk). There is a similar risk where shade from buildings causes trees to grow towards the carriageway (more light and space) and the leaning trees are hazards to passing high-sided vehicles.

In parking areas, trees should be located to minimise accidental damage to the trunk during manoeuvring.

In terms of danger reduction, urban trees can directly and indirectly help create settings which lead people

One-vehicle accidents in 2012[15] Object hit	Fatal	Serious	Slight	All
None	302	5,906	21,550	27,758
Road sign or traffic signal	9	76	437	522
Lamp post	23	152	640	815
Telegraph pole or electricity pole	7	44	172	223
Tree	27	169	486	682
Bus stop or shelter	2	25	58	85
Crash barrier	6	35	262	303
Submerged	6	1	3	10
Entered ditch	0	26	143	169
Wall or fence	4	28	86	118
Other permanent objects	49	358	1,432	1,839
Total[3]	435	6,820	25,269	32,524

14
A summary of existing research on trees and safe streets, conducted by Kathleen Wolf for the USDA Forest Service from Green Cities: Good Health website is found at: http://depts.washington.edu/hhwb/Thm_SafeStreets.html

15
Department for Transport (2013), *Road Accidents and Safety Statistics, Table RAS10001*. London: Department for Transport. Found at: www.gov.uk/government/statistical-data-sets/ras10-reported-road-accidents

16
Department for Transport (2013), *Road Accidents and Safety Statistics, Table RAS10010*. London: Department for Transport. Found at: www.gov.uk/government/statistical-data-sets/ras10-reported-road-accidents

17
One study found a 46% decrease in crash rates across urban arterial sites after landscape improvements were installed (Mok, J-H, Landphair, HC and Nadari JR (2006). *Landscape Improvement Impacts on Roadside Safety in Texas*. Landscape and Urban Planning 78:263-274. Found at: http://d2dtl5nnlpfr0r.cloudfront.net/swutc.tamu.edu/publications/papers/167425TP2.pdf Another study found that placing trees and planters in urban arterial roadsides reduced mid-block crashes by 5% to 20% (Naderi, JR (2003). *Landscape Design in the Clear Zone: Effect of Landscape Variables on Pedestrian Health and Driver Safety*. Transportation Research Record 1851:119-130)

18
The guide observes that "*trees, when located on both sides of the street, create a sense of enclosure that discourages drivers from speeding*". Vegetation is featured as the third main type of approaches to traffic calming, alongside horizontal and vertical measures. The guide is found at: www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/footway2/footways209.cfm

19
Found at: http://ciht.org.uk/en/media-centre/news.cfm/free-to-download-from-ciht-traffic-calming-guidelines-

to take more account of potential dangers as they move through a street[17]. Paragraphs 2.2.3 and 2.2.4 below provide recommendations on how context and tree locations can support the shared use of urban highways.

2.2.3
Trees for traffic calming

Trees can help road users to recognise the spatial geometry of carriageway edges. Tree-lined streets also create a "parallax effect" which helps motorists better gauge their speed.

The use of vegetation, particularly trees, is featured as one of the main types of approaches to traffic calming in both the US Department of Transportation Federal Highway Authority's *Design Guide*[18] and Tim Pharoah's 1991 Devon county council *Traffic Calming Guidelines*[19] . As an added benefit, Pharoah underlines that "*planting can engender pride in the traffic calming scheme and in the street generally*". This will be of particular relevance in a residential context and for all neighbourhoods adopting 20mph speed limits.

In Scotland, government guidance is explicit: "*While appropriate driver sightlines should be maintained, vegetation can be used to limit excessive forward visibility to limit traffic speeds.*" (*Designing Streets*, p49).

Suitable locations and layouts for using trees for traffic calming include:

- Accent planting at junction corners (with sufficient setback to maintain sight lines – see 2.4.1), or within a roundabout to assist with the legibility of the intersection.
- Linear planting in central reservations, central islands and/or kerb extensions to reduce physical and optical width.

2.2.4
Trees for encouraging walking and cycling

Certain elements within the outdoor environment can encourage increased levels of physical activities, such as walking and cycling. Street trees are among the environmental features that can play that role (Foltête et al 2007[20]; Forsyth et al, 2008[21]; Larsen et al, 2009[22]; Lee, 2007).

In its *Connect2 and Greenway Design Guidance*, the national cycling charity Sustrans advocates that: "*Tree lines can provide a buffer between the footway and the carriageway and can help give guidance to routes. The planting of trees will also help to ensure that walking and cycling will be a more pleasant activity*"[23].

Alongside the two Hackney examples presented below (see Case studies 11 and 12 ppXX), the use of trees to increase the take-up of walking or cycling along a particular route or street is also well illustrated by the Wirral Waters Green Streets programme (see Case study 4, pXX) in Birkenhead and the refurbishment of Cheapside (see Case study 29, pXX) in London.

Yet trees that are in the wrong locations or are poorly chosen, planted or managed can also lead to tripping hazards and obstructions, undermining pedestrians' and cyclists' comfort and safety.

Tree location and layouts supporting active travel include:

- Central reservation or islands associated with pedestrian crossings.
- Planting on the road side of a cycle track or a footway (making allowance for the door opening zone) or within the carriageway in lieu of car parking space (where loss of car parking can be minimised).

Tripping hazards caused by tree roots are preventable if the tree has an adequate growing environment (see section 3.3). Strategies to deal with existing trees causing surface disruption are covered in section 3.3.3.

Beyond location choice and planting techniques, tree species choice, tree specifications and provision for maintenance also play an important role in creating a pedestrian- and cycle-friendly hard landscape. Species (and cultivars) that are prone to develop basal trunk suckers are best avoided as they can obstruct the footway and represent an onerous management cost. Specifying adequate clear stem height when ordering the tree and making provision for crown lifting and formative pruning in the first years following planting will considerably reduce likelihood of obstruction issues caused by overhanging branches (see 2.4.1).

Concerns might also arise in relation to trees and physical access. In many ways, footways that work for those who have impaired vision or mobility are better for all users, although clear routes are more

Case study 9
Forthcoming

Location
Town, Country

Text to follow

20
Foltête, JC, Piombini, A (2007). *Urban layout, landscape features and pedestrian usage*. Landscape and Urban Planning 81, 225-234

21
Forsyth, A, Hearst, M, Oakes, JM and Schmitz, KH (2008). *Design and Destinations: Factors Influencing Walking and Total Physical Activity. Urban Studies* 45(9), 1973-1996

22
Larsen, K, Gilliland, J, Hess, P, Tucker, P, Irwin, J and He, MZ (2008). *The Influence of the Physical Environment and Sociodemographic Characteristics on Children's Mode of Travel to and From School*. American Journal of Public Health 99(3), 520-526

23
Sustrans (2009) *Connect2 and Greenway Design Guidance*.. Appendix D: Street trees. Bristol: Sustrans. Found at: www.sustrans.org.uk/our-services/infrastructure/route-design-resources/documents-and-drawings/key-reference-documents-0

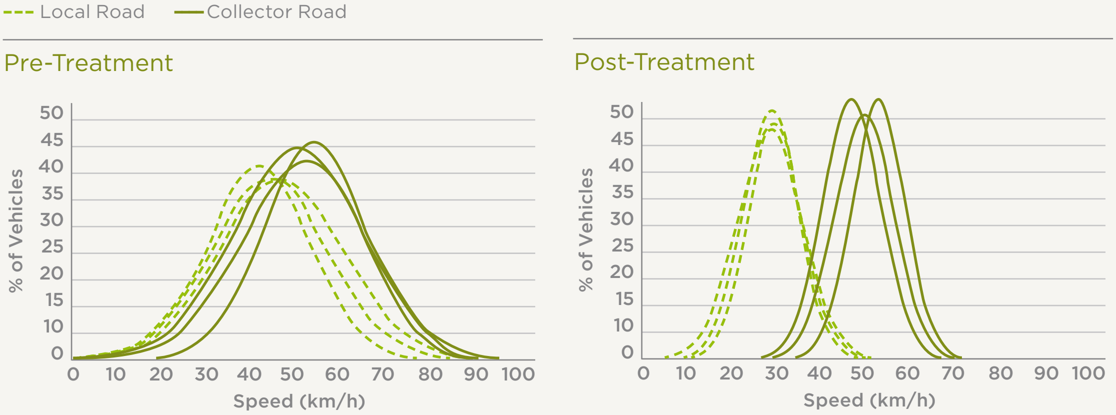
Case study 10
Glen Innes's "self explaining roads" project

Location
Auckland, New Zealand

Back in 2007, the flat street grid of Glen Innes, a low-income residential suburb of Auckland, New Zealand, boasted crash rates that were twice the level of Auckland's seven other wards. This prompted the New Zealand Foundation for Research, Science and Technology to award Transport Engineering Research NZ a grant to work alongside Auckland city council and the Traffic and Road Safety research group at University of Waikato to trial the implementation of "self explaining roads" (SER) to reduce speeding and improve pedestrian safety. The three-year project relied heavily on the use of trees and other vegetation to alter the visual perceptions of motorists and create a street environment more closely aligned to safe speeds. The project also included a thorough monitoring programme with an adjacent block of similar streets used as a "control". The Glen Innes SER process started by identifying the current and desired purpose of the streets within the project area. Designs were then produced that sought to more closely align the physical characteristics of streets with their purpose, using planting, kerb realignment and art works. Consultation was held throughout, involving residents and local schoolchildren. As shown in the graph, implementation of the agreed designs led to a significant drop in the average speeds observed on these local streets, where previously there had been little difference in the speeds recorded on collector roads and on residential streets. Analysis of crash data for the period covering 36 months following project completion showed a 30% reduction in crash numbers and an 86% reduction in crash costs per year. Video analysis of users also identified that on local streets, after the SER works, there was a relatively higher proportion of pedestrians, and less uniformity in vehicle lane keeping along with less through traffic, reflecting a more informal/low speed local street environment. Pedestrians also appeared less constrained in their street use, reflecting an environment that people perceived to be safer and more user-friendly.

Anderson Avenue is one of the three local streets transformed by the Glen Innes SER project. Image: Samuel G Charlton

Speed reduction curves



Consultation draft

24
Department for Transport (2005). *Inclusive Mobility*. London: Department for Transport

critical for those with impairments[24].

Pedestrians with visual impairments can gain orientation guidance from features along a footway. A clear route without tripping hazards or physical obstructions is desirable but where changes in direction are required, cues such as changes to surface or texture help. As other senses are heightened, those familiar with the route can also use noise, smell or touch to establish their location. People with residual sight can more readily perceive highly contrasting visual features. Trees are excellent for this as they give off a smell and their particular sounds (such as leaves rustling) and silhouette against sunlight all provide sensory stimulus.

In new highways, preferred footway dimensions accommodating trees can be designed in from the outset. In many existing situations these dimensions may be more restricted. In retrofit situations it is important to ensure that at least one footway in a given highway has an acceptable minimum clearance.

Case study 11
Linear orchards for attractive cycling

Location
Hackney, London, England

The London mayor's Vision for Cycling in London aims to deliver a "tube" network for bikes, a safer street environment for cyclists, increased uptake in cycling and a better environment for everyone – not just cyclists. The use of street greening, particularly through tree planting, is a critical component of the plan to turn London into a cycle-friendly and greener city. Transport for London's business plan includes around £900 million for projects across the capital over 10 years that will realise the Cycling Vision. Hackney has been one of the most proactive London boroughs in transforming its street environment to better meet the needs of cyclists, while also creating a more generally appealing environment. The new highway designs being implemented to retrofit cycling into a street network that was largely created without cycling in mind is echoed and supported by innovative approaches to tree planting. This includes the use of "linear orchards" to support the creation of a safe dedicated network with high amenity value for local communities. This was first trialled in 2009 on Palatine Road where a gated enclosure was remodelled to create a small civic space and marked cycled route (part of London Cycle Network route 9). A continuous soil trench was dug along the new cycle path and planted with a mixture of apple (*Malus domestica* 'Elstar'), pear (*Pyrus Conference* and *Pyrus communis* 'Doyenne du Comice') and plum (*Prunus Victoria*) trees trained to espalier along a light wood and wire fence – thus creating a fruit-bearing screen between the path and the new public space. The scheme had such a positive impact in lifting the quality of the local area that residents asked the council to plant more trees in nearby streets. A similar linear orchard design was used in 2012 on Powerscroft Road to support the remodelling of a junction were traffic flow needed to be reduced to improve cycle and pedestrian safety. Both schemes are to be featured on the harvest map being issued by local community groups involved in the local food agenda. Once the trees have matured and been further trained, the council plans to use the two sites to host community and school events on how to train espalier trees.

Before and after the remodelling of Palatine Road with espalier fruit trees and cycle track.
Images: London Borough of Hackney (before), Transport Initiatives (after)

Case study 12
Trees for Dutch-style shared space in Leonard Circus

Location
Hackney, London, England

Leonard Circus, at the intersection of two streets in Shoreditch, is East London's first sizeable example of "shared space", an idea pioneered by the Dutch traffic engineer Hans Monderman in Friesland.

This location was identified as suitable to trial a shared space approach because, as a result of the introduction of the congestion charging zone in 2002, motor traffic has fallen dramatically while footfall and cycle traffic have been steadily increasing. The scheme is intended to correct the problems created by the ill-conceived setting of a public art installation from 1996 whose plinth juts out into the space, obstructing pedestrian movement and hampering efforts to restore two-way cycling in both east-west and north-south directions.

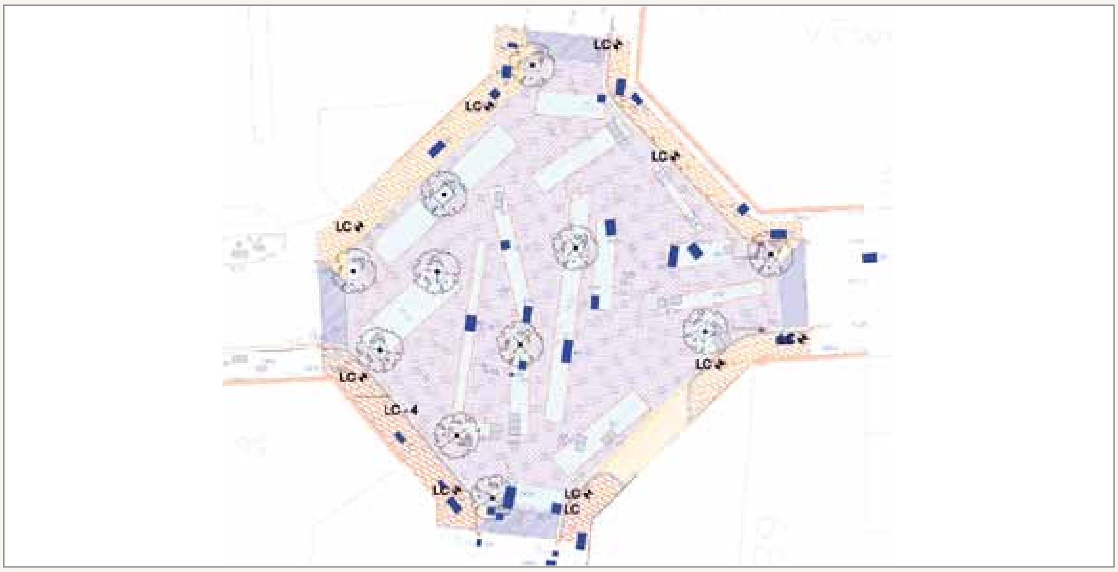
The art piece has been moved to a more suitable location and the area between the buildings has been paved at a single level in unglazed brickwork, broken up by an irregular pattern of panels using contrasting grey granite, York stone and Italian porphyr. Kerbs, signs and carriageway markings are absent and 11 trees have been planted in an apparently haphazard arrangement (carefully chosen to avoid the very dense network of telecommunications cables). Initially, one tree will be surrounded by a circular wooden bench with further benches possibly introduced later on in response to how the space is used post-refurbishment.

The scheme includes a mixture of evergreen and deciduous trees to ensure year-round visual impact. This is of particular importance given the role of the trees as the only cue for street users on how to navigate and use the space. At the centre are four pine trees including Scottish pines (Pinus sylvestris, native to the UK and of a striking bluish colour) and Austrian pines (Pinus nigra, which are particularly effective at removing air pollution). Around the space are also ginkos (Ginkgo biloba) and American sweet gum (Liquidambar styraciflua "Worplesdon", selected for their resistance to reflected heat and their autumn colours), plus a Chinese birch (Betula albosinensis "Fascination", to add an unexpected specimen), and an existing tulip tree (Lirodendron tulipifera). To provide adequate load-bearing capacity, the trees have been planted with a load-bearing crate system (Strattacell).

Top left: Leonard Circus before

Top right: Leonard Circus below-ground utility survey

Bottom: Anticipated layout for finished scheme.
Images: London Borough of Hackney



Consultation draft

2.3
Unobstructed splays and light

2.3.1
Trees and road visibility splays

The provision of adequate visibility for all highway users is essential for their safety. However, in built-up areas, increasing forward visibility for vehicles has been associated with reduced rather than enhanced road safety.

Paragraph 10.7.2 of *Manual for Streets 2* recommends a context-sensitive approach to addressing potential "occasional" obstacles found within visibility splays, such as trees: "*The impact of other obstacles, such as street trees and street lighting columns, should be assessed in terms of their impact on the overall envelope of visibility. In general, occasional obstacles to visibility that are not large enough to fully obscure a whole vehicle or a pedestrian, including a child or wheelchair user, will not have a significant impact on road safety*". In Scotland, *Designing Streets* takes a similar view[25].

As a result, it is not uncommon for British highway or roads authorities to make allowances for occasional vertical obstructions within visibility splays, even at junctions, provided that:

- In combination they do not create a solid visual barrier[26].
- It allows retention of an existing mature tree or continuation of avenue-style planting where the species has a narrow, non-scrubby girth and a minimum clear stem of three to four metres[27].

2.3.2
Trees, commercial signs and shop window visibility

Studies conducted in the US[28] have established that the presence of trees in retail areas positively affects both the perception and behaviour (in the form of increased dwell time and increased product pricing) of shoppers. However, in some instances, retailers and shopkeepers express concern that trees might reduce the visibility of signs and shop windows. Positive responses to these concerns include:

- Planting at final density.
- Using low-density canopy trees.
- Siting trees on the kerbside rather than on the building side of the footway. When interspaced with cars parked along the carriageway, trees create visual openings to retail displays from the road.
- Considering "accent" planting in key locations such as shopping mall entrances, sitting areas, central islands, in place of linear footway planting.
- In car parks, considering linear planting along the internal footway leading to the shop or main shopping area entrance.
- Working with local shopkeepers on the siting of trees and signs, starting with a site visit to a nearby high street that already features trees to analyse together, based on a real-life situation, the advantages and disadvantages that trees can bring.
- Making adequate provision for formative pruning and crown lifting: in a high street environment, formative pruning to achieve four metres of clear stems over time is advisable in order to achieve good visibility of signs.

2.3.3
Trees, daylight, lighting and CCTV

The adverse impact trees can have when overshadowing nearby buildings is often raised during planning application when tree planting requirement are raised. Such negative impact can be significantly mitigated through adequate design and species selection. Location and choice of tree must be based on a sound understanding of the future canopy size, growth habits (eg trees with vigorous side growth habits such as oak are not suited to tight spaces) and foliage density.

If overhead lighting and tree planting are coordinated, they can be integrated in a positive way:

- In new schemes or complete refurbishment projects, light columns and trees should be positioned so that they reinforce rather than distort visual rhythms and patterns. In selecting the pole height and specifying desired canopy height in future management criteria, the tree branch structure can be used to shield the lighting element without interfering with the lighting pattern on the ground. *Code of practice for lighting of roads and public amenity areas* (paragraph 4.3.3.2 of BS 5489-1:2013) recommends an integrated approach to accommodate both lighting and landscaping, particularly trees, satisfactorily. Improvements to lighting, such as high performance LED, are making this more possible.
- In retrofit situations where the lighting columns are already in place, trees have to fit within site constraints. However, pragmatism should not ignore the

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25
Designing Streets, p35

26
Eg Devon County Council (2008), *Highways Development Management Advice for the Determination of Planning Application.* Exeter: Devon County Council. Found at: www.devon.gov.uk/highways-standingadvice.pdf

27
City of York (no date available). *Council Highway Design Guide*, Paragraph 14.5. York: City of York Council. Found at: www.york.gov.uk/info/200274/road_building/409/road_building/2

28
See: Wolf, KL (2005). *Business District Streetscapes, Trees and Consumers Response.* Journal of Forestry 103, 8, 396-400, and other resources provided on trees and consumer environment. Found at: www.naturewithin.info/consumer.html

Case study 13
Trees for revitalised retail and attractive bus routes

Location
Bristol, England

The Greater Bristol Bus Network (GBBN) project was developed to improve 10 strategic bus routes across Bristol and three other adjoining local authorities. Primarily funded through the Local Sustainable Transport Fund (LSTF), the project had to be delivered within four years (2008-2012) – a short timeframe for a scheme of such scale. When discussing the approach he took to achieve successful delivery, Steve Bird, the Bristol Sustainable Transport manager, explained: "*When delivering the project we knew we had to take a different, more holistic approach and to meet the GBBN timeframes we needed strong support from local residents and retailers. Planting 500 trees alongside the bus routes was a huge asset and went a long way to enhancing the local environment and gaining support from the local community*". This proved beneficial not only for local residents but also for retailers doing business along the targeted routes, whether in a traditional high street setting, parade or a mall.

- Along Brislington Hill, one of the first routes that was delivered, retail space vacancy rates were close to 30% before the project started, and disappeared soon after delivery. The positive impact on local businesses was such that, for the remainder of the project, Brislington Hill was used as a demonstration site for shopkeepers from other GBBN strategic routes.
- At Straits Parade, a parking area hosting a monthly market was planted with oak trees (*Quercus robur*). Initially, market stall owners and local shops were concerned about the loss of car parking spaces resulting from space being reallocated to buses and new trees. Since completion of the scheme, the market area has won a "vibrant shopping area" award and the market manager has put forward an application to increase the market's frequency.
- At Broadwalk, a small shopping mall opening onto one of the targeted routes, the GBBN project provided the opportunity to reconfigure the entrance of the mall, removing guardrails preventing pedestrians crossing and creating a green gateway with nine lime trees (*Tilia cordata Greenspire*). One year following completion, the mall manager reported that, for the first time in 12 years, the mall had achieved full occupancy and higher grade tenants were moving in. The scheme received widespread support from retailers and residents and, during the 2012 spring drought, a community group volunteered to provide free watering for the trees following an agreed schedule with the council tree team (to avoid over watering!)

Capacity to deliver such holistic outcomes, from what was initiated as a bus route improvement scheme, was enabled through the creation of a dedicated tree specialist post funded by and embedded within the GBBN project team. This not only allowed sustained arboricultural input from design to delivery but also great availability during consultation events to address and quickly respond to any tree-related questions. Looking back on this experience, Steve Bird concluded that the tree specialist: "*proved to deliver value for money by being able to talk to utility companies, retailers and residents, addressing their concerns and questions about trees and working around the issues in a way only he could. Having a tree specialist embedded within the team taught us a lot and we now consider trees in all our projects where we can.*"

Top left and right: Brislington Hill before and after

Bottom images: Straits Parade, before and after.
Image: City Design Group 2014, Bristol City council




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fact that constraints in manmade environments, such as cities, are largely self-imposed. Relocating a lamp column might be worth considering.

Good coordination is also paramount for avoiding conflicts between CCTV and urban trees. Effective strategies for this start very early in the design process: both the Home Office[29] and the Design Council[30] have issued reports and guidance emphasising that the prevention of antisocial behaviour and crime in public spaces is better addressed through good urban design, promoting natural surveillance and better management, than through the blanket use of CCTV. Research findings also support the positive role trees can play in reducing antisocial behaviour and criminal activity[31].

Where CCTV is used:

- Research has shown that CCTV managers and arboricultural officers rarely design together – a situation that both professions agree needs to change[32].
- Where CCTV is retrofitted in an environment with existing trees, the effectiveness of the surveillance scheme will greatly benefit from site testing during the design phase using lifting platforms when trees are in leaf.
- Where new or replacement planting occurs in an area in which CCTV surveillance is already in place, tree species choice will be an important consideration to achieve non-obstructing leaf density and crown spread. Good maintenance provision for post-installation crown lifting and formative pruning (a good practice that

Evening light play with leaf pattern to enliven the winter scene at the Duke of York Square in London.
Image: DPA Lighting Consultants

29
Department for Communities and Local Government (2004). *Safer places: the planning system and crime prevention.* London: Department for Communities and Local Government. Found at: www.gov.uk/government/publications/safer-places-the-planning-system-and-crime-prevention

30
Design Council and the Home Office (2014). *Creating safe places to live through design.* London: Design Council and Home Office. Found at: www.designcouncil.org.uk/sites/default/files/asset/document/creating-safe-places-to-live.pdf

31
Kuo, FE and Sullivan, WC (2001). *Environment and Crime in the inner city: Does vegetation reduce crime?* Environment and Behaviour, 33(3), 343-367

32
Body, S (2011), *Investigation into the interactions between closed circuit television and urban forest vegetation in Wales,* Trees, People and the Built Environment Conference Proceedings, pp210-218

this guide recommends in all situations, as it helps reduce long-term costs) will also be critical.

