Trees in Hard Landscapes

A Guide for Delivery

Trees & Design Action Group

CIHT

CIBSE

Institute of Chartered Foresters

ice
Institution of Civil Engineers

Trees and Design Action Group

The Trees and 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

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 and other infrastructure dependent upon good below-ground conditions.

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: A Guide for Delivery* 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: A Guide for Delivery* 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
14th September 2014

Overview