2.4 Water-sensitive design

The urban water cycle is under increasing social, environmental and economic pressure.

The challenges of managing the water cycle are demonstrated by the repeated droughts experienced in the south of the UK since the mid-2000s and the severe flooding that occurred in 2007 and 2013.

Much of the UK's infrastructure was built over 100 years ago and has reached its capacity. Ofwat, the regulator for water and sewerage providers in England and Wales, considers some of the traditional approaches to water management to be no longer sustainable or affordable. Alternative approaches need to be explored as existing networks and assets are refurbished and replaced.

For new developments, legislative changes have already made (Scotland) or will soon make (England, Wales) the use of sustainable drainage systems (SuDS) compulsory for new buildings, developments and redevelopments.

In response, the concept of water-sensitive urban design (WSUD) is increasingly gaining momentum among planners, designers and engineers. WSUD seeks to integrate all aspects of water management, including water supply, waste water (sewage and surface runoff) and natural water courses, into urban development from the earliest planning stages through to operation.

Trees in hard landscapes can significantly contribute to and benefit from water-sensitive design. Whether combined with a SuDS component (see 3.5.3) or not, trees inherently contribute to surface water management, through canopy interception, evapotranspiration, infiltration and bioretention. Quantifying this has been the focus of significant research work in the past 10 years.

Canopy interception
Available evidence on the interception of precipitation by trees shows that:
- Measured rainfall interception for individual trees ranges from 8% to 68% of a rainfall event[33] and is dependent on the tree species and rainfall characteristics.
- Evergreen trees generally intercept more water annually than deciduous trees due to greater foliage surface area and the presence of foliage during winter months.

Transpiration
Evapotranspiration is the sum of water evaporated from soil and plant surfaces plus water lost as a result of transpiration from vegetation. Transpiration is the process in which trees absorb water through their roots and transfer it up to the leaves where it evaporates into the environment through leaf pores. Transpiration from trees (and other plants) reduces the water volume stored in the soil long after a rainfall event ends.

Only a few recent studies have attempted to quantify the rate of transpiration associated with different types of trees. These studies found that conifers transpired 10-12% of precipitation while, when in-leaf, deciduous trees transpired up to 25% of precipitation. Evergreens have lower transpiration rates because they are more efficient than deciduous trees at retaining moisture due to the structure of their leaves[34]. This is now being factored into models used to design SuDS components[35].

Infiltration
The growth of tree roots, as well as the decomposition of roots and leaf litter, increase soil infiltration rates and overall infiltration capacity.

Attenuation
In addition to infiltrating runoff, soil stores rainwater during and after a storm, making it available for plant growth and/or later partial release in the drainage system. For example, one tree planted in 28 cubic metres of soil with 20% soil water storage capacity protected from compaction with an underpinned hard surface, can hold a 1-inch, 24-hour storm event from 70 square metres of impervious surface – an area much larger than just the area under the tree canopy[36]. This example calculation accounts only for soil storage, not for interception or evapotranspiration. As highlighted above, more sophisticated models that allow evapotranspiration to be factored into the design of bioretention systems are becoming available.

Pollutants removal
Pollutant removal mechanisms include

33
The Effects of Trees on Stormwater Runoff. Report prepared by Herrera Environmental Consultants for Seattle Public Utilities, February 14, 2008. Found at: www.psparchives.com/publications/our_work/stormwater/lid/clearing_grading/Effect of Trees on Stormwater Lit Review-Herrera.pdf

34
Metro (2002), *Trees for green streets: an illustrated guide.* Portland, OR: Metro. Found at: www.oregonmetro.gov/index.cfm/go/by.web/id=26337

35
See, for example, the Recarga Model. Found at: http://dnr.wi.gov/topic/stormwater/standards/recarga.html

Consultation draft

Top left: Phase one of Garibaldi Street refurbishment nearing completion in January 2014. See Case studies 7 and 15
Top right: Gully and swale detail along newly completed Garibaldi.
Both images: Anne Jaluzot
Bottom: Garibaldi Street's new water-sensitive streetscape coming to life in April 2014.
Image: Sophie Barthelet

36
Marritz, L (2011). *Stormwater Quality Benefits of Bioretention with Trees*. Posted on the Deeproot blog on August 1, 2011. Found at: www.deeproot.com/blog/blog-entries/stormwater-quality-benefits-of-bioretention-with-trees
See also Davis, AP, Traver, RG, Hunt, WF, Brown, RA, Lee, R and Olszewski, JM (2012)

37
Marritz, L (2011). *Stormwater Quality Benefits of Bioretention with Trees*. Posted on the Deeproot blog on August 1, 2011. Found at: www.deeproot.com/blog/blog-entries/stormwater-quality-benefits-of-bioretention-with-trees
See also Davis, AP, Traver, RG, Hunt, WF, Brown, RA, Lee, R and Olszewski, JM (2012). Hydrologic Performance of Bioretention Stormwater Control Measures. *J. Hydrologic Eng*, ASCE, 17(5), 604-614

38
Denman, L (2006). *Are Street Trees And Their Soils An Effective Stormwater Treatment Measure?* Paper presented at the 7th National Street Tree Symposium. Found at: http://contextsensitivesolutions.org/content/reading/are_street_trees_and_their_soil_/resources/STREETTREES_LizDenman.pdf
See also Davis, AP, Hunt, WF, Traver, RG, and Clar, M (2009) *Bioretention Technology: An Overview of Current Practice and Future Needs*. J. Environ. Eng, ASCE. 135(3) 109-117

filtration, absorption and uptake, and sequestration in plant material. Over time, trees can also increase the amount of organic matter in the soil, which binds many pollutants.

Most recent research involving the pollutant removal efficiency of tree-related surface water runoff management practices has focused primarily on bioretention tree planters. Several recent literature reviews of lab and field studies of bioretention pollutant removal have concluded that bio-retention systems are highly effective at pollutant removal[37]. High concentration and load reductions are consistently found for suspended solids, metals, polycyclic aromatic hydrocarbons (PAH), and other organic compounds[38]. The presence of vegetation also substantially improves retention of total nitrogen and total phosphorus.

Further advice for maximising water infiltration, attenuation and/or filtration through the tree-rooting medium is provided in section 4.5.

2.5
Safety, health and comfort

2.5.1
Trees and public safety

A sick tree that might drop branches or fall down completely can, over time, become a safety hazard. However, as the statistics compiled by the National Tree Safety Group[39] in the table below show, such risks are low.

Trees and public safety	
Risks of death	
Cancer	1 in 387
All forms of road accidents	1 in 16,800
Trees	1 in 10,000,000
Number of non-fatal injuries	**(A&E cases)**
Leisure-related injuries	2.9 million
Tree-related injuries	55

Risks associated with tree safety are best managed through:

- Avoiding planting in high use areas those species that are known to have a propensity for failure or rapid decay when wounded.
- Specifying and procuring healthy, nursery-grown trees that have been subjected to non-invasive tests to provide evidence of good physiological health (see *Trees in the Townscape* principle 7, pp48-51). For imported plant materials, demanding that the trees purchased have spent at least one full growing season at the importing nursery before being sold will make it much more likely that any signs of pest or diseases will have been detected.
- Diversifying the range of species being planted. Most pests and diseases are specific to one species. Monoculture creates the perfect conditions for uncontrollable epidemics (see 4.2).
- Conducting a health audit of all trees at least once every five years, taking prompt action to manage or remove diseased trees and adequately discarding infected cuttings.
- Following the guidance issued by the National Tree Safety Group on *Common Sense Risk Management of Trees*[39].

2.5.2
Trees and people health

A large body of academic research demonstrates[40] that urban trees can have a positive influence on the physical and mental health of communities in many ways, including reducing prevalence of respiratory diseases (see 2.5.3 on the impact of trees on air pollution), alleviating chronic stress, encouraging physical activity and protecting people from harmful UV. The health benefits of urban trees have been and should remain one of the primary drivers for urban tree planting. However, urban trees can also affect human health negatively through allergenic pollens and pests, two risks that require management.

Poor air quality in cities has increased people's sensitivity to many substances such as dust, mites and pollens, including pollens from trees, and this is a cause of concern for health professionals. Common indigenous trees with very fine pollens that can be easily carried by winds are among the most seasonally allergenic species. Adequate responses are required at both local and regional levels:

- Locally, within a planting scheme, concentrations of allergenic species should be carefully considered.
- Regionally, information and warnings on air pollen levels need to be provided to sensitive populations.

A limited number of tree pests can also represent a threat to human health. Of particular concern is the oak processionary moth (*Thaumetopoea processionea*). The caterpillars of oak processionary moths have thousands of tiny hairs containing a very irritating substance. The moth is a native of southern and central Europe, where predators and environmental factors usually minimise its impact. However, aided by the movement of plants, its range has expanded northwards over the past 20 years. To address this, as well as other biosecurity risks, it is the responsibility of the design team to specify and procure traceable, high quality trees with plant passports (see 4.5). Advice on how to respond to a sighting of an oak processionary moth is available on the Forestry Commission's website[41].

2.5.3
Trees and air quality

Modelling work conducted by University of Birmingham[42] demonstrates that a context-sensitive approach is required when using trees for localised air pollution removal:

- In a dense inner-city context where multi-storey buildings create street canyons and the pollution source is found within the street canyon (eg local traffic exhaust), a continuous tree canopy can prevent air circulation.
- In dense urban environments with no in-canyon pollution sources (eg a pedestrianised street), trees can produce "filtered" avenues, in which air is cleaner than on the regional scale.

39
National Tree Safety Group (2012). *Common Sense of Risk Management of Trees: Guidance on trees and public safety in the UK for owners, managers and advisers*. Found at: www.forestry.gov.uk/pdf/FCMS024.pdf/$FILE/FCMS024.pdf

40
A good summary of the health benefits of street trees was compiled in 2011 by Forest Research. Found at: www.forestry.gov.uk/pdf/Health_Benefits_of_Street_Trees_29June2011.pdf Another excellent compendium of research findings can be found on the Green Cities: Good Health website managed by the University of Washington, with support from the USDA Forest Service. Found at: http://depts.washington.edu/hhwb/

41
www.forestry.gov.uk/opm

42
Thomas, AM, Pugh, A, MacKenzie, R, Whyatt, JD and Hewitt, CN. *Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons*., Environ. Sci. Technol, 46 (14), pp7692-7699

Case study 14
Westminster's plan for Church Street and Paddington Green

Location
London, England

The Church Street area is at the centre of Westminster city council's ambitious housing renewal strategy aimed at improving existing council homes and creating new housing, while providing better parks and children's play areas as well as improving shops, jobs and business opportunities. The vision for the neighbourhood's transformation, including specific infill plots to be developed and existing buildings to be demolished and rebuilt, was captured in a document known as the futures plan. This was approved in 2011 in a ward-wide referendum. Westminster council also identified the need for an infrastructure and public realm plan (IPRP) to complement these targeted interventions with a wider range of environmental enhancements. Church Street, home to a vibrant market six days a week and lined with one of London's prime concentrations of antique shops, was a key focus for the plan. The final selection of the multidisciplinary design team appointed to lead on the IPRP was also submitted to a ward-wide vote. The team that captured the popular vote had one primary differentiator: its proposed approach relied heavily on greening, and particularly on planting new trees, as a means to secure a wider range of benefits from existing streets and civic spaces – including amenity value, climate resilience, air pollution mitigation and enhanced wildlife. With the council being the freeholder of the land, it was possible and relatively easy to modify boundary alignments so as to turn a set of existing streets and lanes on either side of Church Street into a "green spine" featuring not only trees, but also rain gardens, sitting areas and playgrounds. Trees are also being used to shade all car parking areas and to create "pinch points" for vehicular speed control. In addition to recommended layouts, the IPRP provides clear principles and recommendations for tree selection, below-ground tree-rooting environment design and integration with utilities. Given the objectives assigned to the proposed greening of the public realm, the recommended tree planting list is designed as a matrix highlighting maturity size, rooting habits and management requirements as well as the air pollution removal benefits, ability to withstand varying soil moisture (to suit the rain garden locations) and the wildlife value of each species included – to enable adequate, context-sensitive solutions. The plan also sets as a policy for future planting that three different species will be used per street so as to enhance resilience to pathogens, and that continuous planting trenches will be used to ensure longevity for both the trees and the surrounding hard surfaces.

The IPRP further notes: "*Tree trenches shall be designed in coordination with existing services and proposed service corridors to minimise potential future disturbance of tree roots through utility works. The Stockholm Bed system of tree planting is to be investigated and utilised if shown to be cost-effective and appropriate to location.*" The indicative planting plan proposed in the IPRP was informed by a radar service survey and existing underground utility maps. For delivery, the IPRP is broken down in different sections, each associated with one of the development plots. All principles established in the IPRP are featured in the brief issued to developers tendering. Responsibility for delivery of the public realm enhancements are being funded through the income generated by the new private homes to be featured as part of the regeneration.

Rendering for Orchardson Street.
Image: Grant Associates

- Similarly, in a low density context where the building frontage will not cause a canyon effect, trees can be effective at removing air pollutants, especially particulate matter[43].

However, not all trees are equal when it comes to removing air pollutants. Further advice is available from Lancaster University and the Centre for Ecology and Hydrology[44]. As with any other tree selection criteria, this should be balanced with other considerations, as described in section 4.

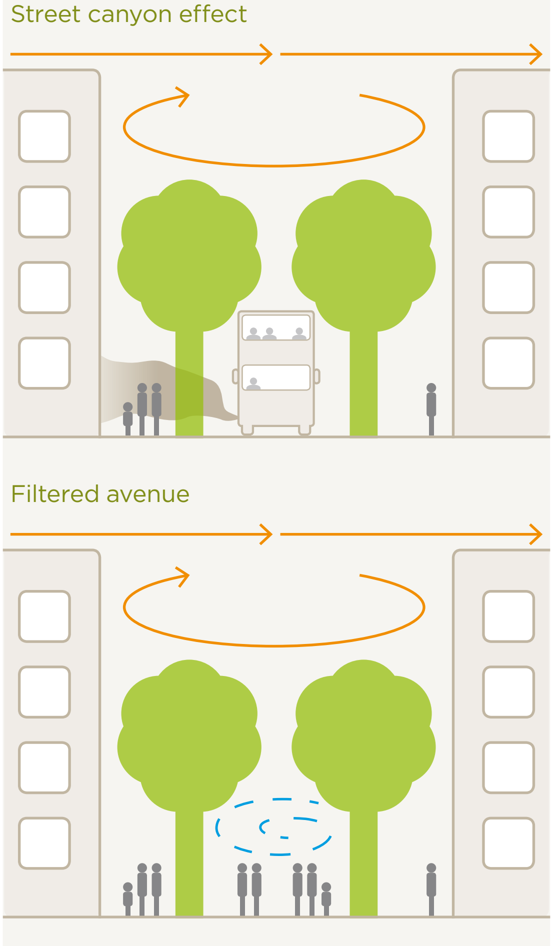
2.5.4
Trees for temperature and wind control

The cooling effect of trees has been established. The impact of this on building energy consumption and human health are also widely evidenced. While the shade provided by tree canopies plays an important role, the primary mechanism by which trees in leaf cool their surroundings is through evapotranspiration. Recent studies[45] aiming to quantify this benefit suggest that evapotranspiration is a direct result of the photosynthetic activity and hence the growth rate of trees. This has important implications regarding the conditions required to maximise cooling benefits from trees. These will be of particular value to those working on hard landscape projects in city centre locations where urban heat island issues are most likely to occur:

- In the design phase, rather than working on the basis of a number of trees, designers should set canopy cover target(s) and maximise tree growth rate by providing as large a non-compacted tree rooting environment as possible, facilitating good and continuous gaseous exchange capacity.
- Maximise tree growth rate by providing large uncompacted rooting environments with good gas exchange.
- Ensure a good supply of water, particularly during extended heatwaves. Strategies for this will include the use of pervious surfacing and other solutions to redirect surface water runoff to tree roots. It might also include incorporating rainwater harvesting and irrigation systems in a major innercity planting scheme as currently under construction along Lyon's Garibaldi Street (see Case study 15 pXX).

Trees can also sometimes be used, with suitable expert guidance, as part of a range of measures to mitigate the effects of wind speed and turbulence to help

Impact of trees on air quality in street canyons



enhance pedestrian comfort.

Research has also demonstrated that trees can provide effective shelter belts to protect buildings from wind, and help reduce building heating energy consumption. A study[46] conducted in Scotland has demonstrated that an optimally positioned row of trees in relation to the prevailing winds and possible solar gains into the sheltered building during wintertime could help save up to 18% energy for heating.

2.5.5
Trees for wildlife health

Trees bring nature into built-up environments in many ways. Trees act as bridges, maintaining connectivity for species through the urban landscape. Trees also support local wildlife, providing food, shelter and habitat for invertebrates and other species. Strategies to enhance the wildlife benefits associated with trees in hard landscapes include:

- Optimising tree location and planting patterns in the wider landscape context so as to increase habitat connectivity to vegetated areas, parks or groups of trees that might be found in the

43
This is also well demonstrated by a recent study by Lancaster University: Maher, BA, Ahmed, IAM, Davison, B, Karloukovski, V, and Clarke, R (2013). *Impact of Roadside Tree Lines on Indoor Concentrations of Traffic-Derived Particulate Matter*. Environ. Sci. Technol., 2013, 47 (23), pp 13737-13744

44
Stewart, H, Owen, S, Donovan, R, MacKenzie, R, Hewitt, N, Skiba, U, Fowler, D (2002). *Trees and Sustainable Urban Air Quality*. Lancaster: University of Lancaster and the Centre for Ecology and Hydrology. Found at: www.es.lancs.ac.uk/people/cnh/UrbanTreesBrochure.pdf

45
Ennos, R (2011) *Quantifying the cooling benefits of trees*. Trees, People and the Built Environment Conference Proceedings

46
Liu, Y and Harris, DJ (2008). Effects of shelterbelt trees on reducing heating-energy consumption of office buildings in Scotland. *Applied Energy* 85 (2-3), 115-127

Consultation draft

Case study 15
Using rainwater cisterns for tree-based cooling on Garibaldi Street

Location
Lyon, France

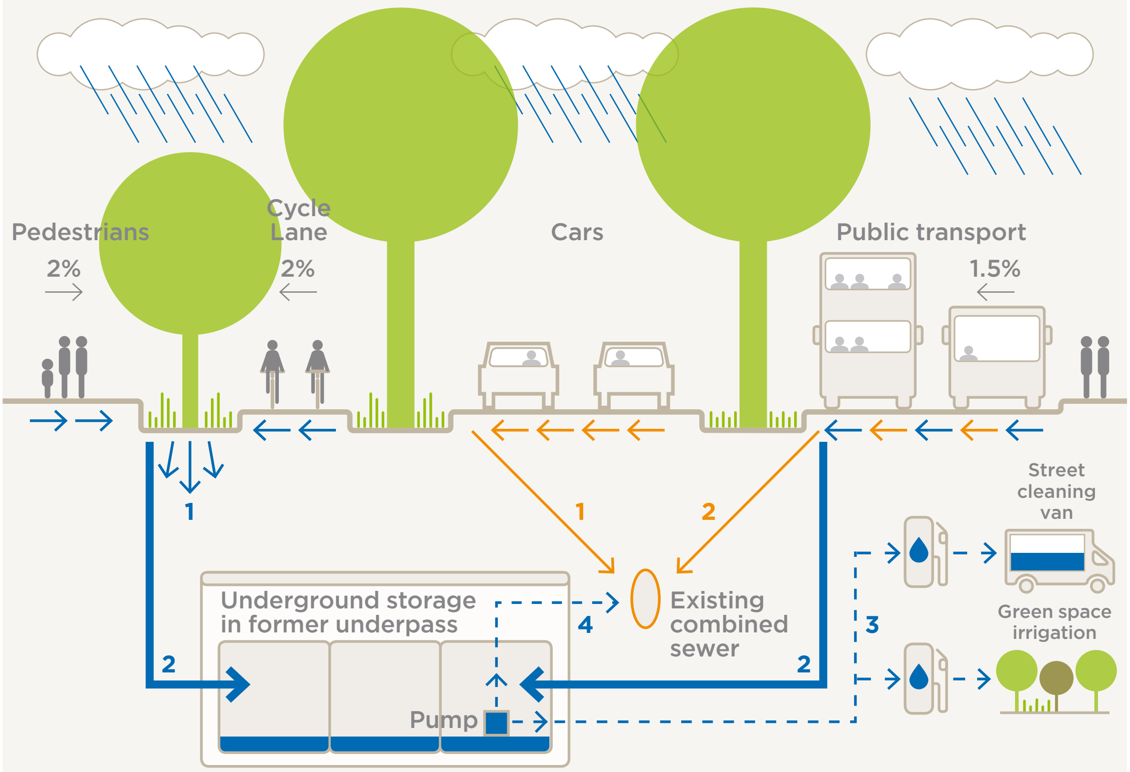
Garibaldi Street is a major arterial road running through Lyon's city centre. Designed as an "urban motorway" in the 1960s, the oversized road no longer serves contemporary needs for development and quality of space. Refurbishment was initiated in the 1990s, and is now entering into a second, more ambitious phase expected to turn the six-lane road into a people-friendly greenway that will also serve economic regeneration. The 2.6km project drastically re-allocates space between highway users. Pedestrians, cyclists and buses now have the lion's share. The scheme features extensive tree planting, designed to provide shade and manage surface water runoff from the footways and cycle path. Structural "skeleton" growing medium is being used underneath footways and cycle paths to maximise the rooting volume: this creates a bridge allowing the roots of trees planted in continuous trenches in hard landscapes to access the open soil provided in nearby linear landscape verges collecting rainwater. The first refurbished section of Garibaldi Street opened in March 2014. This includes an underpass re-purposed as a rainwater harvesting cistern to enable summer irrigation of trees so as to maximise their cooling potential. This receives stormwater runoff from the footways, the cycle tracks and the bus lanes when they are not subject to winter treatment. The reduced carriageway continues to drain into the existing combined sewer (see the diagram illustrating Case study 7). Garibaldi Street is home to the only skyscraper project in Lyon, demonstrating the attractiveness of the sustainable streetscape to private investments.

Garibaldi Street before completion of phase one of refurbishment
Image: Frédéric Ségur

For post-refurbishment images, see pXX and pXX

Water management strategy for Garibaldi Street refurbishment

— Polluted surface water runoff
— Non-polluted surface water runoff



1. Surface water runoff infiltration
2. Overflow and/or storage of surface water runoff
3. Surface water runoff re-use
4. Controlled rate outflow into combined sewer (during heavy storms)

1. Remains directed to existing combined sewer
2. Only directed to combined sewer when winter treatment is applied to the bus lanes

surroundings. This particularly benefits bats, which often use tree lines to navigate.
- Creating several layers by using shrubs and smaller trees such as hazel among taller trees and planting the opening of the tree planting hole with ground cover. This, however, also increases competing demands for water.
- Incorporating nectar and fruit trees within the species selection while considering the potential for negative impact relating to 2.6 below and the suitability of such species in hard surfaced areas.

2.6 Surfacing, cleaning and de-icing

2.6.1 Leaf fall and droppings

Deciduous trees shed leaves in the autumn. Most street cleaning and grounds maintenance teams are logistically prepared for the annual cleaning of fallen leaves before they create a slipping hazard or block gullies.

If, when and to what extent a slipping hazard might develop will depend on local weather conditions and other specific local situations[47]. On busy streets traffic will tend to quickly blow falling leaves aside, limiting the risk of loss of "grip" associated with flattened wet leaves. On footways, smaller streets and cycle tracks this will be different and pedestrians as well as lighter traffic such as bicycles and scooters can be at risk of slipping if leaves are not removed in a timely manner.

If fruiting is a problem for traffic safety (eg the acorns of certain oaks, such as *Quercus spp*), cultivars can be chosen that are sterile. Other droppings, such as honey dew caused by pests (leaf aphids), can also be avoided through cultivar choices, even for lime trees (*Tilia spp*).

2.6.2 Surface treatment and maintenance options

Surface treatment choices should balance considerations of tree health and the use of the space around the tree (footfall, aesthetic and maintenance):
- To survive, the tree will need effective gas exchange (see 3.1.1) between the above- and below-ground environment around its root ball. It will also need water.
- Depending on context, use of the space around the tree (including pedestrian desire lines) will determine the degree to which accessibility will be facilitated, the type of aesthetic and appearance pursued, and the maintenance regime.
- Choice of treatment for the edge of the surface opening (eg. inclusion or not of kerb or low protective railing) will also bear an impact on the material selected for the immediate tree surrounds.

The best management practice for young trees is to cover the tree surrounds with organic mulch. Organic mulch holds water, moderates soil temperature and provides small amounts of organic matter to the soil below. It might be possible to use this over the whole surface of the tree opening where there is an upstand around the tree opening, underneath other systems (eg tree grates) or in wide footways. In tight spaces, or areas with medium or high pedestrian traffic, this is unlikely to be suitable over the whole area of the tree opening as the mulch might get kicked around. However, the design should allow for some mulch to be placed after planting immediately around the base of the tree over the root ball.

Loose aggregate, such as gravel, offers a cost effective and permeable option. This may be combined with a honeycombed mattress to help protect the soil underneath from compaction and help keep the gravel into place. The benefit for the tree is that such material remains permeable. From a street use perspective, aggregates can be walked over and will tend to visually blend in with its paved surrounding. Loose aggregate might be adequate for car parks, large civic squares, and wide footways where the tree surrounds will not get heavily trampled and spread over the surrounding surface.

Self-binding aggregate contains fines and particles which, under compaction, help form a surface that is less susceptible to scuffing and being kicked than loose aggregate. When used around young trees, self-binding gravel should not be laid up to the base of the tree so as to allow a ring of mulch to be applied on the soil area immediately over the root ball to maintain good water infiltration. Not all self-binding aggregate products available on the market are suitable for use as tree surrounds: Ph-neutral products should be preferred. Installation methods also matter: the level of compaction applied during installation should be lower than that typically applied when a self-binding aggregate is laid to create a footpath.

47
Kopinga, J (2008). *Leaf litter and traffic safety* in COST Action C15 Final Scientific Report, Improving relations between technical infrastructure and vegetation. Found at: http://w3.cost.eu/fileadmin/domain_files/TUD/Action_C15/final_report/final_report-C15.pdf

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Self-binding aggregate is inadequate in tight, heavily trafficked footways as it will compact to the point of becoming impermeable.

Bound aggregates will accommodate higher footfall level, maximising accessibility to the space around the tree. Available products broadly fall into two categories: flexible permeable rubber surfacing and resin-bound gravel. Resin-bound gravel has been popular with designers over the past decade as it offers attractive aesthetics and does not trap litter as tree gates do. However, concerns have arisen about its durability (installations have been prone to crack or loosen sooner than expected) and ability to remain water permeable. The interviews conducted in preparation for this guide highlighted that using qualified contractors greatly helped reduce risks of early cracking and deterioration of resin-bound surfacing. Further research is needed to determine the impact of specifications (in terms of temperature, type of binding polymer, size of aggregate used) on long-term porosity and wearing of resin-bound aggregate tree surrounds. Flexible pervious surfacing has not raised similar concerns, but is newer in its use around trees.

Tree grates and tree grilles are effective in maintaining permeability at the base of the tree while accommodating high footfall. However, they tend to be a more expensive option and can be subject to theft in some areas. From a maintenance perspective, tree grates and grilles require manual cleaning as litter can become trapped underneath the installation. Tree grates and grilles materials and design should be carefully selected depending on the context. The choice of material broadly falls within three categories: steel, ductile cast iron and wood. On market squares and other hard landscapes regularly used by vehicles, ductile cast iron adapted to heavy loads (eg 400kN) and mounted with cantilevered support should be preferred. In hard landscapes mostly used by non-vehicular users but occasionally accessed by maintenance vehicles, steel or cast iron grilles or grates are adequate options. The load-bearing capacity of the product specified should account for the occasional presence of vehicles (eg 250kN). In hard landscapes strictly intended for pedestrians, use of tree grilles designed with metal support and wood planking can offer a flexible and cost-effective option. This is particularly worth considering where hard landscape refurbishment includes existing trees as the geometry of the surface opening of wood grilles can easily be tailored in-situ for each tree during installation. Product specification should consider sustainability (eg FSC certification), anti-slip treatment, durability, bending and impact resistance (as would be considered for any wood decking used in outdoor public space). Regardless of the material used, trees grates and grilles require high installation standards: poor positioning or deformation of the supporting frame will cause the grates or grilles to lift and/or break, causing a serious tripping hazard. Long-term maintenance is required to avoid conflicts with trunk flare and buttress roots, particularly in the case of larger growing trees such as planes or limes. The tree grate or grill will need to be removed and replaced or modified before it causes injury to the trunk. However, this is too often overlooked and/or not included as part of future management budgeting. Some contemporary metal products allow for rings to be taken out in response to the growth of the tree trunk. Wooden installations can usually be more easily adapted.

For further recommendations on surface treatment choices around trees in hard landscapes, refer to *Surface materials around trees in hard landscapes* to be issued by the London Tree Officers Association in the late summer 2014.

The choice of surfacing around the tree will have an impact on the extent to which mechanical sweepers can be used and complementary manual cleaning is required. Convenience of cleaning must be balanced with tree health considerations. Mechanical sweepers coming too close to the tree trunk can cause injury to the bark, which, at worst, can result in the death of the tree. Sweeper brushes can also remove material from around the tree opening which can cause trip hazards.

2.6.3
Use of de-icing salt

Salt damage, as a result of the use of thawing salts (sodium chloride) on paved surfaces near trees, is a well-known phenomenon. Damage may occur when a high concentration of salt is present in the surface water runoff entering the tree rooting environment. Damage also occurs when tree branches are exposed

Working Solutions:
Surface opening treatment

In a kerb buildout, woodchips provide a good surface opening treatment (Lyon, France). Image: Richard Barnes

A gentle lip at the edge of the surface opening discourages trespassing and keeps wood shavings in place (Lyon, France).

Continuous strips of loose gravel on the Rhone embankment are easy to maintain for this hard landscape designed to withstand occasional flooding (Lyon, France)

A low kerb and level drop protects the woodchip-covered tree surrounds from trespassing. Kerb opening ensures surface water runoff can flow in (Greenwich Peninsula, London)

Continuous strips of self-binding aggregate between the footway and the tramway in Quinconces Square (Bordeaux, France)

Simple loose gravel, laid slightly below the surrounding asphalt to avoid spilling (Bern, Switzerland)

Self-binding aggregate used for roadsides in a new development (Lyon, France)

Non-slip timber tree grates provide a cost-effective and flexible solution. (Lyon, France). Image: Frédéric Ségur

All non-credited images by Anne Jaluzot

Grate with watering inlet and resin-bound infill and watering/aeration inlet on Ocean Road (see Case study 2). Image: South Tyneside Council

The opening of timber tree grates can easily be resized or tailored to accommodate trunk growth or mature trees (Lyon, France). Image: Frédéric Ségur

Tree grill with Limestone infill matches surroundings and facilitates water infiltration as well as gas exchange. Laid perpendicular to pedestrian flow to reduce slip risks (Place Bellecour, Lyon, France). Image: Sue James

Extensive ductile cast iron grate facilitates water infiltration and effective gas exchange between above- and below-ground environments (Stockholm, Sweden)

Grate with watering/aeration inlet and York stone infill matches surrounding paving at busy Dalston Junction bus station (Hackney, London)

Grate with removable rings in resin-bound gravel and watering/aeration inlet on Swansea Boulevard (see Case study 17). Image: Sue James

Substructure and completed conditions of the prominent bespoke tree grate installed at Apeldoorn Station Square (see Case study 22). Images: Ron van Raam (substructure), Jeremy Barrell (completed)

Tree surrounds treatment options			
	Suitable context	**Maintenance**	**Cost**
Organic mulch	Where space is available for open planters. Where footfall is very low, in wide footways and hard surfaced areas. Underneath other systems (eg tree grates).	Mulch will need to be replenished from time to time. Unsuitable for mechanical sweeping	Very low
Loose aggregate	Wide footways and hard surfaced areas, where the tree surface opening will only be expected to accommodate low/occasional footfall.	Aggregate will need refilling from time to time. A ring of mulch should be included (and regularly refilled) immediately around the tree trunk. Unsuitable for mechanical sweeping.	Low
Self-binding aggregate	Wide footways and hard surfaced areas, where the tree surface opening will only be expected to accommodate low to medium footfall.	Aggregate will need refilling and loosening from time to time. A ring of mulch should be included (and regularly refilled) immediately around the tree trunk. Unsuitable for mechanical sweeping.	Low
Resin-bound aggregate	Footways and hard surfaced areas where the tree surface opening will be expected to accommodate medium to high footfall.	Subject to cracking under the pressure of buttress roots. Subject to clogging – particularly if subject to mechanical sweeping. A ring of mulch should be included (and regularly refilled) immediately around the tree trunk.	High
Flexible permeable rubber surfacing	Footways and hard surfaced areas where the tree surface opening will be expected to accommodate medium to high footfall.	A ring of mulch should be included (and regularly refilled) immediately around the tree trunk.	Medium
Tree grille or grate	Footways and hard surfaced areas where the tree surface opening will be expected to accommodate medium to high footfall, and/or vehicular access.	Frame subject to deformation due to settling or pressure from buttress roots. Traps litter under the grille/grate requiring manual cleaning. Mulch should be laid beneath the grille/grate (and regularly refilled).	High

to melted salt water blown into the air by traffic. Indirect damage may occur when physical and chemical soil properties are adversely affected by the salt. The presence of sodium can lead to the disintegration of the soil particles and the production of fines which enter and clog soil pores. This reduces aeration and promotes soil compaction. Salt also alters the osmotic potential of the soil solution. The tree therefore has to use more energy to absorb water from the soil matrix.

Mitigation requires a combination of tree and non-tree-based measures:

– Minimising the amount of de-icing salt utilised in highway winter service operations by following the guidance and recommendations contained within the latest edition of Well Maintained Highways – Code of Practice for Highway Maintenance Management, published by the UK Roads Liaison

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48
The current version can be found at: www.ukroadsliaisongroup.org/en/UKRLG-and-boards/uk-roads-board/wellmaintained-highways.cfm (dated 18 September 2013)

49
See the appendix of De-icing salt damage to trees. Found at: www.forestry.gov.uk/pdf/pathology_note11.pdf/$FILE/pathology_note11.pdf

Group[48].

- Adjusting the tree planting environment design, allowing for the temporary installation of protective barriers for salt spray in the winter alongside heavily trafficked streets, as routinely done in Copenhagen.
- If surface water runoff is directed to the pit, ensuring high drainage rate and dilution with non-contaminated water (roof-runoff).
- Selecting salt-tolerant species. In 2011 Forest Research provided a simple rating[49] of the soil salt tolerance of common species in the UK. This list is non-exhaustive, and complementary advice should be sought from an arborist as well as the supplying tree nursery.
- Flushing the tree opening and planting hole with water in spring after a bad winter.
- Avoiding pollarding after a bad winter.
- Avoiding as much as possible placing street salt bins near to existing trees.

Salt spray protection installed on trees alongside high-vehicular traffic routes. Image: Anne Jaluzot

Image forthcoming.
Image:

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In Summary

Find purpose and space
- Align tree design to the objectives of the scheme; pursue multiple benefits.

- Consider reallocating carriageway space to overcome above-ground constraints to planting or retaining trees while improving the quality of place eg better for walking, cycling, socialising and resting.

- Consider using or retrofitting a common utility enclosure or shared trench to overcome below-ground constraints while enhancing protection and access to utilities.

Exploit tree benefits
- Consider using trees for traffic calming.

- Consider using trees to enhance conditions for walking and cycling.

- Consider using trees and their growing media to receive and manage surface water runoff, and consider how this can also benefit the tree.

- Consider how trees can enhance human health and support urban wildlife.

- Consider the benefits of trees for microclimate control (eg shading, shelter from wind, reducing overheating on glazed frontages) and associated energy impacts on buildings.

- Consider how trees can improve the quality of the local environment and increase the time people spend walking, shopping and socialising.

Ensure compatibility
- Protect visibility for vehicles, commercial signs and shops, street lighting and CCTV.

- Secure vertical and horizontal clearances through adequate planting and management specifications. Take a pragmatic approach to existing trees with a view to retaining wherever possible.

- Make informed choices for surface treatment around trees to suit context and capital and maintenance budget.

- Spend time and collaborate on the design of the below-ground environment.

Keep maintenance in mind
- Balance use and biodiversity considerations such as leaf falling, fruit, seed and bird droppings, with the practicalities of and budget for surface cleaning.

- Beware of de-icing salt damage. Follow guidance to manage impact.

- Ensure provision of aftercare for trees so that they flourish.

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Technical Design Solutions

Consultation draft

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Technical Design Solutions
Building in sustainable success

Trees, like other types of infrastructure, require investment. The costs involved are justified by the benefits expected from a mature tree. Return on investment fails to materialise when the tree does not survive and/or the surrounding infrastructure is damaged due to inadequate design or maintenance provision – two scenarios unfortunately commonly observed in our towns and cities.

Whether in the context of retrofitting existing hard landscapes or developing new ones, provisions and procedures are usually in place to allow for innovation. However, this opportunity is often little exploited, particularly in the context of highway adoption. This guide takes the view that research findings and technical innovations should be fully exploited.

This section examines the technical solutions available to help designers to build success into their design of the below-ground environment. It recognises that no single technique or solution fits all situations and highlights the evidence-based pros and cons, relevant context and success factors. The goal is to enable an informed analysis and decision-making process.

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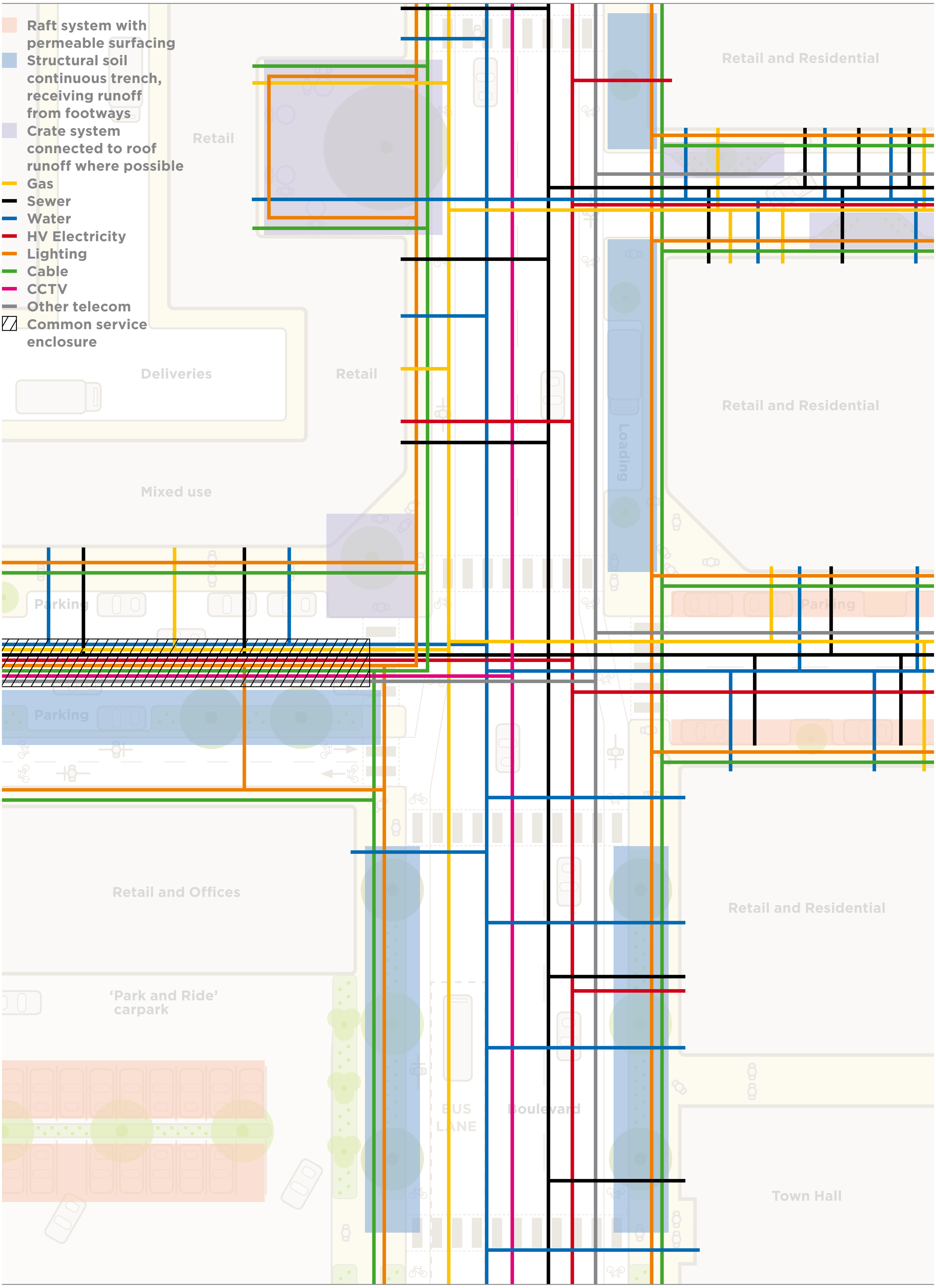
Not to scale – for illustrative purposes only



3.1
Basic tree knowledge for success

Trees are living organisms. Predicting and controlling their behaviour with full certainty is not possible. However, a better understanding of the lifecycle and fundamental requirements of trees goes a long way in enabling design choices that reduce the risk of conflict with the surrounding infrastructure.

Familiarising oneself with the "tree fundamentals" covered below does not remove the need to involve the right professionals throughout the decision-making process, but will make joint working easier and more fruitful.

3.1.1
Terminology

The term "tree pit" is widely adopted to refer generally to the space created for accommodating trees in paved areas. Depending on circumstances, the term might be used to refer to:

- The *surface opening* created for and left after the planting of the tree.
- The *planting hole* created to fit the root ball of a newly planted tree into the ground.
- *Rooting volume* or *environment*, ie the wider area of soil (or other growing medium) that roots will be able to explore to support the growth of the tree. Part of this might also have been excavated during the construction of the planting area to place a root barrier around utilities or install a load-bearing growing system.
- All of the above plus the infrastructure laid above and below ground to support tree growth, such as an anchoring system for the tree, a watering tube, an aeration well, etc.

The term "tree pit" can also be misleading, as it conveys the image of a confined space, which is not an accurate representation of what trees need to grow and last while maintaining maximum compatibility with the surrounding infrastructure. To avoid confusion and misconceptions, this document uses, where applicable, the more specific and accurate terms listed above rather than the term "tree pit".

3.1.2
Why longevity matters

A planted tree is a promise. As shown in the cost/benefit diagram illustrating Case study 16, it is only through growth over time that a tree can fulfil its potential to deliver its full range of benefits and, through these, a return on investment. As such, trees have a very different lifecycle to other highway assets: their value increases with time.

To maximise returns, both the design and the management strategies need to cater for this unusual value appreciation process. This might involve:

- Moving away from "single point in time" design to integrate an understanding of the changing needs and size of the tree over time.
- Taking a strategic approach to managing costs.

The total lifecycle cost of a tree and the net benefits generated by it will likely be higher if investments are made at an early stage:

- To invest in selection of provenances and species at the production stage that are better able to survive in harsh urban conditions.
- To provide an adequate type and volume of growing medium.
- To provide suitable protection.
- To provide for adequate post-planting care, including formative pruning which addresses the correction and adjustment of branch structure when it is most inexpensive to do so.

3.1.3
Roots, oxygen and rooting volume

The more a young tree is provided with or can access conditions conducive to root development, the greater the chances that the tree will successfully reach independence after planting and fulfil its potential without upsetting the surrounding infrastructure.

Root access to oxygen is crucial

It is common knowledge that, like other plants, trees require water, nutrients and some space. What is less well understood is how much the ability of a tree to access these requirements is predicated on soil aeration.

No matter how nutrient rich and moist a soil may be, if it lacks voids (ie soil pores) and oxygen, tree roots will not be able to absorb the water and nutrients the soil contains. When oxygen levels are below 10%, tree roots cease to grow and lose their ability to protect the tree against harmful gases present in the soil (such as carbon dioxide, ethanol etc)[50].

In hard landscapes, soil aeration can be severely compromised:

50
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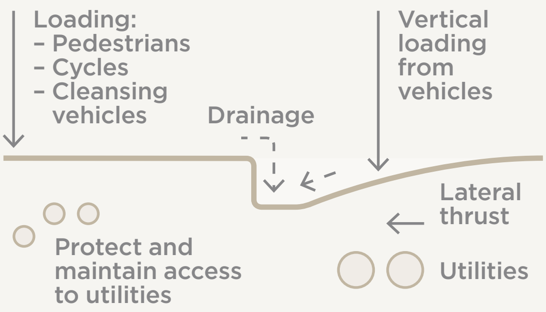
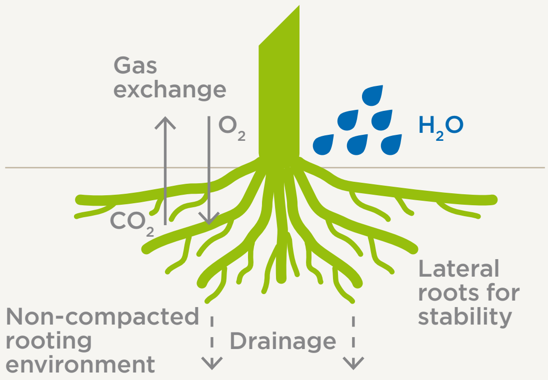
Key points for success with trees in hard landscapes

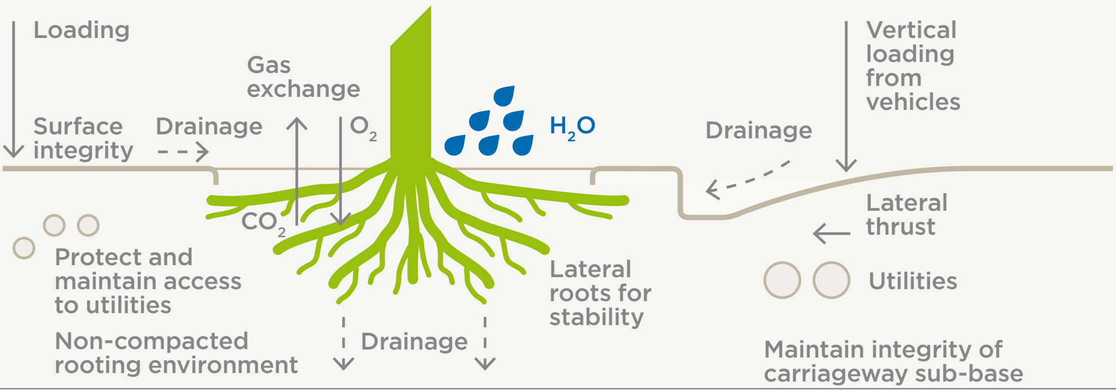
Highway needs



Tree needs



Setting the brief



Case study 16
Cost, benefits and lifespan figures for two typical UK street trees

Location
UK

Data collected from TDAG members shows the typical costs and benefits of two tree species most commonly planted in streets: the ornamental pear (*Pyrus chantecleer*) and large canopy-growing London plane (*Platanus x acerifolia*).

Tree valuation specialists from Treeconomics helped assess the typical financial value of the benefits of these two species growing in a street environment by using the i-Tree Eco model. The benefits taken into consideration in the UK version of this evaluation tool, which originated in the US, include carbon sequestration, air pollutant removal and amenity value (based on replacement costs).

Cost information was provided by Amey Birmingham. As the two cost curves below show, creating the right conditions for having a freestanding canopy for much of the mature life of a large tree significantly reduces total management costs. Shifting resources away from systematic pollarding and towards formative pruning as well as replacement planting can provide a means to manage more trees for less. It is such strategic shifts in management strategies that has enabled the Greater Lyon Authority to double its tree population (see Case study 30, pXX) without doubling its tree maintenance budget.

Image: forthcoming

- Soil sealing with hard impervious surfacing prevents gas exchange between the above- and below-ground environments: oxygen from the atmosphere cannot get into the soil and carbon dioxide produced by tree roots remains trapped below ground.
- Through poor drainage and artificially high water tables due to local design.
- Soil compaction similarly compromises gas exchange and also leaves no room for oxygen to be present (no soil pores) in the ground.

Under such circumstances, two scenarios are likely:
- Early tree decline and death: a newly planted tree will continue to grow at a slow rate until its roots have filled the original planting hole. When the needs of the tree exceed the capacity of the soil, the health of the tree will begin to decline. The tree will eventually die without providing the benefits and return on investment that mature, healthy trees offer.
- Infrastructure damage: tree roots can only grow in the space where air is present, which, in urban settings, will often mean between the compacted soil and the overlying surfacing materials (ie in the footway of road sub-base) or along utility pipes. This is likely to increase the future risk of conflict with these structures.

Understanding and providing for this fundamental need for soil aeration goes a long way in enhancing the ability for trees and infrastructure to share space.

Rooting volume

Together with soil aeration, providing adequate rooting volume is the other fundamental precondition to secure a healthy cohabitation between trees and urban infrastructure.

Strategies to increase rooting volumes include:
- Estimating rooting volume requirements early in the process – if brought in as an afterthought, too many parameters will have already been set for enhanced rooting condition and volume to be provided cost effectively.
- Expanding as much as possible the rooting volume beneath the paved surface, using load-bearing planting substrates (see 3.2).
- Planting trees in a continuous trench, enabling the roots to spread into the space between trees. To be effective, the width of the trench needs to be in excess of and commensurate to the size of the root balls of the trees planted. Once installed, care must be taken to protect the soil in the trench from compaction.
- Making provision to connect to and exploit adjoining soil areas. Trees planted in hard landscapes are often in close proximity, though not immediately adjacent, to areas of grass or other vegetation. One idea is to create “break out” zones for roots, also called “root

Different tree sizes reflect the variation in available rooting volume and soil compaction in this carpark in Gelsenkirchen, Germany. Image: Johan Östberg

Consultation draft

paths" or "root channels". Rooting conditions can be improved in specific areas, directing roots away from kerbs and hard surfaces, into the soil beneath nearby vegetation. Future tree stability should be a design consideration when adopting such specifications.

3.1.4
Dispelling the topsoil myth

What is topsoil?

Topsoil is often unconditionally thought to be "better for the tree". This is a mistake. One of the main characteristics that differentiates topsoil from other soil horizons (ie layers) is the presence of an intense microbial activity that is, indeed, highly beneficial to plant life, including tree roots. This beneficial microbial life feeds off oxygen. When oxygen supplies are not sufficient, harmful anaerobic bacteria take over.

In hard landscapes, most tree rooting environments are below impermeable surfaces and access to oxygen is dependent upon soil compaction levels and provision of an aeration system. If imported soils are used, the most appropriate mix for the site condition should be used[51]. If good knowledge relating to tree development under the prevailing conditions found within the planting site is not available among the professionals involved in the project, specialist advice should be sought[52].

Testing and re-using existing soil where fit for purpose

The medium used to backfill the planting hole should be as close as possible in texture and structure to the soil excavated. Where possible, the soil dug from the excavated hole should be used as the backfill medium[53].

Importing soil comes at a significant financial and environmental cost. Disposal of excavation materials (spoil) is also costly. While in some cases excavation only reveals rubble, in many situations reuse of the existing soil will be possible. Often the mineral component of the soil is reasonable, and simple changes to the compaction, organic matter and drainage can make the soil acceptable. Conducting soil testing and seeking professional advice at the outset of a project can bring significant savings if spoil can be used on site[54].

3.1.5
Securing access to water and drainage

Too little water shortens both the lifespan and growth of the tree but too much water creates anaerobic conditions (no oxygen) that are lethal to roots. The tree-growing environment therefore needs to facilitate water infiltration and retention as well as drainage. Without careful design consideration, most hard landscapes do very poorly at all three.

Hard landscapes are mostly impervious and little water infiltrates into the ground. Even when moisture is present, soil compaction further limits the amount of water available to the tree. The smaller the voids between soil particles, the greater the surface tension holding the water in place. As a result, in highly compacted soils, roots will not manage to use the little water that is present.

The juxtaposition of soils of very different textures typically found in urban areas prevents uniform water percolation. This is exacerbated:

- When using high quality infill within the planting hole in contrast to the surrounding soil (see 3.1.4 above on re-using existing soil). The discrepancy created results in a "tea cup effect" whereby water collects at the bottom of the hole and generates harmful anaerobic conditions.
- When geotextiles, geomembranes and other barriers are introduced into the tree-growing environment.

This can be mitigated through:

- Increasing the size of the tree opening at the surface.
- Limiting soil imbalances that might interfere with water percolation.
- Using pervious surfacing materials facilitating water infiltration and/or directing surface water runoff into the tree pit (see paragraph 3.5).
- Maximising opportunities to create expanded and continuous soil trenches underneath surrounding weight-bearing surfaces (see paragraph 3.2).
- Making provision for easy watering of the tree in its younger years, using irrigation tools such as waterbags. As demonstrated in *Sustainable Water Management: Trees are part of the solution*[55] by the London Tree Officers Association, the watering of young trees should not be restricted in times of drought.
- Accounting for drought tolerance in tree species and provenance selection.
- Limiting the use of tightly woven geotextiles unless there is a specific and necessary engineering requirement. The use of such products may impede

51
Refer to BS 8545:2014, paragraph 10.2.8

52
Refer to BS 8545:2014, paragraph 10.2.2

53
Refer to BS 8545:2014, paragraph 10.2.5-10.2.6

54
Refer to BS 8545:2014, paragraph 6.3

55
Published in 2013. Found at: www.trees.org.uk/aa/news/LTOA-Sustainable-Water-Management-Trees-are-part-of-the-solution-200.html

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56
Refer to BS 8545:2014, paragraphs 10.3.1-10.3.6

gaseous exchange, water movement and root extension beyond the tree planting hole, which will all limit the ability of trees to access water.

3.1.6 Above-ground protection

A number of design choices for the above-ground environment will also have a significant impact on health and growth. These include:
- The size of the surface opening.
- The nature of the surface immediately surrounding the base of the tree.
- Protecting tree bark from injury.
- Providing support to avoid destabilisation.

Surface opening

Adequate sizing of the surface opening around the tree helps facilitate water infiltration and aeration of the soil below. The potentially adverse impact on aeration from a restricted surface opening at the base of the tree can be compensated for by the provision of an aeration system. The opening must always be designed to accommodate radial trunk growth and flare over time without causing injury.

Surfacing at the base of the tree

Surface treatment choices play an equally important role in allowing water infiltration, facilitating moisture retention and aeration of the soil below. Surface treatment choices can also help protect the soil underneath from compaction by pedestrian traffic. The use of the above-ground space will be the first driver for surface treatment choices. Cost and lifespan as well as long-term maintenance requirements and ease of street cleaning will also be important considerations. Available options and trade-offs are further discussed in 2.6.2.

Providing support[56]

It will take newly planted trees a few years to establish stabilising roots and adequate anchoring. Some support is therefore necessary during the establishment phase. A degree of continual movement stimulates root growth and is essential in enabling the tree to develop adequate strength. The support provided should not inhibit gentle oscillations of the tree canopy or stem. This might be provided through:
- Above-ground wooden stakes: the ties used must allow for the tree to increase in diameter without getting “strangled”.
- Below-ground root ball anchoring systems. The biggest benefit of the use of below-ground ties that ratchet the root ball firmly into the ground is that they are completely invisible once the tree has been planted and thus produce a more tidy aesthetic effect following planting. However, such systems require more knowledge and skills for installation and can only be used with a healthy root ball that is more than 150L. Smaller root balls result in the system being ineffective at supporting the tree. Once installed, this system does not

Blooming plum trees fitted with waterbags in Stockholm.
Image: Björn Embrén

Consultation draft

need to be removed and can remain in the ground for as long as the tree.

57
Refer to BS 8545:2014, paragraphs 10.3.11-10.3.13

58
Found at: www.ltoa.org.uk/resources/dog-damage-to-trees

Protecting the tree bark from injury[57]

Maintaining the integrity of the bark and outside layer of the trunk of a tree is essential to its survival. The phloem layer of tissue just below the bark is responsible for carrying food produced through photosynthesis in the leaves to the roots. Without this food, the roots ultimately die and cease sending water and minerals back to the leaves.

In tight spaces or high traffic areas, providing protection for the tree bark might therefore be necessary, particularly when the tree is young as bark is then thinner and easier to damage. This might involve the use of temporary tree protection such as hessian wrapping, bamboo mats, plastic mesh or light cages. Those are usually inexpensive as well as being easy to install, remove and reuse.

In public realm areas used for large events such as markets where trees are more vulnerable to damage from vehicles and temporary structures, sturdier and possibly longer-term protection might be required. Options for this include:

- Metal tree guards. Often these are expensive and must be removed as the tree grows. Depending on the design, the space between the trunk and the guard can collect litter. A budget for removal and cleaning must be included in overall project costs. Failure to do so will result in the guard seriously injuring the tree.
- Raised kerbs, low railing and bollards. These provide more permanent protection which might be required to protect against vehicles for car park planting for instance. However, these can contribute to clutter and trip hazards.
- Urban furniture (seating, bicycle racks) adequately positioned around or on each side of a tree. This unarguably offers the most space-efficient and people-friendly solution. However, most of these elements will have a shorter lifecycle than the tree. Care is therefore required in the chosen design and installation method to allow for any furniture placed near a tree to be replaced or removed without causing damage to the rooting zone.

Some dog owners strengthen their dogs jaws by encouraging them to hang form low branches and chew bark. This can represent a very serious source of damage. Advice on how to protect young and mature trees from dog damage, but also address the issue through education, community engagement and enforcement is available in *Better Bark than Bite – Damage to trees by dogs*, the Best Practice Note published by the London Tree Officers Association in 2010[58].

3.1.7 Implications for tree rooting environment design

The overall aim when planting trees in hard landscapes should be to create conditions in which the tree can thrive and survive its potential lifespan successfully.

There are situations, particularly the footways of existing suburban streets, where soils have not been heavily disturbed or compacted and there is limited competition for above- and below-ground space. In these cases it has been possible to plant street trees by doing no more than providing space for the tree root ball and adequate aftercare in terms of protection, watering, mulching, and formative pruning, as described in BS 8545:2014.

However, most hard landscape

Conducted with active community endorsement and participation (eg watering), simple tree planting along Hackney's residential streets has been very successful (see *Trees in the Townscape* Case study p58)

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Temporary bamboo mat for light protection in Lyon, France. Image: Sue James

Temporary light cage in residential setting in Hackney, London

Bamboo mat and tree grate-mounted timber guard where greater protection needed in Lyon, France. Image: Sue James

Sturdier metal guard in busy high street in Hackney, London

All non-credited images: Anne Jaluzot

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Tree grill-mounted bicycle hoops in Stockholm, Sweden

Popular circular benches in Norwich

Low-level multipurpose protection in central Stockholm, Sweden

Rural timber frame protects tree and biodiversity along Parisian boulevard

circumstances are more demanding and some more sophisticated designs will be required to secure the successful integration of the tree and the surrounding infrastructure. Such demanding circumstances include where:
- Soils are heavily disturbed, compacted or poor draining.
- No settling can be tolerated.
- Hard surfacing is required over the root ball area.
- Medium to high pedestrian or bicycle traffic is required over the tree-rooting environment.
- Vehicular parking or vehicular traffic is required over the tree-rooting environment.
- Utilities are in close proximity (ie three metres or less) to the tree.
- Contribution to surface water management is also expected.

A range of design options and technical solutions are outlined below that will help mitigate these demands, without compromising the performance of the tree or that of the surrounding infrastructure.

3.2 Load bearing

The engineering load-spreading requirements for hard surfaced areas are at odds with the biological needs of trees:
- Sub-surfaces often need to be compacted to within 95% of their peak density, to prevent settling under design loads. Base layers are usually unbound granular materials that facilitate high compaction and drain water away.
- By contrast, the biological requirements for root growth include: low bulk density; a distribution of pore sizes providing adequate storage capacity for available water, as well as good drainage and aeration; and sufficient fertility to provide an adequate supply of nutrients.

Incorporating trees in hard landscapes with adequate space for growth means that some tree root-growing medium may have to be provided under load-bearing hard surfaces.

The technical solutions available to achieve this broadly fall into three categories:
- Structural growing media.
- Modular crate systems.
- Raft systems.

These techniques are not mutually exclusive. It is not uncommon for designers to use them in combination to suit the particular circumstances of a project. An overview of the main systems available under each category is provided below, highlighting:
- How the system works.
- Benefits.
- Limitations.
- Relevant locations.
- Cost.
- Examples.
- Tips for success.

Any load-bearing system should be designed and specified in accordance with expert advice. The overview descriptions provided below are for information only. They were compiled from feedback from experts and users and published academic evidence. The system described might encompass both patented and unpatented techniques or proprietary products. With patented techniques or proprietary products, each provider has its own performance specifications and warranties. These are not detailed in this guide and require direct investigation with suppliers, in the light of the needs and constraints of each site. The advice from suppliers should be cross-referenced with the project engineer and tree specialist in order to ensure the specification is fit for purpose for the particular site conditions and project objectives.

3.2.1 Structural growing media

The main principles and parameters differentiating structural growing substrates are presented below under the three main types:
- Sand-based substrates.
- Medium-size aggregate substrates.
- Large-stone skeleton substrates.

This categorisation is, to a degree, a simplification as a wide range of solutions have been developed to suit local circumstances, some based on the availability of raw materials. Some will fall halfway between categories, particularly the two latter ones. For example, the Greater Lyon Authority uses a structural growing medium relying on large stones but follows an installation process (pre-mixing of soil and stones) more commonly found with medium-size aggregate substrates.

For those with the capacity and appetite to experiment, structural growing media

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lend themselves to local fine tuning and less reliance on manufactured products.

Sand-based substrates

How it works

Sand-based tree soils were developed in the Netherlands in the 1970s in response to the decline of trees in Amsterdam due to its high water table and heavy clay. What subsequently became known as Amsterdam Tree Soil and similar sand-based growing media are predominantly (approximately 90%) a medium-coarse silica sand (medium particle size of 0.22mm) with small amounts of organic matter (4-5% by weight) and clay (2-4%) to add capacity for water and nutrient retention. More recent adaptations of this sand-based model include:

- Rotterdam Tree Soil (developed approximately 20 years ago), using coarser silica sand (0.75mm) to provide more air and voids in the soil after compaction.
- Coarser mixes made from recycled materials such as glass (cleaned and grinded to 1-2mm granular size) and coir pith (ie coco peat and fibre) to provide organic matter.

The components are mixed prior to installation and then installed in layers, each compacted to the required density. The total depth is limited to 800mm as aeration is too poor for root growth at greater depths. Provision of an aeration system either around the root ball or at the bottom of the planting hole is recommended (see tips for success).

Benefits

- Relatively long implementation history (40 years+): good understanding of long-term impact on trees, limitations and possible mitigation measures[59].
- Availability of patented and unpatented options.
- Effective load-bearing capacity for pedestrian and cycle traffic where minimal settling is acceptable.
- Tolerates high level of compaction (up to 80% of dry density) before restricting root growth. It is possible to achieve higher compaction levels (up to 95% of dry density), particularly if very high standards of quality control have been applied to the installation (see tips for success). However, this will inevitably reduce effectiveness as a rooting medium.
- Cost effective.

Limitations

- Low water holding capacity creates sensitivity to drought: unless water recharge can consistently be provided throughout the growing season by rainfall infiltration or capillarity from a high water table, installation of an automatic irrigation system is required.
- Risks of low soil Ph (acidity) induced by organic matter content (see tips for success).
- Existing soil will not be re-used which may result in expensive haulage and disposal costs.
- Sand-based substrates are unsuitable when compaction at 3MPa and above is required because roots are entirely

Working solutions: Sand-based substrate installation process

Image: forthcoming

Image: forthcoming

Image: forthcoming

Image: forthcoming

59 Couenberg, E (1998). *Urban tree soil and tree pit design* in Neely, D and Watson, GW (eds) *The Landscape Below Ground II: Proceedings of an International Workshop on Tree Root Development in Urban Soils*. Champaign, IL: International Society of Arboriculture

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unable to grow in such circumstances.
- Good technical oversight is required to ensure adequate specifications are issued and followed (see tips for success).

Relevant locations
- Underneath footways supporting low to medium pedestrian traffic and bicycle tracks.
- In areas with high water table or in conjunction with pervious surfacing to provide surface water runoff infiltration.
- Use in combination with other systems, particularly raft systems, to obtain better loading capacity and improved growing medium (see 3.2.3).

Costs: Relatively inexpensive, although the installation of an automatic irrigation system will increase installation and maintenance costs.

Tips for success
- Getting the sand granular size specification right: the effectiveness of sand-based substrates requires the use of sand with consistent granular size. About 80% of the sand grains must be of the same size or within a very narrow distribution spread. Failure to achieve this will, following compaction, result in small grains filling all the voids left by larger grains with no space for air or root growth. On-site verification of the quality of the sand mix supplied is essential.
- Understanding the age and quality of the organic matter used: new organic matter produced from household waste will not only be acidic, it will also use a lot of oxygen and produce methane as it starts to mature and continues to decompose in the first few years following the installation. If mature and more stable green waste-derived compost cannot be sourced, an aeration system around the root ball or at the bottom of the installation is highly recommended.
- Monitoring water content during application: the water content of the mix when applied should not be greater than 8%. The delivery truck supplying the material should be covered and installation should not take place in the rain. If standing water is present in the planting hole at the time of application, a layer of standard drainage sand should be applied before installing the compost-rich sand mix.
- Backfilling and compacting in layers with adequate equipment: the mix is to be applied in layers of approximately 30cm. Each layer requires compaction with a wacker stamper rather than with a vibrating plate (this would create undesirable layers of impermeable crust).
- If root growth beyond the pit boundaries is required, then geotextiles that prevent root extension should not be used.

Medium size aggregate substrates

How it works
Medium size aggregate substrates use an angular stone matrix allowing compaction to high load-bearing requirements (eg 95% of dry density) while still supporting root growth thanks to the air voids and soil provided in the interstitial space.

There are many versions of such stone/soil mixes. Some are patented. The main differentiating variables are:
- The relative proportion of stone and soil: depending on the stone size used (25-35mm; 50-100mm), soil might represent between 20% to 35% of the mix.
- Stone type (porous aggregate v dense stone such as granite). Increased water absorption capacity will normally compromise strength and therefore load-bearing capacity.
- Composition of the “soil” element added to the stone matrix (some combine clay, sand and compost, others use only clay).
- Use of complementary ingredients (eg binding polymer gel, soil stabiliser).

Benefits
- 20-year implementation history has allowed for comparative testing with a sand-based and traditional, loam-based growing medium, enabling the impact on tree growth to be understood[60].
- Availability of both patented and unpatented options.
- Effective load-bearing capacity for pedestrian traffic and light vehicular traffic where no settling is acceptable.
- Tolerate high level of compaction (95% of dry density).
- Can be incorporated into a sustainable urban drainage strategy.

Limitations
- Growth is limited by the net soil volume contained within the soil/aggregate mix. With mixes having 20% of soil, providing one cubic metre of soil requires five cubic metres of space. Where designs have failed to account

60
Monitoring was initiated in 2004 at the Bartlett Tree Laboratory in Charlotte, NC in the US and carries on to date. Initial results were published in Smiley, ET, Calfee, L, Fraedrich, BR, and Smiley, EJ (2006) *Comparison of Structural and Noncompacted Soils for Trees Surrounded by Pavement*. Arboriculture & Urban Forestry. 32(4):164-169. Further updates can be found at: www.deeproot.com/blog/blog-entries/suspended-pavement-at-the-bartlett-tree-lab-year-7
and Bühler, O (2007). Below the Surface: In-depth Investigation of Tree Development, Root Growth, and Soil Conditions in Structural Soils in Copenhagen, Denmark. Copenhagen: University of Copenhagen

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Case study 17
Building a long-lived maritime boulevard treescape

Location
Swansea, Wales

The heavily trafficked route from Swansea's Tawe Bridges to Princess Way not only provided a poor entrance to Wales' second city, it also acted as a barrier between its city centre and waterfront.

Having secured funding from the Welsh Government, the Wales European Funding Office and its own budget, Swansea Council launched in 2010 an ambitious refurbishment programme aimed to turn Quay Parade, Victoria Road and Oystermouth Road into a tree-lined boulevard

The goals of the £8 million scheme due for completion in autumn 2014 are to create a visually and environmentally enhanced gateway in and out of the city centre and a setting for development. The project also aims to encourage and facilitate pedestrian and bicycle movements between the city centre, the Maritime Quarter, the promenade and SA1 – a brownfield development located on Swansea's docks where the new consolidated campus for University of Wales Trinity Saint David is to be built.

To deliver this without reducing vehicular flows, traffic signals have been modernised, key junctions reconfigured, the number of turning points restricted, footways widened and close to 120 elm trees are being planted. They were selected for their longevity of up to 300 years and capacity to withstand maritime exposure with a compact habit, small seeds and leaves that decompose quickly. A licensed cultivar resistant to Dutch elm disease were procured.

Tree spacing on both sides of the boulevard and in the central reservation varies according to the curvature of the roadway so as to maintain consistent framing of the street perspective. Some electrical, gas and telecom services were diverted to make room for the planting. However, where utility relocations would have been too costly, or where construction revealed unexpected underground structures: the design was modified. Good communication and collaboration within the project team ensured the delivery stayed true to the design intent while being pragmatically adaptive to the unavoidable complexities of retrofit situations. Great level of attention was dedicated to the quality of the natural stone paving materials used and to the detailing of the tree planting environment so as to secure long-lived, conflict-free, results.

To grow healthy elms in this high quality setting, sand-based load bearing soil was used to backfill the tree planting pits. This cost effective choice is particularly well suited for this location given the high level of the ground water table, which, through percolation, will help keep the trees well supplied in water. Where utility constraints allowed, the dimensions of each tree planting holes were extended to enable roots to access good growing environment found in adjacent landscaped areas. The surface of each pit is covered with an adaptable tree grill made of incrementally removable concentric rings of aluminium in-filled with 10mm resin-bound red granite chippings. The are a immediately adjacent the tree is in-filled with matching unbound clean red granite chippings. The unbound gravel, rings and shallower depths of resin bound gravel found immediately around the tree can be removed over time to make room for unimpeded trunk growth. The grills are level with the surrounding footways, thus maximising pedestrian access while allowing for some of the surface runoff to enter the 'tree pit'.

Swansea boulevard in April 2014, a few weeks after completion.
Image: Crown Copyright 2014 (CCS)

61
Smiley, ET, Calfee, L, Fraedrich, BR, and Smiley, EJ (2006) *Comparison of Structural and Noncompacted Soils for Trees Surrounded by Pavement*. Arboriculture & Urban Forestry. 32(4):164-169

62
Found at: http://offlinehbpl.hbpl.co.uk/NewsAttachments/WOH/100322%20GH_HB%20STHLM%20-%20Engelsk%20version.pdf

for the small amount of soil present in the mix, trees have shown evidence of nutrient deficiency[61].

- Increased tree vulnerability to drought conditions: structural soil does not hold water in the same way as a normal soil and drains quickly.
- Handling and mixing requires good technical knowledge and oversight (see tips for success).
- The cost effectiveness of the technique is dependent upon good local availability of stone or aggregate to be used in the mix.
- Existing soil will not be re-used which may result in expensive haulage and disposal costs.

Relevant locations

- Installed in continuous trenches underneath a footway or plaza with light to high pedestrian traffic where no settling can be tolerated; underneath bicycle tracks; underneath car parks with light vehicular traffic.
- In conjunction with pervious surfacing to provide surface water runoff infiltration.
- In tight, contorted or irregular spaces to provide a load-bearing break-out to adjoining uncompacted soil.

Costs: Inexpensive to medium expensive.

Tips for success

- The stone aggregate used in the mix has to be angular and consistent in size. As with sand-based structural substrates, good specification and on-site verification of the size distribution of the aggregate used is essential.
- Use of stone/soil mixes with larger stones (>50mm) allow for a greater proportion of soil to be available in the mix (30%).
- The soil element of the mix also needs to comply with the specification. Moisture level needs monitoring: excessive wetness can create glazing if compacted with a vibrating plate during installation.
- If mixed off-site, the stone aggregate/soil mix should be carefully inspected on delivery to ensure the soil has not separated from the stone.
- Stone/soil mixes need to be installed and compacted in layers (from 150-300 mm deep – dependent on the type of mix chosen).
- The bottom of the installation needs to be compacted. Provision of an under drain will ensure water does not accumulate.

Stone skeleton substrates.

How it works

One of the places where large-stone skeleton soil is most commonly used is Stockholm.

"What is Stockholm's system? Plant beds built with granite stone where we infiltrate storm water and ensure that the gas exchange works. With strong control over both construction work and maintenance program for the establishment of trees."

Björn Embrén, arboricultural manager, City of Stockholm

The system consists of an extensive base, made of large angular stones (granite, recycled concrete blocks, etc – 100-150 mm in grade size), covered with an aeration layer (washed granite 63-90 mm in grade size). Soil is flushed into the stone base after it has been compacted, and prior to the installation of the aeration layer. The road or footway surfacing and its subgrade are installed over a geotextile layer placed on top of the aeration layer.

The aeration layer is fitted with a well which is covered by a grate (similar to that used for a gully). The air temperature difference between above and below ground allows for the gas exchange to take place. The aeration well and layer can also be used to direct surface water runoff into the planting bed. This provides access to water for the tree while enhancing the effectiveness of the aeration system (water pushes out the CO_2, avoiding risk of build-up and root poisoning). The aeration layer also helps moisture retention during the warm season through condensation. Wells are equipped with a sand/silt collector to allow for periodic cleaning. Latest developments of the system integrate biochar to help retain water and nutrients as well as filter out pollutants. Further details, including sections of a typical installation can be found in the English version of the handbook issued in 2009 by the Municipality of Stockholm[62].

Benefits

- Growth rates measured on both refurbished and new installations are very high but testing has been conducted for less than ten years.
- Minimal reliance on patented products.
- High load-bearing capacity, including

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Case study 18
Structural soil for resilient footways in Slaney Road

Location
Walsall, England

Slaney Road, a narrow residential street in Walsall with a main road at one end and the local park at the other, had turned into a highway maintenance headache. Plane trees (*Platanus acerifolia*) planted in narrow footways had outgrown their planting environment with their roots severely damaging surfaces in the footways and carriageway as well as pushing kerbs and adjacent property walls.

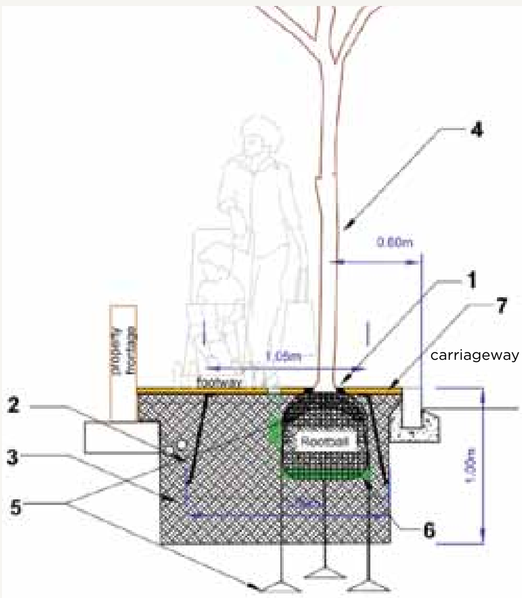
Following consultation with local residents and representatives, it was decided that approximately 60% of the trees would be removed in the narrowest portion of the street, providing that adequate replacement planting was made. While consensus was reached, there were conflicting views, including: strong dissatisfaction with the conditions of surfaces in the street, concerns over the recurring cost of patching and other remedial works, and attachment to the majestic streetscape created by the mature trees.

To succeed in meeting the agreed brief, the highway maintenance team and urban forestry officers decided to turn the project into a showcase scheme, combining footway reconstruction, carriageway resurfacing and tree replacement. The rooting environment for the replacement trees was engineered with a medium-size aggregate structural soil consisting of 80% single size stones and 20% fine sand and soil mix. The structural soil was laid one-metre deep, except in a few locations where the layout of underground services required a shallower depth.

For replanting, 14 extra heavy standard sweet gum trees (*Liquidambar styraciflua "Red Star"*) were preferred to planes due to their drought tolerance, striking autumn colours and smaller overall size yet ability to maintain continuity of leaf shape for the avenue affect. Each tree was fitted with a root deflector and an irrigation ring. The surface immediately around each tree was finished with a porous resin bonded layer of aggregate that was loosened around the trunk base to allow for growth and flare. The £27,000 scheme was funded through the highway maintenance budget and completed in 2010.

Below left: Sweet gum trees planted to replace mature limes that had overgrown their location

Below right: Tree planting detail used on Slaney Road. Image: adapted from Walsall Council



Not to scale: for illustrative purposes only

1. Loose pea gravel for trunk expansion
2. Root deflector
3. Structural soil
4. Liquidambar styraciflua "Red Star"
5. Root ball anchoring system
6. Irrigation/aeration system
7. Resin-bound gravel

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Working solutions: Skeleton soil installation process

Excavations start on Kornhamnstorg a public square in Stockholm's old town where lime trees show early sign of decline

Large stones for the skeleton soil layer are being positioned and compacted in the newly created continuous trench

Some roots have been pruned. Excavation and soil clearing near the root ball is carefully conducted with non-invasive tool

High quality soil is applied around the pruned/cleared root balls. Notice the root deformations caused by deep concrete casing used in the earlier planting hole design

Root balls with new soil under protective cover and irrigation (notice the green watering bag around each tree). More soil is being flushed into the skeleton soil

The aeration layer of smaller dry rock has been placed over the skeleton soil. It includes an aeration well, to be capped with a grate sitting flush with the paving

The limes show signs of vigorous growth the following spring. Notice the aeration/water inlet between the two foreground trees

All images: Björn Embrén

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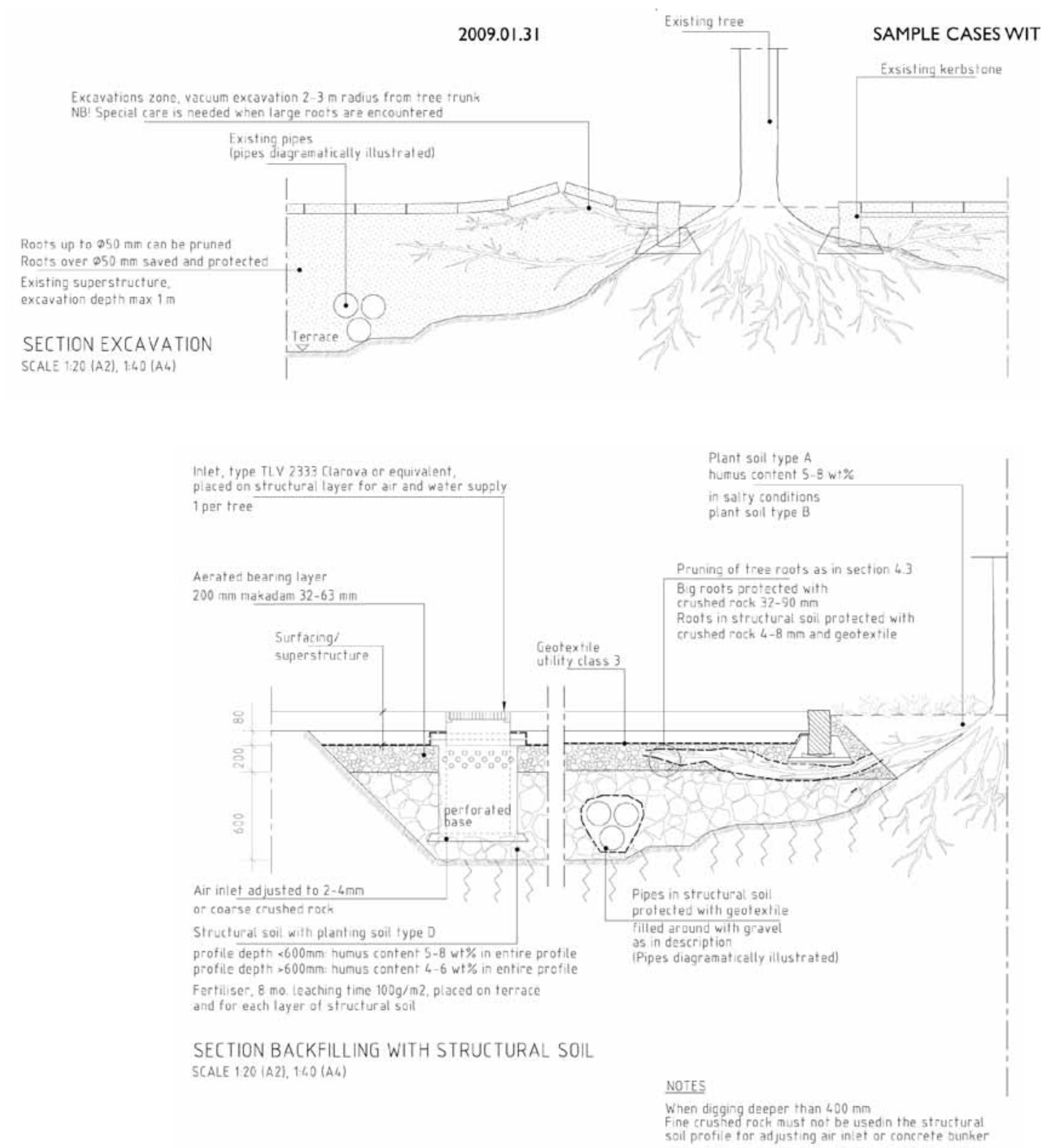


Revised image forthcoming

Typical sections for retrofitting skeleton soil around an existing large tree with shallow roots as shown in the *Stockholm Handbook*. Contrary to what is shown left, the refurbishment above is motivated by issues of surface upheaval caused by roots but the same approach is used. Image: Municipality of Stockholm

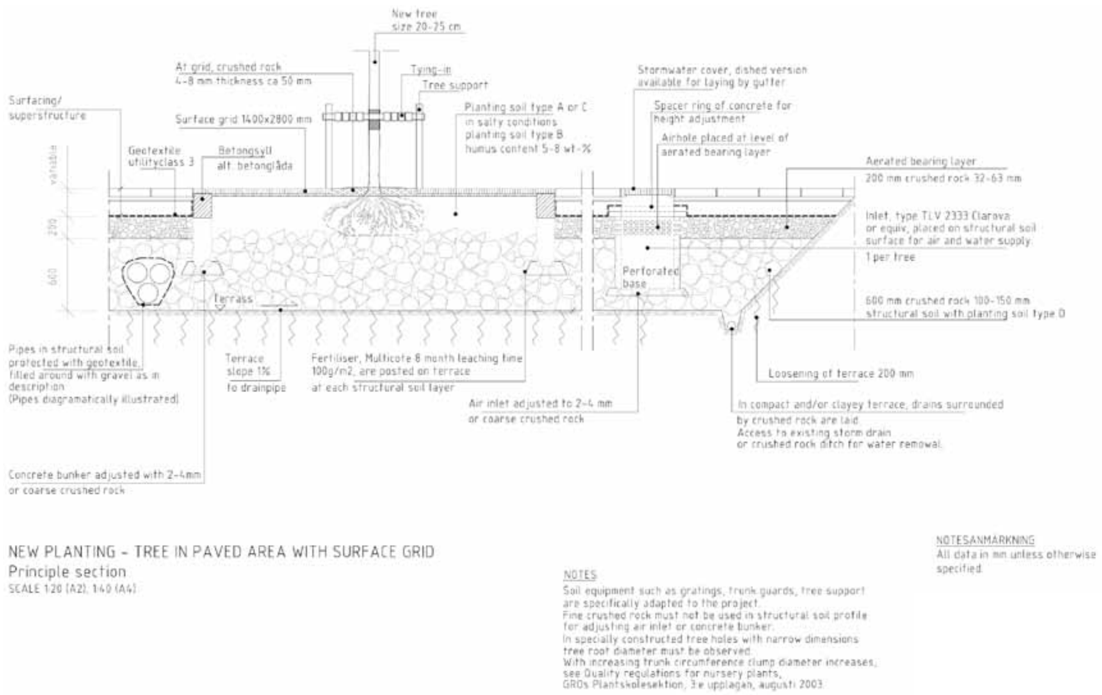
Working solutions: Skeleton soil installation process continued

Positioning of concrete frame in continuous planting trench with large stones for skeleton soil along Hornsgatan, Stockholm (see Case study 25)

Soil has been flushed into the first layer of compacted large stones. A second layer of large stones is being applied

Utilities are being accommodated as part of the installation

A geotextile separates the aeration layer (dry stones, smaller grade) placed above the skeleton stone-soil mix, and the paving sub-base



Revised image forthcoming

All images: Björn Embrén

Section of a skeleton soil installation for new planting, as shown in the *Stockholm Handbook*. Image: Municipality of Stockholm

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Case study 19
Skeleton soil breathes new life in trees in Erik Dahlbergsallén

Location
Stockholm, Sweden

When a new arboricultural lead was appointed by the municipality of Stockholm, an extensive inventory was conducted of the city's street tree assets. Findings were as follows: approximately one third of the trees were dead, another third were seriously sick and/or in very poor conditions, and the remaining third were healthy. These results led to change. There was strong public support for keeping the "green"character of the city. But if replacement planting was conducted using the same techniques as before, the same lack of longevity, heightened tree safety risks and poor overall return on investment would ensue. The highways department therefore decided to trial a new approach, using skeleton soil. This would allow rich oxygen and water supply to the roots to promote good tree health, prevent risks of surface upheaval and guarantee good load-bearing capacity while requiring only local materials and construction techniques that were familiar to the contractors and workmen the municipality usually employed.

Erik Dahlbergsallén, a street in the district of Östermalm in central Stockholm that the inventory had found to contain 12 dead horse chestnut trees, was scheduled for resurfacing and was therefore targeted for trialling replacement planting using this new technique. New horse chestnut trees (Aesculus hippocastanum of the double-flowering sterile variety baumannii) were planted in 2004 in continuous 3.5-metre wide trenches filled with skeleton soil and topped with an aeration layer connected to the surface with aeration wells. A traditional sub-base was laid on top and finished with concrete slabs sitting flush with the cast iron grilles covering the aeration well s. Grilles were connected to one another and to water coming from disconnected downpipes through gentle gullies integrated into the paving slabs, allowing all surface runoff from the footways and adjacent rooftops to flow into the below-ground root-growing environment.

Ten years later, the "new" trees have grown just as large, if not larger, than the only 80-year-old horse chestnut that had been kept from the original planting. The project was quickly identified as a great success and allowed for the skeleton soil technique to become the preferred solution for planting below load-bearing hard surfaces across Stockholm. According to the lead arboriculturist, the key to this success wasn't only in the ingenuity and holistic mindset underpinning the design, it was also in the rigour of the in-house construction manager who oversaw execution: "He made the effort to understand how the system was intended to work and really forced the contractors to work as per the specifications, without taking any shortcut… every time I can, I take the opportunity to thank him, because he made that proof of concept into a success. None of what we've achieved since would have been possible without this."

The growth observed for the 12 new horse chestnuts trees on Erik Dahlbergsallén since planting, as measured through the tree trunk diameter as breast height (dbh), has been as follows:

Gentle gutters in the paving direct the roof and footway stormwater runoff into the aeration wells as permitted in public highways in Stockholm. Image: Björn Embrén

	2004	2008	2012	2013
Dbh measured at 1m above ground every autumn	35-40cm	60-65cm	70-83cm	78-90cm

resistance to lateral forces (vehicular traffic, including heavier vehicles such as buses).
- Construction details are similar to that used for the sub-base of paved areas and therefore more readily adopted by the industry.
- Designed to receive surface water runoff.

Limitations
- The system is only nine years old and challenges common wisdom on the importance of soil and tree requirements to access nutrients. The system prioritises good aeration and voids in the growing medium over abundant provision of loam soil. Investigations conducted in Sweden so far suggest that naturally occurring fibrous root decomposition combined with minerals found in surface water runoff are able to meet the nutrition needs of trees while good access to oxygen and space for unimpeded root development boosts tree growth. Further monitoring is required.
- Installation costs are high. This is largely due to the time required to flush the soil into the stone base.
- In areas where adequate stone supply is not available, importing suitable stone may increase costs.
- Existing soil will not be re-used which may result in expensive haulage and disposal costs.

Relevant locations
- Prominent/high profile city centre locations with strong load-bearing requirements, where continuous trenching is feasible: plazas/squares, streets where narrow footways require expansion of the root zone beneath the carriageway.

Cost: expensive.

Tips for success
- The "Stockholm model" is not technically complicated but it requires rigorous implementation. Good technical oversight from the beginning to the end of the works is therefore critical. Training the site supervisor is an important first step to enable this.
- During project design, the water needs of the tree during the growing season need to be estimated to ensure the volume of surface water runoff to be directed to the planting bed will be sufficient. Consideration of the drainage rate of the sub-grade is also required. Installation of an overflow drain connecting the installation to the sewer system might be required.
- When developing the specification, great attention should be paid to the stone grading and to the quality of the soil mix. If stone fractions of the wrong grade are used, there are no voids left for roots to spread once the soil is flushed in. A soil mix with too high a clay or organic matter content leads to issues with watering the soil down into the system.
- During construction stones and soil should not be pre-mixed. Stones need to go in first and be thoroughly compacted before the soil is watered in. Flushing the soil down is an iterative process that needs to be carried out layer by layer.
- A geotextile membrane needs to be placed between the aeration and the road or footway subgrade so as to prevent any settling. However, there should be no geotextile or any other barrier between the dry stone aeration layer and the skeleton stone/soil mix underneath as this would prevent the system from operating effectively.

3.2.2
Crate systems

In contrast to structural substrates, which includes both patented and unpatented techniques, crate systems rely exclusively on commercial products and require specialised providers for supervision of the installation process.

How it works
Crate systems are made out of modular plastic or concrete cell structures and provide load-bearing capacity by acting as a bridge or vault. The space thus created under the hard surfacing is filled with loose soil to support tree growth. Most cell designs can be stacked to achieve increased depth. Hard surfacing and its sub-base are installed over a geotextile covering the matrix of cells.

Such systems allow variable degrees of water and gas exchange with the surroundings. Cells are installed over a compacted aggregate subgrade with an under drain. An open grid system (designs vary) is wrapped around the sides of the installation. This surround helps to hold the crates and their contents in place while preventing gravel from migrating into the planting soil and undermining the edge of the road, car park or footway surface. The weight-bearing capacity of such systems

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Case study 20
Coed Aber – creating a tree-lined gateway to Aberystwyth

Location
Aberystwyth, Wales

The vision for greening the approach road to Aberystwyth in West Wales started with members of Greener Aberystwyth Group (GAG) walking the length of one the main routes into town, looking for potential tree planting sites. This reflected a widely shared local concern that developments from the past two decades along the main town entrances lacked any form of welcoming aesthetic or coherent sense of place. This was deemed a real obstacle for a market town and seaside resort where the visitor economy plays an important role in enhancing job and economic growth prospects.

Detailed feasibility work was led by Forestry Commission Wales (now Natural Resources Wales), which joined forces with GAG to build up support among Ceredigion county council and the Welsh government for creating a tree-lined approach to the centre of town. Key to securing wide buy-in was the creation of a short animation video which helped to visualise the kind of townscape the scheme could create. The project secured £300,000 from the Welsh government's regeneration area fund. This was supplemented by £75,000 match funds from the county council. Both sums had to be spent within three years, with a minimum spend of £100,000 per annum, creating very tight delivery deadlines.

The feasibility work had identified that the one-mile approach offered a range of possible planting sites on both highway and private land. The planting scheme responded to the varying character and conditions found along the route by using, on a context-sensitive basis, naturalistic tree groups, large feature specimen trees and more formal avenue planting. This approach also offered the advantage that it helped to diversify the species being planted and made the most of available trees in nurseries, while still maintaining a coherent identity for the whole project. For the first year (2013), delivery focused on easy wins with the planting of naturalistic tree groups on highway verges found along the retail park and flood attenuation pond in the outer section of the approach. The second year (2014) started tackling hard landscapes sites closer to the town centre, including footways located along car parks and railway land earmarked for redevelopment – which could in the future bring much greater pedestrian traffic to the area. In an effort to maximise the growth and longevity of the planted trees, as well as that of surrounding hard surfaces, the project team turned to engineered design options for a continuous planting trench. The chosen solution combined the use of a skeletal stone/soil mix inspired by the Stockholm model and a cell system (Strattacell) right around the root balls of the trees. Given the availability of locally quarried 150mm granite gabion stone, this proved more cost effective than a sole reliance on manufactured products. Project timeframes meant that it was not possible to get the concrete crates used in Stockholm to hold the root balls in place manufactured – hence the hybrid approach used. As of April 2014, 150 trees have been planted along Aberystwyth's approach, with 50 to 80 more due to be planted by end of 2015. Commenting on the project, Alun Williams, Ceredigion council cabinet member for transport, explained: *"As a council we are always looking forward to working with communities to integrate transport planning, the environment and economic development. This is a shining example of what can be achieved by thinking in an integrated way."*

Below left: Installation of the combined crate and structural soil system. Image: Jon Hadlow

Below right: May 2014, a few weeks after completion of the works. Image: Dafydd Fryer

Working solutions:
Installation process for various crate systems


Filling the crates with tree soil


Placing the crates, accommodating the water main (see Case study 6)


Placing the geotextile layer over the crates


Tree planted within root deflector; grill in place ready for surface reinstatement

All four above images: Martin Gammie


Excavation is starting along Ocean Road (see Case study 2)


Compacting base and placing crates


Crates with aeration/watering tubes being filled with soil


Tree planted

All four above images: South Tyneside Council

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Positioning concrete crates on prepared island base at Apeldoorn station square (see Case study 22)

Placing cellular units around concrete crates

Ready for filling island with soil

Filled islands topped with geotextile over a set of cellular units similar to those used around the installation. Protective covers are placed over planting holes

All four above images: Ron van Raam

Case study 21
St George's Street

Location
Norwich, England

St George's is a shop-lined medieval lane leading into the historic centre of Norwich. It was turned into a one-way street and the intersection with St Andrew's Street reconfigured to create greater continuity with St Andrew Hill and the pedestrian quarter surrounding Norwich Castle Museum. The kerb on St George's Street was extended out to increase the footway width, introducing a bend forcing vehicles to approach the intersection at reduced speed and creating a small plaza and a straight crossing into the pedestrian quarter. Two tulip trees (Liriodendron tulipifera) were planted in the new widened footway using a crate system to guarantee good load-bearing capacity without compromising the volume of soil and nutrients. Circular benches provide protection for the trees and enhanced amenity value for users – granting the space a distinct plaza feel. The space also accommodates cycle parking.

The scheme was implemented eight years ago at a time when crate systems were seldom used and little known. To convince his colleagues to trial the technique, the arboriculturist organised a training day, arranging for the anticipated product supplier (Greenleaf) to come and demonstrate its product, including how it was installed and how it worked. Three arboriculturists, four landscape architects and four engineers from Norwich city council took part and commitment to trial the crate cell system was only secured after the training day.

St George's tulip trees have transformed the intersection into a welcoming public space. Image: Anne Jaluzot

Consultation draft

Case study 22
A pine forest for Apeldoorn station square

Location
Apeldoorn, The Netherlands

The city of Apeldoorn in the Netherlands wanted a landscaped square reminiscent of the sandy pine forest of the Veluwe natural park located on its doorstep – and it wanted it right in the town centre, in front of its newly refurbished train station.

The square was expected to provide a high-profile gateway into the city. This meant offering very easy and inclusive access to the train platforms and to the station building, effective lighting and open vistas to maximise safety, attractive features to encourage both adults and children to linger, as well as a smooth and sensible cycle environment for what is the most frequented cycle route in the city. The plaza also had to be able to meet very high load-bearing requirements to allow for lorries, fire engines and cranes to service the train station and the adjacent railway underpass when and if required.

The simple bowl-shaped mineral design created by landscape architect Lodewijk Baljon is planted with 48 Scots pine trees (Pinus sylvestris) fitted with purpose-designed angular tree grates matching the surrounding sand-coloured granite stone paving. Underneath the paving is an extensive load-bearing system made out of prefabricated concrete crates (Treebox High Performance). The system was laid as a series of connected "islands", creating slopes and a smooth transition between the rail underpass and the surrounding urban environment. The installation rests on a layer of drainage sand to protect the tree-growing environment from the high ground water table. The design of the square also includes some shallow ridges that collect surface water runoff, some of which is directed towards the trees.

To reduce installation time and costs, the concrete crate installation was carried out by the grounds contractor responsible for the rest of the civil engineering work for the project. The team worked under the supervision of a representative of the product manufacturer (Permavoid Ltd) to ensure the specifications were well understood and adequately implemented.

Inaugurated in March 2006, the scheme received the Dutch Design Award in 2008 and the German Design Prize in 2010. Eight years on since planting, the 48 pine trees are thriving and truly define the space, which has become one of the most popular public squares in the city.

The pine forest at Apeldoorn station square.
Images: Jeremy Barrell

Consultation draft

depends on the material used for the cells. Plastic crates are usually made of glass-reinforced polymer. Concrete units provide the greatest strength.

Benefits

- The structural component uses about 10% of the below-ground volume, allowing 90% uncompacted soil rooting by volume. Some products consume more space than others.
- Effective load-bearing capacity for lightweight, low speed traffic (pedestrians, cycles, car parks). Greater load-bearing capacity is offered by concrete cell systems and might also be offered for other products.
- Opportunity to use the system for surface water attenuation.
- Possibility to re-use some of the existing soil subject to soil analysis and improvement measures.

Limitations

- As with large stone skeletal substrates and raft systems, crate systems have been used for only ten years. While good results have been observed so far, there is no evidence available on the impact on trees over time and the longevity of the crates.
- Not all available crate designs have provision for easy removal should this be unavoidable – crates with more intricate patterns will progressively get entangled with roots. Such products could be unsuitable for integration with below-ground utility cables.
- The flexibility to mould around obstacles or fit into restricted or irregular areas is restricted by the unit size of crates.
- The installation requires specialist intervention.

Relevant locations

- In prominent/high profile locations with strong load-bearing requirements: underneath plazas/squares, streets with narrow footways requiring expansion of the root zone beneath the car parking lane in the carriageway, surface car parks.
- To provide a break-out or root channel linking street tree roots with nearby soil volumes such as parks and soft landscapes.

Cost: expensive.

Tips for success

- If the system is to be used for surface water attenuation, careful consideration is needed in sizing the installation and controlling inlet and outlet water volumes that maintain appropriate soil to water ratios.
- Product selection should facilitate existing and potential future need to accommodate utility cables: easy removal of the crate is only permitted with some models.
- Ducted services with inspection chambers at regular intervals facilitates future maintenance and avoids the need to dig up the whole installation if problems arise.

3.2.3
Raft systems

How it works

Raft systems provide a base layer that floats over the rooting environment and beneath the road, car park or footway surface, helping to dissipate vertical and dynamic loading across the width the installation. Raft systems are also intended to protect hard surfacing from upheaval and provide an air-filled void facilitating enhanced gas exchange. Like crate systems, raft systems rely exclusively on commercial products. These include:

- Plastic honeycomb-shaped mattress systems (also sometimes called geocell or cellular confinement systems) that are stretched over the root zone and pinned to the ground.
- Shallow plastic tiles (80-150mm in depth) that are mounted together, either through pre-assembly or onsite, and anchored into the ground.

The raft installation is typically partially filled with a soil mix, allowing for water infiltration to bring additional nutrients to the protected root zone.

Benefits

- Effective load-bearing capacity for pedestrian and cycle traffic and, for some products, parked vehicles.
- Helps provide aeration and enhance load-bearing capacity in schemes using sand-based or medium size aggregate substrates.
- Ease of installation in retrofit situation around mature trees, without having to dig out the rooting zone.
- Possibility to combine the system with sustainable drainage strategy.

Limitations

- With tile raft systems, while good results have been observed so far, a limited implementation history with trees (ten years) means there is no

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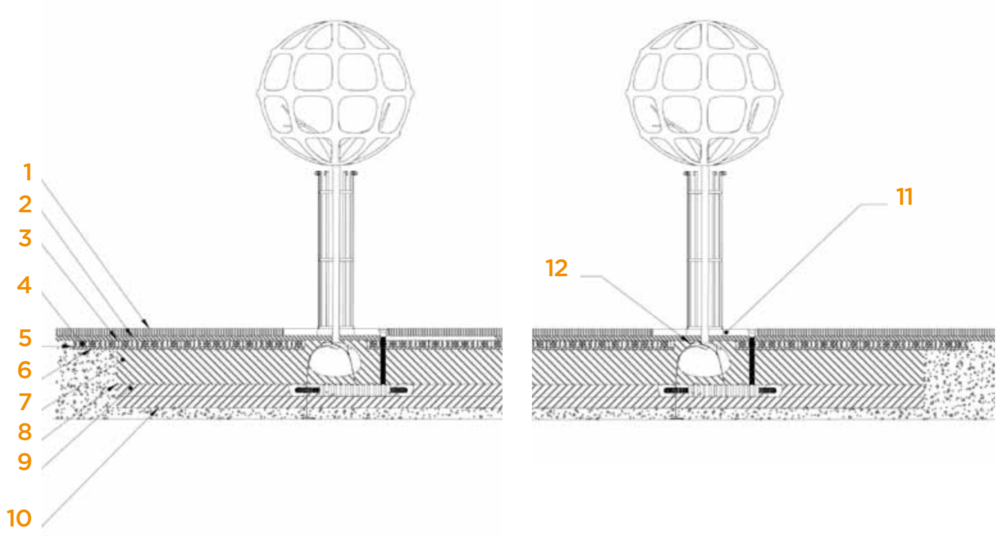
Working solutions:
Raft system installation process

Drainage layer and root ball anchoring system

Root barrier lining

Soil and irrigation system

Permavoid units over geotextile membrane. Image: South Tyneside



1. Paving over sand layer
2. 300mm membrane over Permavoid units and geotextile membrane
3. Permavoid 85 units
4. Backfill Permavoid units
5. Geotextile membrane wrapped round Permavoid units
6. 20mm sand bedding layer for Permavoid units
7. Tree screened topsoil layer
8. Root barrier lining all sides of tree pit
9. Sub-base tree soil compacted with single pass of wacker plate
10. Dig and loosen base to aid drainage and tree growth
11. Tree grill including vent for irrigation
12. Anchor system

Generic section through raft system.
Image adapted from: GT Specifier, Landscape Solutions

All non-credited images: Barry Browne

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evidence on the long-term impact and resilience of the system.
- Honeycombed-shaped mattress systems have been used for longer with good results, but their load-bearing capacity is more limited.
- Maintaining access to the area below the raft comes at a cost. With tile products, if specified, the manufacturer can usually incorporate lids for easy removal but this increases unit prices. Cutting out a portion of any raft system is possible but will compromise the strength of the overall installation. Complete removal and reinstating is the only alternative.

Relevant locations
- Underneath plazas, squares, footways with medium to high pedestrian and cycle traffic.
- Underneath car parks (not all raft products are suitable for this).

Cost: Inexpensive to moderately expensive.

Tips for success
- Anticipating future needs to access the area beneath the system is essential for durability.

3.3 Integrity of surfaces and above-ground structures

A common feature of older planting is that maturity can result in significant disruption of hard surfacing close to the trunk by large structural roots. Roots are very small when they start growing into base layers then increase in diameter, resulting in lifting or cracking of the hard surfacing. When the lifting is excessive, a tripping hazard may be created.

The best time to deal with tree-related damage to hard surfaces is at the time of planting and/or surfacing, combining tree-focused and infrastructure-based strategies. For remedial action, this guide advocates a similar approach and offers a range of options.

In areas of shrinkable clay soils, trees can also contribute to local subsidence issues, causing indirect damage to buildings and other structures. Such damage is here again most effectively prevented at the time of planting. This guide offers a simple introduction to this more complex topic, together with key references and sources to go further.

Case study 23
Haaksbergerstraat cycle lane retrofit

Location
Hengelo, The Netherlands

Haaksbergerstraat is one of the main access roads to Hengelo in northeast Holland. Just before reaching the ring road circling the city centre Haaksbergerstraat is lined on both sides with over 160 70-year old lime trees growing in grass verges. The municipality undertook construction work in 2007 to narrow the grass verges and accommodate dedicated cycle tracks along the footways on both sides of the road. Weakened by root pruning and trenching, two trees fell during a storm as the works were in progress. Designs were promptly modified to introduce the use of a raft system (in this instance, Permavoid Sandwich Construction System) that would both protect the hard surfacing from root upheaval and help enhance the below-ground root growing environment. Root-inflicted damage to footways had been a persistent problem along this road in the years leading to the creation of the cycle track. The makeover of Haaksbergerstraat was completed in 2010 and, since then, no further tree loss has occurred and the limes have been growing healthily, without causing damage to the cycle tracks and footways. Cycle use along this route has increased, with over 1,000 users per day. The cost of the half kilometre-long raft installation was 60,000 Euros, which is less than half what it would have cost to remove all the mature trees.

Below: Installation of the raft system on the east side of Haaksbergerstraat in progress (top) and completed (bottom).
Images: Municipality of Hengelo

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3.3.1
Tree-based strategies for surface integrity

Species selection
Root damage to hard surfaces around trees often occurs where so-called "pioneer species" are planted such as willow (*Salix spp.*), poplar (*Populus spp.*) false acacia (*Robinia pseudoacacia*) and birch (*Betula spp.*). While so-called "secondary" trees such as pendunculate oak (*Quercus robur*), beech (*Fagus sylvatica*) or lime (*Tillia spp.*) are less likely to have fast-growing shallow roots in comparable circumstances and conditions[42]. *The Design Manual for Roads and Bridges*[63] on footway design therefore recommends that new developments give preference to trees that have deep rather than shallow roots. It also emphasises that "sufficient space must be provided for root growth".

While general rooting habit is an important factor to consider when selecting tree species, it will not in itself meet the problems of surface conflict. A primary influencing factor of root architecture is soil profile and structure. As a result, root behaviour in urban environments can be quite different from that observed in natural, temperate forest settings.

Rootable volume and aeration
If the rooting environment provided is not adequate, roots will exploit voids and oxygen wherever it is available in their immediate surroundings they are present, such as road subgrades. Planning for and providing ample aerated space for root growth is one of the most important considerations in any comprehensive strategy for avoiding damage.

3.3.2
Infrastructure-based strategies for surface integrity

Accounting for trunk flare
At the point where the tree trunk joins the roots, a transition area transfers wind and crown loads in the trunk to the roots. The tree puts on more wood in this area to resist this force. The extra wood swells the base of the tree and this is called the trunk flare or root collar.

When trunk flare comes into contact with an object, the tree adds wood in that location, in response to the restriction, to provide increased provide increased stability. The radial force exercised by this increase in wood can damage hard surfaces and walls.

It is therefore critical that the design of the hard surface around each tree anticipates the growth of the trunk flare. Increasing the distance from the edge of the hard surface to the base of the tree will help to reduce conflicts. In tight urban spaces, the width of a tree opening will be limited by pedestrian traffic and accessibility concerns (see paragraph 2.2.3). However, it is not a requirement that all tree openings should be of the same size: flexibility with tree opening dimensions will enable the opening size to be maximised where space allows, while maintaining pedestrian comfort at pinch points. Good urban designers can develop solutions to vary the size of the openings while still accomplishing well-designed spaces. Design standards should encourage a flexible approach, while establishing minimum dimensions in the context of anticipated trunk flare growth.

Surfacing sub base
The type and thickness of material for the sub-base layer can also influence the incidence of root conflict. Root damage mainly emerges in lightly constructed hard surfaces that are laid on a base layer of compacted sand. Research[64] has shown that a sub base made of compacted coarse gravel with limited size range and no fine particles can decrease root penetration.

Surfacing and edge details
The type of surfacing next to the tree opening also influences strategies for managing conflicts between hard surfaces and tree roots.

Some materials such as asphalt, brick and loose-set paving stones can adapt to the dynamic movement of the surface caused by root expansion. Adding a layer of woven geotextile or geogrids under the paving can make the pavers rise in smoother lines, reducing tripping hazards.

Underpinned hard surfaces offer the most effective, but also the most expensive, civil engineering solution to eliminate risks of upheaval and reliably grow large trees. This might be delivered through the use of load-bearing tree planting systems, such as structural substrates, crates or raft systems.

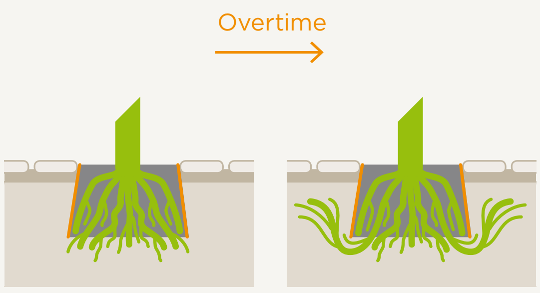
Root deflectors

63
Volume 7 Section 2 Part 5 HD 39/01, paragraph 2.17. Found at: www.dft.gov.uk/ha/standards/ghost/dmrb/vol7/section2/hd3901.pdf

64
Kopinga, J (2008) *Preventing damage to pavements by tree roots* in COST (2008) *Improving relations between technical infrastructure and vegetation*. Final scientific report. Brussels: COST. Found at: http://w3.cost.eu/fileadmin/domain_files/TUD/Action_C15/final_report/final_report-C15.pdf

Root deflectors are intentionally designed physical impediments to lateral root growth. Often constructed from plastics and installed so as to surround the root ball of the tree, root deflectors redirect initial lateral root growth downward and away from the kerb and the hard surface, etc. In theory, by directing buttress roots to grow deeper, the forces that they exert will dissipate through a larger volume of soil before reaching the hard surfacing above. By leading roots to surface further away from the root flare, root deflectors also allow remedial root pruning that might be conducted as a last resort to address surface distortion to be carried out with much-reduced impacts on tree health and structural integrity.

Root deflector and impact on roots



On this basis, root deflectors are often systematically specified for trees in hard landscapes and feature as a requirement in many street and footway design manuals. A review of the available evidence on the structural stability of trees and field verification on the impact of deflective devices for tree roots invites greater caution in prescribing their use:

- Root deflectors (particularly when 600mm deep and over) inhibit lateral root development and, in doing so, go against the root structure established by nursery providers to maximise establishment stability and good future root design. While nursery practices are anchored in long-accumulated knowledge on root pruning and architecture, root deflectors are only about 35 years old. Their impact on the stability of mature trees is not known.
- Available research on the effectiveness of root deflectors shows a high level of sensitivity to soil types and species. A comprehensive review conducted in 2008 of available research on the impact on root density, diameter and mean depth proved inconclusive[65].

3.3.3 Addressing existing root-inflicted damage to surfacing

Several strategies are available to alleviate or remediate root damage to hard surfaces:

- Resurfacing the area affected by root damage, using flexible surfacing materials. This will not remove the problem but will alleviate the tripping hazard, pending full resurfacing of the affected footway or paved area (when the rising of the footway level might take place, combined – or not – with retrofitting of a load-bearing solution in the rooting environment).
- Bridging the footway over the roots. Bridges are simply footways that are raised above the root growth beneath. They may be supported by concrete piers or the sub-base layer.
- Increasing the size of the surface opening (the area between the tree trunk and the edge of the surround hard surface) and enhancing the quality of the rooting environment immediately around the root ball of the tree (reducing soil compaction, using an air-powered excavation tool, introducing organic matter). This will only be possible where enough space is available to introduce greater protection of the surface opening (eg kerb, low railing) while maintaining the usability of the surrounding hard surface.
- Retrofitting a load-bearing solution in the rooting environment. Raft systems (see paragraph 3.2.2) and stone-based structural substrates (see paragraph 3.2.1 and section pXX) can be installed around existing trees to provide an enhanced growing environment for tree roots and alleviate pressure on the road, footway or other surfacing.
- Root pruning. The removal of roots will have the greatest negative impact on tree health and stability – as shown in Case study 23 (pXX). It should only be considered as a last resort before removal and conducted under expert supervision.

Regardless of the strategy chosen, all excavations around the root ball of an existing tree should be conducted by trained operative with non-invasive excavation tools (eg vacuum or pressurised air powered excavators).

3.3.4 Trees and subsidence

Subsidence is a complex and well-documented issue, mostly associated with shrinkable clay soils. It is aggravated by a range of contributing factors, among which trees can play a role.

65
Morgenroth, J (2008). *A Review of Root Barrier Research*, Arboriculture & Urban Forestry 34(2):84-88

Consultation draft

66
NHBC Standards, 2014 version

67
BRE on behalf of the LINK Consortium for Horticulture (May 2004). *Controlling water use of trees to alleviate subsidence risk*, Final Report. LINK Project No. 212

68
Provisionally titled *The Subsidence Pilot*. Once released, will be found at: www.tdag.org.uk

69
www.ltoa.org.uk/resources/joint-mitigation-protocol

70
Found at: http://www.ltoa.org.uk/resources/risk-limitation-strategy

71
www.mappingtheunderworld.ac.uk

Minimising future risk of tree-related subsidence requires:

- Adequate foundation design for buildings and structures. Part 4 of the National House Building Council (NHBC) Standards[66] is the industry reference for house foundation design. Section 4.2 specifically addresses building near existing trees.
- Great care in the selection of tree species being planted in subsidence-prone areas to avoid trees with high water demand, such as willow (*Salix spp.*), oak (*Quercus spp.*), poplar (*Populus spp.*) or leyland cypress (*Cuprocyparis leylandii*). Appendix 4.2A of the NHBC Standards sets out species risk according to soil plasticity index and water demand.

Occurrences of tree-related subsidence are best handled:

- Through tree maintenance, as cyclical pruning may provide an effective method to limit the water uptake of trees. A consortium made up of representatives from government, insurance and local authorities has commissioned a report to complement existing evidence[67] and examine the feasibility of using historical claims data and local authority pruning records to confirm whether or not pruning can be an effective remedy in tree-related building subsidence claims. Initial case study comparisons are encouraging but the report[68] makes clear this is a feasibility pilot using a small sample size and the author recommends extending the study to a much larger sample using existing local authority records.
- Adherence to the Joint Mitigation Protocol[69] to manage claims.

For further information, refer to the London Trees Officers Association's Risk Limitation Strategy[70].

3.4 Underground utilities

A key reference concerning utilities and trees is the National Joint Utility Group (NJUG)'s publication volume 4 – *NJUG Guidelines for the Planning, Installation and Maintenance of Utility Apparatus in Proximity to Trees* and the associated Operatives Handbook. This was produced in collaboration with the arboricultural profession and Defra and can be downloaded from the NJUG website at: www.njug.org.uk/publications. The advice the *Guidelines* provide on precautions to be taken when working on existing underground apparatus close to established trees (eg a tree protection zone, use of trenchless techniques) is not repeated here.

The points highlighted below focus on opportunities for enhanced cohabitation between trees and utilities in new developments or when new planting is introduced in retrofit situations.

3.4.1 Documenting and optimising the use of the below-ground space

Sewage and surface water pipes (which in some existing situations can be combined), gas and electricity tend to be placed under the carriageway and cable and fibre optics under the footways. Unfortunately there is, to date, no complete, comprehensive mapping of the "underworld".

As part of current research led by the University of Birmingham, a knowledge-based system is being developed to use intelligence from records of the ground held by the British Geological Survey, along with utility records and results of bespoke site testing to improve knowledge of the subsurface for any precise UK location (at the level of street, town)[71].

Until this system is fully developed, when tree planting is proposed, whether on an existing highway or in a new development, there is no certainty that the trees can be planted unless specific site investigations are undertaken. Records of underground apparatus should be obtained from utilities and used in conjunction with on-site apparatus detection techniques.

To minimise future conflict with utilities in new developments the creation of a common utility enclosure with the necessary provisions for safely including both mains services and ducting should be a prerequisite of planning consent, required by condition as part of the overall site design proposals. This is preferably located adjacent to the property boundary, under the footway, to facilitate service connections.

Constructing a common utility enclosure may be too costly in existing situations but in this case, in order to reduce the uncoordinated spatial chaos of individual trenches, the National Joint Utilities Group (NJUG) recommends the use of

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shared trenches: "*Trench sharing may be beneficial in reducing disruption to both vehicular and pedestrian traffic, as well as offering cost savings in construction methods and reinstatement liability for utilities. Trench sharing can also be useful in maximising the limited available space in the highway. Wherever practical and appropriate trench sharing should be considered*"[72].

3.4.2
Avoiding indirect damage

In areas with a high risk of vegetation-related subsidence, the use of flexible pipes will help underground services better tolerate movements of the subsoil. The risk of indirect damage caused by tree roots inducing soil shrinking will depend on the ability of the apparatus, in particular any joints, to resist or tolerate distortion. Special precautions for differential movement should be incorporated where pipes join rigid structures.

For more information, refer to NJUG's publication volume 4 – *NJUG Guidelines for the Planning, Installation and Maintenance of Utility Apparatus in Proximity to Trees*, paragraphs 2.1.1 and 3.1.4.

3.4.3
Avoiding direct damage

Direct damage caused by root intrusion can occur with surface water and sewer pipes. One of the primary causes of this problem lies with the inadequate performance of the elastomeric rings used as joints to assemble pipe segments. Research initiated in Malmö, Sweden[73] and further developed through Swedish and British collaboration[74] has shown that roots have a penetration force of 15 to 20 bar per cm^2, whereas the commonly used rubber joints only withstand 6 bar pressure. While older clay pipes are more prone to intrusion, the problem also affects concrete and plastic apparatus, since all use joints with insufficient resistance. The research conducted has shown that in real life (as opposed lab settings), root intrusion – if it does occur – tends on average to happen after two decades following the installation. This long lead-time creates little incentive for resource-constrained water companies and their suppliers, to invest in the development of higher performance elastomeric joints.

Instead, to address what still remains a costly problem for the industry, some of its representatives have in the past requested that no tree be planted within canopy distance of a surface water or sewer pipe, which excludes a very large proportion of the built environment. Towns and cities need both well-functioning sewers and trees, therefore better alternatives are to be preferred. The Welsh Ministers' 2012 *Standards for New Gravity Foul Sewers and Lateral Drains*[75] indicates that sewer pipes may be planted within canopy spread of trees provided adequate protective measures are taken (paragraph R6). The 7th edition of *Sewers for Adoption* by WRc plc, which is widely used for guidance by Water Companies in England, includes similar wording. WRc plc has undertaken in 2014 an extensive review of suitable protective and preventative measures to avoid root intrusions into pipes, and will likely release its results in the near future.

For new developments or retrofit situations where older pipes are being replaced, suitable preventative and protective measures include:

- Provision of an adequately sized, non-compacted and well-aerated growing environment for the trees.
- Choice of tree species with slower root growth, as described in 3.3.1.
- Use of welded polyethelyne (PE) pipes. This requires more expensive supplies and higher skilled labour, which results in total installation costs being on average 30% higher than non-welded options. PE welded pipes are recommended in Paragraph 7R6 of the Welsh Ministers' 2012 Standards referenced above as an "adequate protective measure" against root intrusion.
- PVC pipes assembled with solvent cement joints. This technique is commonly used in Australia.
- Use of geotextile liners along the backfill material (rather than around the root ball of the tree) to discourage root growth into the pipe bedding.

For existing sewers, application of in-pipe liners can provide an effective remedial solution to pipe intrusion, granted the material used are able to resist a pressure of 2 bars. As in-pipe polyester liners typically shrink after application, this ensures that, should roots penetrate in the interstice found between the pipe and its liner, it is the pipe, rather that the new liner, that collapses under the radial pressure exercised by roots. Limitations are:

- Use of liners reduces the effective diameter of pipes.

72
Paragraph 6 of *Guidelines on the Positioning and Colour Coding of Underground Utilities' Apparatus*. NJUG publication volume 1. Found at: www.njug.org.uk/publications

73
Stål, Ö (1998). *The interaction of tree roots and sewers: the Swedish experience*. Arboricultural Journal 22, 359-367

74
The Department of Landscape Management and Horticultural Technology at the Swedish University of Agricultural Sciences (SLU), Thames Water in UK, the City of Malmö and the Swedish Water & Wastewater Association carried out a thorough test at SLU in Alnarp. In April 1993, a 32-metre long, closed system of interconnecting concrete and PVC pipes was laid out. Poplars were then planted directly over every junction. Eleven years later, in 2004, the pipes were excavated and inspected. Results are presented in: Management and planning solutions to modern PVC- and concrete sewer pipes' lack of resistance to root penetration. Ridgers, D, Rolf, K and Stål, O (2008). In *Improving relations between technical infrastructure and vegetation. Final scientific report, Final Report COST Action C15*. Found at: http://w3.cost.eu/fileadmin/domain_files/TUD/Action_C15/final_report/final_report-C15.pdf

75
Found at: http://wales.gov.uk/docs/desh/publications/121001sewerdrainstandardsen.pdf

Consultation draft

76
CIRIA (2013). *Water Sensitive Urban Design in the UK: Ideas for built environment practitioners*. London: CIRIA. Found at: www.susdrain.org/files/resources/ciria_guidance/wsud_ideas_book.pdf

- Where a high number of side connections exist, lining does not remove the weak point associated with the pipe connection. Use of seals called "top hats" at lateral connection can significantly reduce this risk.
- Liners do not address issues associated with roots found in manholes. However, roots found in manholes are much easier to remove.

3.5 Sustainable drainage systems (SuDS)

The simple integration and/or protection of trees in hard landscapes reduces and attenuates surface water runoff. Big trees with large, dense canopies manage the most surface water. The first strategy to increase the surface water utility of trees in hard landscapes is to provide non-compacted, well-aerated rooting environments that will effectively support tree growth.

Some of the soil properties essential to root and tree growth, such as porosity (amount of available pore space), permeability (how interconnected pore spaces are), and infiltration rate (how quickly the water moves through the soil), are also those facilitating surface water runoff management. The techniques presented above to enhance the weight-bearing capacity of well-aerated growing substrates for trees also offer these properties.

Capitalising on this, a range of techniques and designs have been developed to use, rather than bypass, the capacity of trees to contribute to the management of surface water runoff, using their immediate planting environment and growing medium to provide extra capacity for volume, rate, and pollution reduction.

Implementation of such approaches requires accurate capacity calculations in the design and carefully controlled input and output facilitation in a well-engineered system. Only then can the system deliver the multi-functionality desired.

3.5.1 Key considerations for success from design to operation

Integrated approach to urban design
Use of surface drainage systems has sometimes in the past resulted in poor quality of place, yielding little other benefits than the water management purpose for which they had been designed. Emphasis on integrated design solutions is one of the benefits of the approach championed under water-sensitive urban design principles[76].

The integration of trees with surface water runoff management systems in paved areas must consider impacts on:
- The use of the hard landscape, including motorists, cyclists and pedestrians. Care is required to maintain adequate clearances, safety and accessibility standards.
- The health and growing condition of the trees.
- The amenity value of the proposed design. Well-designed SuDS with rich plantings and quality building materials can provide a centrepiece, gateway feature or community enhancement in residential and high streets, on public squares, near bus stops and transport interchanges or in surface car parks.

Key parameters to choose the most appropriate SuDS approach
Several approaches are available to integrate trees and SuDS. An overview of available options is provided in section 3.5.3 below. Key parameters to consider in selecting the most appropriate approach for a given site include
- Nature and infiltration rate of the sub-soil.
- Available space and urban context at ground level.
- Load bearing requirements.
- Available space below ground.
- Surface water runoff management objectives: level of attenuation, infiltration and pollutants removal desired or required.

Successfully addressing frequently asked questions.
Integrating SuDS in streets and areas of public realm is often perceived as adding an extra-level of complexity to projects. To a degree, so do trees. The idea of combining both trees and SuDS in hard landscapes may, as a result, generate anxieties and concerns. These deserve a thorough examination by the project team. Issues often raised include:
- *Why bother?* Both surface water management and provision of green infrastructure are fundamental elements of urban design. Legislative changes are underway (in England) or largely already in place (Wales, Scotland) encouraging an integrated approach to delivering these design

objectives. For example in England, Paragraph 157 of the National Planning Policy Framework (NPPF) states that "*the use of sustainable drainage is a key consideration in determining planning applications*". Furthermore, once enacted, the Flood and Water Management Act 2010 will require drainage systems for new developments and redevelopments to be approved against a set of National Standards for Sustainable Drainage before building can begin and a connection to the sewer can be allowed (if needed).

- *Impact on utilities*. It is not uncommon for below-ground utility apparatus to be laid underneath a grass verge or through a park. Adequately installed utility services can withstand running through soils where water infiltrates. The backfill material used around utility runs is designed for water to go through. Even for SuDS systems providing for temporary storage, design solutions are now available to avoid waterlogging of the utility backfill media, allowing for such systems to be installed next to, or immediately above, utilities.

- *Tripping hazards*. As with any other hard landscapes, good quality design and workmanship is required to avoid creating tripping hazards. Where open bioretention planters are used, adequate edge treatment can successfully address the difference in height between the footway and the bottom of the planter.

- *Impact on conventional drainage*. The presence of a large tree will in itself reduce the rate and volume of surface water runoff generated by the surrounding hard landscape. Where the tree-growing media is used to provide additional water management capacity, an overflow system will typically be provided. This might include an overflow inlet and/or an under drain connected either to a surface water storage tank (such as a rainwater collection system for harvesting) or to the conventional drainage system. Where the growing medium and overflow has been adequately designed, surface water runoff directed from SuDS to conventional systems will be typically cleaner than if entering the surface drains directly.

- *Impact on the surfacing sub base*. The overriding mindset when designing highways, roads and other hard surfaces has typically been to prevent water ingress to the sub base. The presence of water in traditional sub base materials can lead to loss of strength and stiffness. The severity of these effects depends on the sensitivity of the soil types and materials chosen for the different sub base layers to increased moisture content. The materials used for permeable surfacing are selected to not lose strength when wet and should be installed according to the CIRIA's *SuDS Manual*[77]. Where trees are used as part of SuDS, the tree rooting environment should be designed so that water cannot enter the sub base of adjacent hard surfaces. Details such as the design of the kerb haunching running along the tree planting opening that is taking in surface water runoff can usually be adapted to ensure the sub base of adjacent non-permeable hard surfaces remains dry.

- *Impact on tree health*. Research has demonstrated that, in spite of the presence of contamination, urban trees grow better when irrigated with nutrient-rich surface water runoff than with mains fed, potable tap water. Equally, 10 years of experimentation with trees planted in skeleton soil receiving runoff from the footway in Stockholm has shown that where surface ponding was avoided and salt-contaminated water could be flushed through, trees did not show signs of salt-related stress. The trees selected need to be relatively hardy and tolerant of freely draining soils and regular inundation.

- *Impact on maintenance*. An appropriately selected tree planted in SuDS does not require more maintenance than other urban trees and will have a better chance of successful establishment. Provided the design is fit for purpose the presence of the tree is unlikely to generate more maintenance for the SuDS installation. In parts of Australia SuDS and trees have been usefully combined to provide irrigation. This is now also being tested in Lyon, France, as illustrated in Case study 15 pXX.

3.5.2
Design options for surface water runoff management systems with trees

As mentioned above, provision of a

large canopy tree, with an adequate rooting environment will in itself already significantly contribute to water management. This can be further enabled through the use of pervious surfacing over all or part of the rooting zone of the tree or by otherwise facilitating drainage of the surrounding surface into the rooting area. When adequately sized and appropriately designed with structural soil, crate or raft systems or as bioretention planters (ie rain gardens), the tree-rooting environment can manage the runoff generated by paved areas extending significantly further than its own drip line.

CIRIA's *SuDS Manual*[77] is the industry reference for best practice guidance on the planning, design, construction, operation and maintenance of SuDS. The updated version of the *SuDS Manual* to be released in mid-2015 will provide detailed guidance on the design, construction and operation and maintenance of SuDS components featuring trees, or exploiting tree rooting environments.

Pervious surfacing

Pervious surfacing refers to a wide variety of surfaces, including porous concretes, porous asphalts, concrete block permeable paving and various types of reinforced grid and paver systems, that allow water to soak into the sub base below. Water in the sub base can then either infiltrate into the soil below or discharge to a pipe system.

When combined with other engineered systems that promote tree growth, such as structural soil or crate systems, the volume of runoff infiltrating into the root-growing environment can be increased significantly and tree growth maximised.

Proper design, construction, and maintenance is required to reduce clogging and failure. Tips for success include:
- Design, specification and construction of pervious surfaces in accordance with the *SuDS Manual*.
- Avoiding blooming or fruit-producing trees, as droppings will accelerate clogging.
- Vacuuming instead of sweeping of debris, to ensure void spaces do not clog.

Crate systems and structural growing substrates

While a small crate installation (see 3.2.2) or a few strips of structural stone/soil mix (see 3.2.1) may be sufficient to expand the tree rooting environment below a load-bearing hard surface, while alleviating compaction and maintaining surface integrity, using such systems

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The 2007 edition of The *SuDS Manual* (Ciria C697) is found at: http://www.ciria.org/Resources/Free_publications/the_suds_manual.aspx
Pending the release of the 2015 update of the *SuDS Manual*, the project team involved in this update has produced, as an interim output, a series of priority checklists and frameworks on the planning, design, construction and maintenance of SuDS. Found at: www.susdrain.org/resources/SuDS_Manual.html (referenced April 2014)

Newly installed permeable paving laid over a raft system (Permavoid Sandwich Construction) in Amsterdam, The Netherlands. Image: Jeremy Barrell

Consultation draft

to assist with surface water runoff management requires larger, continuous installations. Overflow and under drain systems ought to be integrated to prevent surface flooding and prolonged waterlogging of the tree when the installation reaches capacity. Sizing of the installation, as well as that of the water inlet and outlets, will require robust calculation with input from a drainage engineer.

Tips for success include:

- Carefully considering the elevation and position of inlet, overflows and under drains to ensure good water flow – seeking expert advice when needed.
- Being mindful of tree specie selection, particularly when using stone/soil substrates, where the pH of the soil and water will be influenced by the type of stone used in the mix.

Bioretention tree planters

Bioretention tree planters are designed with the primary intent of removing pollutants from surface water before the water is discharged to the local waterway or reused. They work like rain gardens and can be scaled and shaped to a range of urban hard landscape situations. Commonly, surface water runoff enters the bioretention tree planter through a break in the kerb and is filtered through the soil media as it infiltrates. Treated surface water is then collected at the base of the installation via perforated pipes located within a gravel drainage layer before being discharged into conventional surface water pipes or collected for reuse. In most designs the conventional surface water pipes also act as an overflow.

The inclusion of bioretention tree planters into the surface water drainage system does not affect other conventional drainage elements. Surface water discharge that exceeds the capacity of the installation may continue down the gully to be collected in a conventional kerb side inlet or may overflow into a pit located within the planter that is directly connected to the conventional drainage system.

The tree and groundcover species need to be relatively hardy, tolerant of freely draining sandy soils and regular inundation. The filter media into which the trees are planted has a specified hydraulic conductivity (generally between 100-400 mm/hr depending on the local climate and the configuration of the system). The groundcover vegetation reduces the likelihood of clogging at the surface of the tree pit.

Infiltration trench directs footway surface water runoff to structural soil supporting the trees in Melbourne, Australia. Image: City of Melbourne

Caution with the use of organic matter in the growing medium used for water biofiltration should be applied, to avoid risks of nutrients leaching into the water.

Key conditions for success:

- The design must provide an appropriate footprint and filtration depth which meets functional water treatment criteria.
- It must then be adapted to the surrounding urban environment, including constraints of confined space and interaction with existing services. Surface water tree planters can be integrated with other streetscape elements to reduce their footprint, for example in build-out for traffic calming or facilitating pedestrian crossing.
- Interactions with street users must also be addressed. Of particular concern is public safety and liability. Rain gardens require an extended water detention area set some distance below footpath level, creating a potential tripping hazard.
- Aesthetics and visual appearance are significant factors in gaining community support. Installations in highly urbanised areas may require a more formal, geometrical and hard-edged design than in suburban streets.
- Correct filter media specification and installation. It is crucial that the filter media installed maintains its hydraulic conductivity in the long term.
- Dense vegetation cover. The pollution removal efficiency of bioretention tree planters is related to the root structure and density of the plants within the system. Dense fibrous roots provide the most efficient pollutant removal. Further, as plants mature, root growth helps to maintain the surface porosity and the infiltration capacity of the filter media. As a result, it is important that dense vegetation cover is established at an early stage to prevent compaction or surface sealing by promoting extensive root penetration.
- Protection during construction phases. Protection of bioretention tree planters during construction allows for good plant establishment and prevents clogging of the filter media by heavy sediment loads or other wash off (eg cement washings).
- Trees in surface water tree planters will probably require watering during the first two to three growing seasons post-planting depending on the incidence of rainfall. Irrigation should be applied directly to the surface of the filter media. The use of irrigation tubes for watering young trees is not recommended as it creates a short circuit pathway, or preferential flow path, for surface water.

Swale in car park in Portland, Oregon. Image: Martin Gammie

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Swales with trees

Swales are shallow vegetated channels that provide for surface water runoff conveyance as well as treatment. Swales are well suited for linear landscape strips in hard landscapes such as continuous verges or medians and islands in car parks. Street cross-sections can be redesigned to fall towards drainage swales, with conventional kerbs replaced with "permeable kerbs" to allow the entry of surface water runoff. Trees can enhance the effectiveness of the swale by facilitating the infiltration of surface water runoff into the ground, and helping to stabilise its slopes. Planting should take place on the edge or upper part of the channel so as to avoid blocking water flow, while still providing shade for water cooling in the lower part of the channel during the summer months. Trees will also increase the scale and impact of the swale as an aesthetic landscape feature.

Case study 24
Lidl's New Milton car park manages roof runoff with trees

Location
New Forest, England

In December 2010 a new Lidl superstore opened on Lymington Road in New Milton, a market town in Hampshire, bringing 40 new jobs, a convenient place to shop, and five plane trees (and all that was needed for them to become long-lived specimens). Given the prominent location of the site – a former garage that had remained unoccupied for several years – the New Forest district council tree officer made a firm request to the prospective applicant, right from the first pre-planning meeting, for the inclusion of large, long-lived trees in the car park. This, the officer explained to the Lidl development team, would require provision of 20 cubic metres of soil volume per tree, the use of a load-bearing crate system (SilvaCell) in the design of the rooting environment underneath the car park and connection of the installation to the downpipes collecting surface runoff from the 800m^2 store roof. The request was translated into robust, enforceable planning conditions associated with the landscaping schemes attached to the planning permission. Time was allocated to allow the officer to conduct regular site visits during construction to ensure the installation was carried out according to the conditions described in the planning consent.

When reflecting back on the project, the officer observed that provision had not been made to water the trees after the planting. The first spring following the planting was extremely dry, submitting the young trees to severe stress. Under such drought conditions, newly planted trees in a less favourable rooting environment would most likely have died. At the New Milton Lidl, although the five planes have shown a slower development than could have been expected, they are now showing signs of strong establishment. Once rain came, the surface water attenuation features incorporated into the design have proven effective. The water first enters an inlet gully pot to help dissipate its energy before being piped to the tree-growing medium. After it has filtered through the bioretention soil, the water is collected into a holding tank. If a critical water level is reached inside the tank, it is automatically pumped from the tank directly into the local sewers. Further overflow provision to prevent prolonged waterlogging of the installation is provided by the inlet gully pot which enables excess water to back up into the car park and enter into the conventional sewer system.

Below right: Completed installation, with permeable paving.
Image: Jeremy Barrell

Below left: Pipe directing the stormwater roof runoff to the crate installation.
Image: Jeremy Barrell

Consultation draft

Case study 25
Hornsgatan's environmental remediation

Location
Stockholm, Sweden

Hornsgatan is one of central Stockholm's major streets, spanning over two kilometres on the southern side of the city centre. With 27,000 vehicles per day on average, airborn particle concentrations exceeding EU standards were being recorded on a regular basis due to a combination of vehicular exhaust and non-exhaust particles arising from the wear and tear of the road under the effect of studded tyres. This crisis generated the momentum to initiate an "environmental remediation" scheme that would help tackle the air pollution issue and create a more attractive setting for small retailers as well as enhance cycle safety. These two latter agendas progressively became the primary drivers of the project as the municipality imposed a ban on the use of studded tyres that resulted in a dramatic drop in air pollution levels.

To allow greater, safer and more attractive space to be dedicated to pedestrians and cyclists above ground, a complete re-design of the below-ground environment was undertaken. All utility representatives were convened to extensive coordination meetings to agree a relocation strategy for below-ground pipes and cables that would enable the narrow footways on either side of the road to be widened by one metre and nearly 300 trees to be accommodated. Some of the pipes that were moved, such as the gas pipes, were over 100 years old and had been scheduled for replacement. The streetscape scheme provided the opportunity to conduct multiple infrastructure upgrades in one operation. The kerb realignment was designed to create a continuous cycle route on either side of the road. The existing provision of non-continuous cycle tracks alongside Hornsgatan's heavy traffic of private vehicles and buses had resulted in poor accident records for cyclists. The below-ground design also featured a continuous trench for the trees, built with "Stockholm-style" load-bearing skeleton soil, complete with a top aeration layer connected to the surface with aeration wells. Each well was carefully located at low points in the footway in order to collect surface water runoff from the adjacent cycle track, footway and rooftops.

With air pollution being an important initial objective, the specie first proposed was Scots pine (Pinus sylvestris), which is particularly effective in removing airborn particles. As the primary drivers for the scheme evolved, so did the choice of specie to be planted. Ginkgo (Ginkgo biloba) was selected for its tolerance to air pollution (Hornsgatan still has rather poor air quality levels, even though the concentration of certain airborn particles no longer places the municipality under the threat of EU fines), and its ability to remove carbon monoxide – thus contributing to creating a healthier environment for residents, pedestrians and cyclists. Ginkgos were also selected for their limited spread, so as to avoid conflicts with adjacent building frontages or retail signs, and their striking golden autumn colours. Planting was initiated in 2010 and is due to be completed in 2014, following an extension of the project scope in response to very positive feedback from the local community.

Below right: Vigorous ginkos between carriageway and cycle track where space allows.
Image: Björn Embrén

Below left: Surface water runoff directed to tree rooting environment.
Image: Anne Jaluzot

Consultation draft

Case study 26
Creating green links through East Walworth

Location
Southwark, London, England

An experiment to retrofit a rain garden planted with trees in the residential streets of East Walworth, a neighbourhood located just south of Elephant and Castle in Southwark, London, evolved from a community-initiated proposal to create safe and enjoyable walking and cycling routes across the borough.

The "green links" network proposed by Southwark Living Streets and Southwark Cyclists aimed to enhance alternative routes to the vehicle-dominated main streets, enabling residents to get around Southwark in a healthy, safe and pleasant environment and encouraging people to make more journeys by walking and cycling.

The proposal was taken on board by Southwark council, and its delivery team seized the opportunity offered by the scheme to trial, on a modest scale, the retrofit of rain gardens in streets. In East Walworth, the green link connects existing green spaces (Burgess Park and Salisbury Row Park) through small streets and redundant road or tarmac areas in housing estates. Like other green link routes, the scheme relies on resurfacing, kerb realignments and the introduction of vegetation – particularly trees – to deliver the traffic calming and environmental quality enhancement required. The proposed designs for some of the new footway planters and landscaped kerb build-outs to be created in East Walworth along Bagshot, Kinglake and Huntsman streets were modified to allow the collection of surface water runoff from the surrounding hard landscapes. The goal for the in-house highway and design team was to learn both how to do it and how much it would cost, in order to build capacity for future delivery.

Where trees were included in the landscaped kerb build-outs used to collect surface runoff, a stone/soil mix was used to provide a load-bearing substrate with both water storing and draining capacity. The mix relies on large stones emulating what is routinely done in Stockholm, Sweden or Lyon, France, and was trialled in Wales (see Case study 20, pXX). However, the installation does not feature the "aeration layer" typically used as part of the Stockholm model presented in this guide. Instead, the rain garden bedding was directly laid on top of the skeleton soil substrate. Professional advice was sought to select the plant materials used in the rain garden, to maximise hardiness and ability to filter pollutants out of the surface water runoff received in the planting bed. Feedback from local residents, including shops located along Huntsman Street, has been positive: people like the new look of their street. On the technical side, the design team involved has learned a great deal from the project: the settling that occurred over the first few months after November 2013 hasn't been as extensive as anticipated and, as a result, some the levels of the swales will require adjustments. The design team has issued a five-year maintenance schedule to the street tree care contractor, featuring two visits per month to allow for watering, formative pruning and tidying up. The cost of this post-planting care programme was budgeted for as part of the capital sum earmarked to deliver the project.

Kerb extensions with rain gardens built along Bagshot Street
Images: Anne Jaluzot

Case study 27
Thames Water sponsors green streets in Counters Creek

Location
London, England

Counters Creek is one of London's "lost rivers", a former stream that has become part of the underground drainage system. Urban densification in the Counters Creek area, which includes most of the Royal Borough of Kensington and Chelsea and the London borough of Hammersmith and Fulham, has led to a 20% loss of green space between 1970 and 2007. Densification has also taken place underground with basements often extended below the level of the existing sewer system. As a result, more than 2,000 properties are at risk of sewer flooding. To alleviate this risk, Thames Water has initiated a £250 million investment programme combining the creation of new strategic sewers, local sewer upgrades and "cut and pump" protection for basements together with SuDS measures. The strategy proposed for SuDS is to test a range of solutions in both private locations (eg green roofs, rainwater cisterns, rain gardens in private gardens) and streetscape locations (eg permeable paving, rain gardens), monitor results, and expand what is found to work best. Installation of the SuDS measures is due to take place during the 2014/15 winter season. Meanwhile, flow depth and velocity censors have been installed in sewer pipes in each pilot street as well as in control streets since May 2012 to allow accurate "before" and "after" measurement of the SuDS performances. One of the streetscape pilots is on Melina Road, a partially pedestrianised residential street bordered by small terraced homes and a primary school in the London Borough of Hammersmith and Fulham. There, the root zone of existing mature trees will be retrofitted with permeable paving. This will be complemented with several rain gardens further down the street, some of which may include new trees. The rain gardens will be fitted with a raft system. Implementation will be paid for and project managed by Thames Water, using the local borough's own highway team maintenance contractor. This is expected to help build up knowledge and capacity for successful maintenance from the start, avoiding any handover issues when responsibility for maintenance will be transferred from Thames Water to the borough on the third year following planting.

Rendering of proposed improvement at Melina Road.
Image: forthcoming

Image: forthcoming

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In Summary

Start with a minimum shared understanding

- Establish a shared understanding of what trees need to grow and mature successfully in hard landscapes.

- Establish a shared understanding of the requirements of the surrounding above- and below-ground infrastructure especially footways and utilities.

Design/maintain quality rooting environments and root systems

- Provide an adequate rooting environment in quality and size, as described in BS 8545:2014. This is the best strategy to maximise the longevity of both the tree and the surrounding infrastructure.

- Consider designing in or retrofitting the tree rooting environment with a load-bearing system. Review pros and cons of all available systems. Anticipate implications on the sequencing of works and training needs.

- Aim to reduce the need for expensive and damaging excavation by maximising the use of common utility enclosures in new large or green field developments and of shared trenches in smaller, infill regeneration and existing situations.

- Conduct excavations around existing trees with non-invasive excavation tools.

Plan for trees and infrastructure together

- Make careful choice of tree species in proximity to sewer pipes or in areas prone to subsidence.

- Follow NJUG and best practice guidelines to avoid direct and indirect damage to utilities, whether existing or new.

- Refer to NHBC standards on designing building foundations so as to avoid tree-related subsidence when building next to existing trees.

- Use root-intrusion resistant pipe technology whenever possible, particularly in greenfield developments.

- Maximise opportunities to integrate trees and SuDS components.

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P = Professional publications and resources; S = Scholarly publications; i = Non-technical publications and resources

Non-technical publications and resources | Professional publications and resources | Scholarly publications

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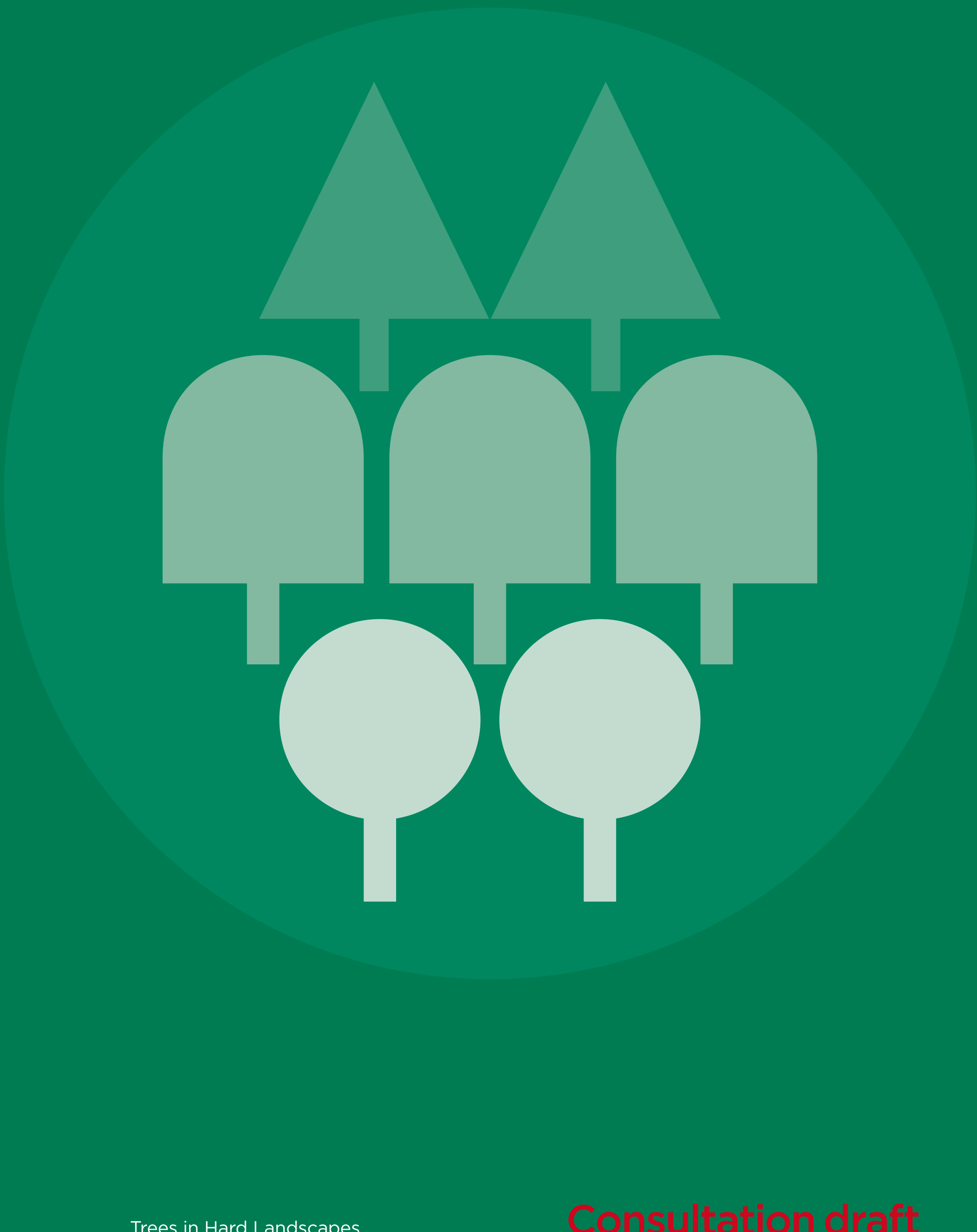
Species Selection Criteria



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Species Selection Criteria
Asking the right questions to get the right answers

While tree species selection alone cannot make up for a poor design strategy or inadequate underground growing conditions, choosing the right tree for the right place is an essential final ingredient for success. (Principles 5 and 6 in *Trees in the Townscape*).

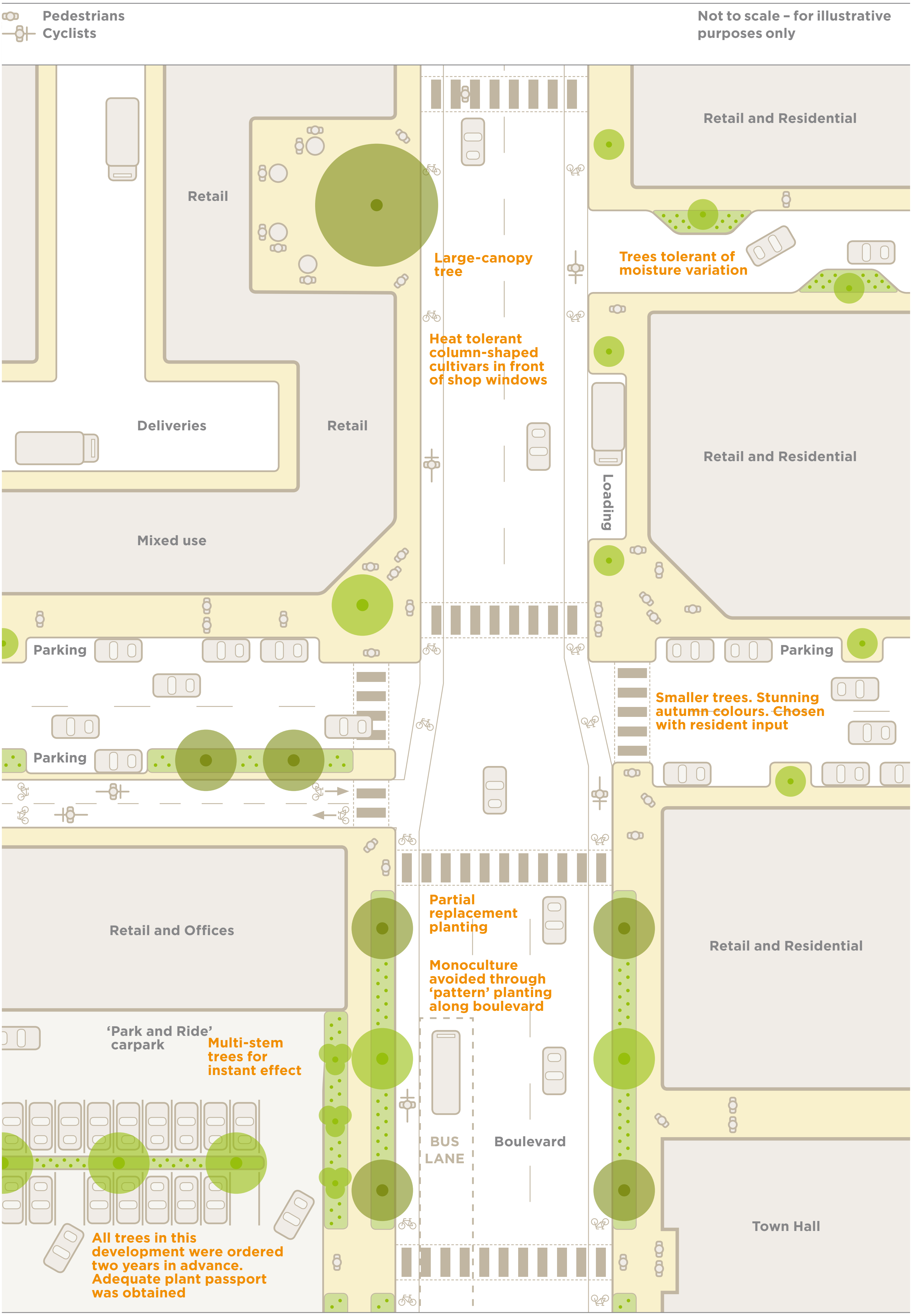
Those within the design and engineering professions often call for simple lists of “suitable trees” for urban settings. This is less useful than it might seem: “safe” lists can result in overly limited choices that produce the disease-prone monoculture biases that most towns and cities face today.

As the possible combinations of the variables that influence tree choice – existing wider and local constraints, future climate conditions and design objectives – are so numerous, failing to conduct an individual robust assessment with support from those with expert tree knowledge can lead to high failure rates.

Interviews with arboricultural managers in Hackney in London and Lyon in France, revealed that, in both instances, over 250 different tree species are successfully growing in streets and other hard landscaped areas. A wider choice of tree species is available than commonly thought. However, with the imperative to avoid monocultures for future resilience, there are design challenges for multiple species design especially in street and avenue situations where tradition tends to favour the use of one, or at most two, species.

Given the above, rather than attempt to produce a list, this section offers designers and engineers a five-step process to guide the analysis required to make the best choice of available options to achieve a longlasting and successful tree choice.

Consultation draft



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4.1
Key site constraints

Site constraints will vary depending on whether the site already exists or is a new development. In existing situations the constraints will tend to be embedded and it will be necessary to work with them. In new developments there is an opportunity for site planning to create elements, such as microclimate, that are conducive to trees (and people). To achieve this, developers, architects and the landscape and arboricultural specialists need to collaborate at the design stage.

However, in either situation, assessing the planting site in respect of the tree's biological requirements – what it needs to survive – is essential for long-term success. Bearing in mind any potential conflict or nuisances inflicted by the tree on the surrounding built environment is equally important. Finally, maintenance is the third dimension to consider during this initial assessment.

With tree health in mind, key elements to factor in include:
- Soil Ph.
- Water access.
- Sunlight.
- Pollution, including from salt.
- Temperature, including reflected heat from buildings.
- Wind exposure, including localised turbulence generated by buildings.
- Pest and pathogens present in the area.
- Climate change – the Right Tree for a Changing Climate online database[78] provides the most up to date information on the characteristics of tree species that will be suitable and adaptable to the predicted climatic conditions for urban areas for the rest of this century.

Other site constraints to factor in, in order to minimise conflicts and nuisances include:
- Water uptake from the tree where soil subsidence is a concern (see 3.4.4).
- The tree root system's proximity to sewer and surface water pipes (see 3.4.3).
- Available space at ground and above-ground level to prevent undesired obstructions to movement, light or views, and interference with buildings and walls when the tree has reached its mature size.
- Impact of litter: all trees will shed something at some point in the year, whether flowers, leaves, needles, fruits or bark. In some locations droppings may be less of an issue than in others. Fruit and bird droppings will not be desirable in an area with high pedestrian traffic. Trees producing honeydew are best avoided over a surface car park, on-street parking or in areas of regular pedestrian access.

Selected species should need little in terms of watering, fertilising and

78
Found at: www.righttrees4cc.org.uk

Deciduous and evergreen mix for ecological resilience and year round interest, in Stoke Newington, Hackney, London. Image: Anne Jaluzot

Consultation draft

79
Santamour, FS (1990). *Trees for urban planting: diversity, uniformity, and common sense*. USDA, Proceedings of the 7th Conference of the Metropolitan Tree Improvement Alliance

pruning once established. Maintenance will be required for all tree species (see paragraph 1.4), but some will require far more than others. Where budgets are limited, it makes sense to give maintenance requirements a relatively high priority among selection criteria. The need for pruning, fertiliser, water, pest management and root control should all be anticipated.

4.2 Ecological resilience requirements

Ecological resilience requirements relate to the contribution the scheme makes to enhancing or sustaining the diversity of the local tree population. Failure to take into consideration ecological resilience will lead to increased sensitivity to the spread of pests and diseases and high vulnerability to the future impacts of climate changes.

Principles to take into consideration include:

- The 10% species diversity rule. Following the disastrous impact of Dutch elm disease, research[79] conducted in the United States identified that, to improve resistance to similar epidemics in the future, it is best to ensure that no single species represents more than 10% of the overall population. BS 8545 recommends an even more ambitious objective of 5%. As demonstrated in the Lyon example below, putting this principle in practice must consider scale.
- Diversification of the age spread. Not every tree or every planting situation lasts for hundreds of years. Being dynamic, cities have some spaces that are available for relatively short periods, making them suitable for short-lived trees or those that may have youthful benefits but begin to exhibit undesirable traits as they mature. When used in combination with slower-growing, longer-lived trees, specimens with fast growth will quickly maximise and sustain canopy coverage.

Case study 28
Choosing trees for South Street, St Andrews then and now

Location
Fife, Scotland

South Street is one of the two principal streets that form the basis of St Andrews' medieval town plan, which was laid out on a rough grid iron. The street was scaled and designed to accommodate ceremonial processions to the cathedral precinct.
As shown in the two photographs below, the street has preserved today the 19th century tripartite design. Both sides of the carriageway feature a paved footway and cobblestone strip planted with large leaved lime trees (Tilia platyphallos). The *St Andrews Design Guidelines for buildings, streets and shop fronts in the St Andrews Conservation area and on the main approaches* (2008) recommends that any new or replacement tree planting use the same detail. Some of the 118-year-old limes have had to be replaced following fatal contamination from escaping gas from the old mains system, waterlogging, and various forms of physical damage by vehicles. Given its location, some drawbacks associated with the species and cultivars selected for the 19th century planting include:
- The very large size of the tree crowns which tend to obstruct light and views from upper windows, and as a result require regular pruning.
- The trees tend to produce aphids and honey dew, to the detriment of people and objects beneath.

Because of their visual importance and historic character, Fife council has identified the replacement and improvement of the lime trees as a priority for the town centre improvements underway. However, the caucasian lime (Tilia euchlora) is being preferred to its UK-native, large-leaved cousin as it is smaller in size with a similar form, and offers disease and pest resistance – including against aphids.

Postcard of South Street in 1896

South Street in 2014. Image: Stephen Liscoe

Case study 29
Wise microclimate tree selection for Cheapside Street

Location
City of London, England

In the centre of the City of London, between St Paul's and Bank, the Cheapside area is undergoing a dramatic transformation. Since 2010, a series of major new developments have more than doubled the amount of retail floor space. The equivalent of a significant shopping mall is being created in a high street location, primarily along Cheapside itself. In response, the City of London Corporation launched a streetscape improvement programme aimed at rebalancing the relationship between pedestrians and vehicles, creating a safer and more inclusive environment while maintaining the current traffic capacity. Traffic lanes have been narrowed to four metres and footways widened by an average of three metres. Clutter and unnecessary street furniture have been removed and dedicated loading bays have been created to service the shops without interfering with bicycle or vehicular traffic. The scheme also features one tree replacement and the planting of 19 new trees – helping to calm traffic, enhance the pedestrian environment and alleviate the urban heat island effect prevalent in such an inner city setting. The positioning of the trees was carefully considered in relation to the extensive amount of underground utilities found in the area. Collaboration with the utility providers meant that some cables, including fibre optics, could be moved about a foot along the street. Without this, the planting would not have been possible. The most challenging negotiation for the client team related to tree selection. The planning and urban design leads were keen to plant avenue-style, with a single specie. Their open space and arboriculture colleagues pointed out that very different conditions were found on either side of this east-west street: the northern footway being very hot due to sun exposure and intense reflection from the south facing (often glass) façades, and the southern side lying mostly in the shade. The arboriculture and open space staff also pointed out that, while Cheapside is a historic street, it has lost its historic building frontage. Following extensive redevelopment, Cheapside is now lined with mixture of unevenly set buildings. While a strong line of trees would help to hold together what could have otherwise been a disjointed frontage, the eclectic nature of its development didn't require a planting style reminiscent of the past. A more contemporary approach to planting was therefore adopted, maximising adaptation to local climate conditions, using alder trees (Alnus spaethii) on the shady side, and American sweet gum (Liquidambar orientalis) on the opposite, sunnier and hotter footway. Counts conducted before (2006) and after (2013) the schemes have shown that the objectives that had been set for the streetscape improvements have been fully achieved: pedestrian footfall has increased by 50% (from 24,487 to 36,728 per day), bicycle traffic has risen by over 200% (from 871 to 2124 cyclists per day between 7am and 7pm), while motorised traffic has remained stable (from 7723 to 7277 vehicles per day between 7am and 7pm).

Cheapside in the early autumn.
Image: City of London

4.3
Functional and aesthetic attributes

Once the constraints associated with the site and the resilience of its wider environment have been identified, the desired functional and aesthetic attributes of the tree(s) can be added to the list of selection criteria previously identified to guide final choices based on available options.

Aesthetic considerations (tree crown volume, shape, density and colour of foliage, flowering attributes) often dominate tree selection processes.

Other desired tree benefits arising from the brief's design objectives should also be taken into consideration, including:

- Expected shade provision: a broad tree will cast greater shade compared to a columnar tree.
- Contribution to air pollution removal.
- Contribution to surface water attenuation: canopy size and leaf area index will affect water interception, while waterlogging-tolerant species will be required where trees are associated with rain gardens and swales.
- Contribution to wildlife and habitat conservation.

Consultation draft

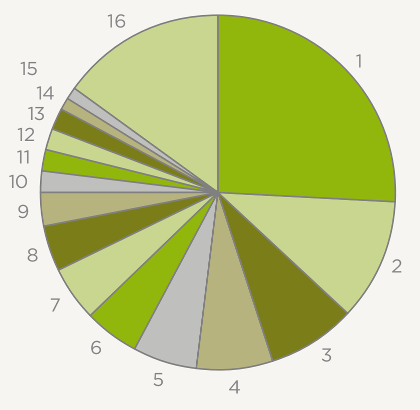
Case study 30
Building local identities through tree diversification

Location
Lyon, France

In the mid-1990s, plane trees represented over 50% of the tree population managed by the Greater Lyon Authority (GLA). In 2013, this had been brought down to 26%, while the overall number of species found in hard landscapes in the Lyon area had increased by 68%, with over 260 different species and 70 genres represented. This stark increase is a result of a strategic commitment to diversification. The goal set in the GLA Tree Charter is that, for trees in highways and other public hard landscapes, no single tree species should represent more than 10% of the whole. To deliver this, the GLA monitors the composition of its tree population at a strategic level. For each neighbourhood, it takes cues from the existing character of the landscape to agree a local plant palette: this combination of species is used to help build upon and reinforce local identity, ensuring that the strategic 10% diversity goal does not result in a loss of local coherence and character. At a project level, the GLA encourages the designers it works with to enrich the composition and plant design vocabulary with which they work wherever possible. Where a regular, single-species avenue planting is required in a historic context this is accommodated within the agreed preferred tree palette defined for the neighbourhood. In new developments, whether as part of urban extension or major infill regeneration schemes, designers are encouraged to use compositions and patterns combining species (see Garibaldi Street pX, and Castellanne pX for examples). According to Frédéric Ségur, the GLA arboriculturist, the GLA's success in greatly diversifying the population of trees found in Lyon's streets and civic spaces is the result of three key factors: "First, we've got to assume control of not only strategic policy but also procurement of design and management, allowing us to set some objectives at all three levels that are congruent and mutually supportive. Second, we've got to build strong relations with our suppliers. We work with contractors that supply trees, and the climate of trust we've created has enabled them to stimulate the local nursery grower to increase the quality and diversity of their production. While, back in 2007, less than 50% of the newly planted trees were of local provenance, this is now close to 80%. Third, we do not prescribe a plant palette to designers. The 10% objective set in the tree charter is used as a means to initiate a dialogue: it sets a framework for collaboration rather than dictates a solution. For each scheme that is not done in-house, designers come to us to validate their plant palette and we use this opportunity to make suggestions with alternatives options where we feel inappropriate choices have been made given local climate, soil, condition or space availability."

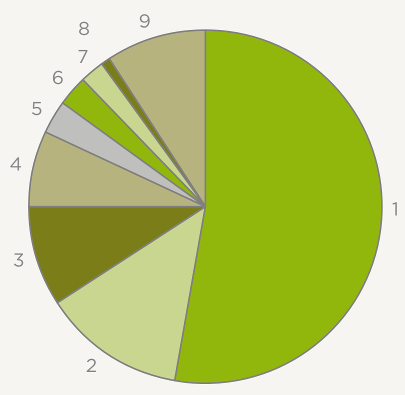
In Greater Lyon, 254 different tree species grow in hard landscapes (+69% compared to 10 years ago)

Species distribution in 2013 (%)



		%
1	**Platanus**	**26**
2	**Acer**	**11**
3	**Tilia**	**8**
4	**Celtis**	**7**
5	**Fraxinus**	**6**
6	**Quercus**	**5**
7	**Prunus**	**5**
8	**Pirus**	**4**
9	**Sophora**	**3**
10	**Corylus**	**2**
11	**Gleditsia**	**2**
12	**Aesculus**	**2**
13	**Ulmus**	**2**
14	**Malus**	**1**
15	**Zelkova**	**1**
16	**Other**	**15**

Species distribution in 1994 (%)



		%
1	**Platanus**	**53**
2	**Acer**	**13**
3	**Tilia**	**9**
4	**Robinia**	**7**
5	**Aesculus**	**3**
6	**Prunus**	**3**
7	**Celtis**	**2**
8	**Populus**	**1**
9	**Other**	**9**

– Low potential as allergen: most allergies are specific to one type of tree or to the male cultivar of certain trees.

4.4
Shortlist of options and customer feedback

The final selection will require specialist advice. Substantial knowledge of tree species and their clones will be required to identify a shortlist of suitable trees, based on the limiting factors considered in 4.1 and 4.2 above, as recommended in BS 8545:2014, paragraph 7.2.1.

Design and technical choices might need to be altered to overcome some of the constraints and enable the desired attributes and benefits (see 4.3) to be realised. Detailed design and species selection, are, to a degree, an iterative process.

4.5
From tree choice to tree specification

Specifications are particularly important in ensuring that trees purchased from tree nurseries are of the highest quality and fit for purpose. These should include details of stem girth, tree height, central leader and branch structure. Additional features such as stem taper and height/stem ratio can also be specified.

Beyond morphological conditions, it is also important to ask for evidence of good physiological health and full traceability, which will contribute to biosecurity.

Refer to Principle 7, Procure a Healthy Tree of Trees in the Townscape as well as Appendix D1 of BS 8545 for further background. Recommendations presented in Chapter 7 of the same standard should be observed.

Seven different species grow along Sydner Road in Hackney, including almond trees, chosen by local residents who enjoy picking the fruits. Image: Anne Jaluzot

Tall trees on this Amsterdam residential street shade building where needed while smaller flowering trees protect cycle racks and offer amenity for walk and play. Image: Anne Jaluzot

Consultation draft

Image forthcoming.
Image:

In Summary

Identify key site constraints
- Understand soil Ph, water access, sunlight, pollution (including from salt), temperature (including reflected heat from buildings), wind exposure (including localised turbulence generated by buildings) as well as pest and pathogens present in the area.

- Recognise the implications of areas of shrinking clay soils and potential subsidence, as well as of proximity to existing sewer and surface water pipes.

- In new developments, explore opportunities to influence site planning to create an environment to provide suitable space and conditions for trees.

- Evaluate the implications of, or tolerance for, tree litter ie flowers, leaves, needles, fruits, bark, honey dew etc in a given situation.

- Consider the maintenance budget and the achievable maintenance programme.

- Where appropriate engage community support for tree care.

Meet ecological resilience requirements
- Consider planting a range of tree species to create or contribute to a diverse ecology: eg no more than 10 percent or 5 percent of any one species of tree. Include more than one species of tree in more formal locations such as avenues to mitigate species loss.

- Consider using species with different growth rates with early impact from fast growing, short-lived trees, alongside slower growing long-lived trees.

Meet aesthetic and functional requirements
- Factor in the “tree benefits” to be gained in a particular situation such as shading; reducing air pollution; contributing to surface water management; enhancing wildlife habitats; low allergen planting.

Shortlist options
- Seek expert tree advice to make an informed pre-selection.

Consultation draft

References

Non-technical publications and resources

Professional publications and resources

Scholarly publications

The Right Trees for Changing Climate Database.
www.righttrees4cc.org.uk

Santamour, FS (1990) *Trees for urban planting: diversity, uniformity, and common sense*. USDA, Proceedings of the 7th Conference of the Metropolitan Tree Improvement Alliance.
www.ces.ncsu.edu/fletcher/programs/nursery/metria/metria07/m79.pdf

Sjöman, H (2012). *Tough trees for tough sites: Learning from nature*. PhD thesis. Alnarp, Sweden: University of Alnarp.

Case study finder

Case study number and name		Location	Page	Context: Arterial street	Context: High street	Context: Residential street	Context: Public square	Context: Car park
1	Melbourne's coordinated approach to streetscape projects	Melbourne, Australia	00	●	●	●	●	
2	South Shields' Ocean Road	South Tyneside, England	00		●			
3	Exemplar partnership for Dortmund Square	Leeds, England	00				●	
4	Wirral Waters Green Streets project	Birkenhead, England	00	●		●		
5	Bath Road's integrated delivery model	Bristol, England	00	●				
6	Joint working with Waitrose to retrofit trees in public car park	Henley-on-Thames, England	00					●
7	Research and development in the Greater Lyon Authority	Lyon, France	00	●	●	●	●	●
8	Lyon and London reclaim road space for trees	Lyon, France and City of London	00	●	●	●	●	●
9	Info: forthcoming							
10	Glen Innes's "self explaining roads" project	Auckland, New Zealand	00			●		
11	Linear orchards for attractive cycling	Hackney, London, England	00			●		
12	Trees for Dutch-style shared space in Leonard Circus	Hackney, London, England	00				●	
13	Trees for revitalised retail and attractive bus routes	Bristol, England	00	●	●			
14	Westminster's plan for Church Street and Paddington Green	Westminster, London, England	00		●	●		
15	Using rainwater cisterns for tree-based cooling on Garibaldi Street	Lyon, France	00	●				
16	Cost, benefits and lifespan figures for two typical UK street trees	UK	00					
17	Building a long-lived maritime boulevard treescape	Swansea, Wales	00	●				
18	Structural soil for resilient footways in Slaney Road	Walsall, England	00			●		
19	Skeleton soil breathes new life in trees in Erik Dahlbergsallén	Stockholm, Sweden	00	●	●			
20	Coed Aber – creating a tree-lined gateway to Aberystwyth	Aberystwyth, Wales	00	●				
21	St George's Street	Norwich, England	00				●	
22	A pine forest for Apeldoorn station square	Apeldoorn, The Netherlands	00	●				
23	Haaksbergerstraat cycle lane retrofit	Hengelo, The Netherlands	00	●				
24	Lidl's New Milton carpark manages roof runoff with trees	New Forest, England	00					●
25	Hornsgatan's environmental remediation	Stockholm, Sweden	00		●			
26	Creating green links through East Walworth	Southwark, London, England	00		●	●		
27	Thames Water sponsors green streets in Counters Creek	London, England	00					
28	Choosing trees for South Street, St Andrews then and now	Fife, Scotland	00					
29	Wise microclimate tree selection for Cheapside Street	City of London, England	00		●			
30	Building local identities through tree diversification	Lyon, France	00	●	●	●	●	●

Consultation draft

	Design objectives								Use of load-bearing or load-spreading tree planting solutions				
Case study number	Provide a setting for regeneration and growth	Slow vehicular traffic	Enhance the walking environment	Extend the cycle network	Enhance public transit	Remedy conflict between trees and surroundings	Manage or recycle surface water runoff	Reduce urban temperatures	Structural growing medium: sand	Structural growing medium: medium-size aggregate	Structural growing medium: large stones	Crate system	Raft system
1	●						●	●					
2	●		●									●	●
3						●						●	
4	●		●	●									
5					●								
6							●					●	
7													
8	●		●	●	●								
9													
10		●											
11				●									
12			●	●			●					●	
13	●				●								
14	●		●										
15			●	●			●	●			●		
16													
17	●		●						●				
18						●				●			
19						●					●		
20	●										●	●	
21	●	●	●									●	
22				●		●							●
23						●					●		
24							●					●	
25			●				●				●		
26		●	●				●				●		
27													
28													
29	●	●						●					
30													

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Glossary

Biochar: the name for charcoal when it is used as a soil amendment.

Bioretention: the process by which soils and both woody and herbaceous plants are used to remove contaminants and sediments from surface water runoff.

Buttress root: large roots that extend partly above ground as a plate-like outgrowth of the trunk to support a shallowly rooted tree.

California bearing ratio: a penetration test for evaluation of the mechanical strength of road sub grades and base courses.

Crate system: modular load-bearing plastic or concrete underground system that incorporates uncompacted soil volumes to accommodate tree root growth while supporting the hard surface above.

Crown lifting: the removal of the lower branches of a tree to a given height.

Dynamic Kinematic Envelope (DKE): the outline of the space occupied by a vehicle when in motion, including the effects of tilt, sway, etc.

Formative pruning: the removal of appropriate branches of a young tree to avoid future structural defects while giving it the desired form.

Geogrid: woven, net-shaped, synthetic polymer-coated fibres that provide a stabilising force within soil structure as the fill interlocks with the grid.

Geotextile: a synthetic fabric, applied to either the soil surface or between materials, providing filtration, separation, or stabilisation.

Geomembrane: an impermeable liner usually made of synthetic polymers used with soils, rock, earth, or other geotechnical material in order to block the migration of fluids.

Hessian wrapping: a rustic cloth typically employed by nurseries to protect tree trunks and root balls when moving tree stock around. It can occasionally be seen left on newly planted trees to help insulate the young stem against very cold weather or as a method of soft protection for the tree if in an area where damage to the bark is likely.

Parallax: the apparent displacement of an observed object due to a change in the position of the observer. Tall features located very near to the carriageway and viewed from a travelling car will seem to "move" more quickly than other objects in the far background, reinforcing the driver's impression of his or her own speed.

Raft system: Floating modular or web-structured load-spreading underground plastic system avoiding compaction of the soil volume below. It accommodates tree growth while protecting the hard surface above from root disruption.

Root ball: the main mass of roots at the base of a tree.

Root deflector: a barrier placed below the surface, around the upper part of the root ball of newly planted trees, to direct future root growth downward and away from nearby footways and kerbs.

Shared space: an urban design approach which seeks to minimise demarcations between vehicle traffic and pedestrians, often by removing features such as kerbs, road surface markings, traffic signs, and regulations.

Structural growing medium: a tree-growing medium combining soil and sand or stone that can be compacted to the required level to support a load-bearing hard surface above (eg footway, car park, carriageway) while permitting root growth.

Subsidence: the downward movement of the ground supporting a building. Problems arise when the movement varies from one part of the building to the other, when cracks and structural damage can occur.

Swale: a shallow vegetated channel designed to partially treat water quality, attenuate flooding potential and convey surface water runoff away from critical infrastructure.

Trunk flare: the widening of the base of a tree trunk. Trunk flare development is directly linked to the growth of the tree.

Consultation draft

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Consultation draft

Afterword

A wide range of experts have contributed to both the content and the peer review of this document. While the ideas and practice presented are the most current that TDAG's expert contributors can provide, new ideas and challenges are constantly emerging and TDAG is very aware that periodic updates will be needed to keep this document current. These will be available in subsequent editions of the guide on the TDAG website.

Inevitably, the extensive research undertaken has shown that the issues and solutions associated with trees in hard landscapes are complex: each situation requires a bespoke response. To assist with this process, rather than specification, this guide provides the information on which to base appropriate decisions for delivery.

A wide range of case studies has been included to demonstrate what has been achieved in the UK and beyond. Examples from overseas are included because they demonstrate interesting and sometimes inventive approaches to problem solving which can inspire new ideas here. However, any work undertaken in the UK will have to be carried out in a way that is appropriate to local circumstances and satisfies UK regulations and requirements.

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Trees & Design Action Group

More information found at:
www.tdag.org.uk

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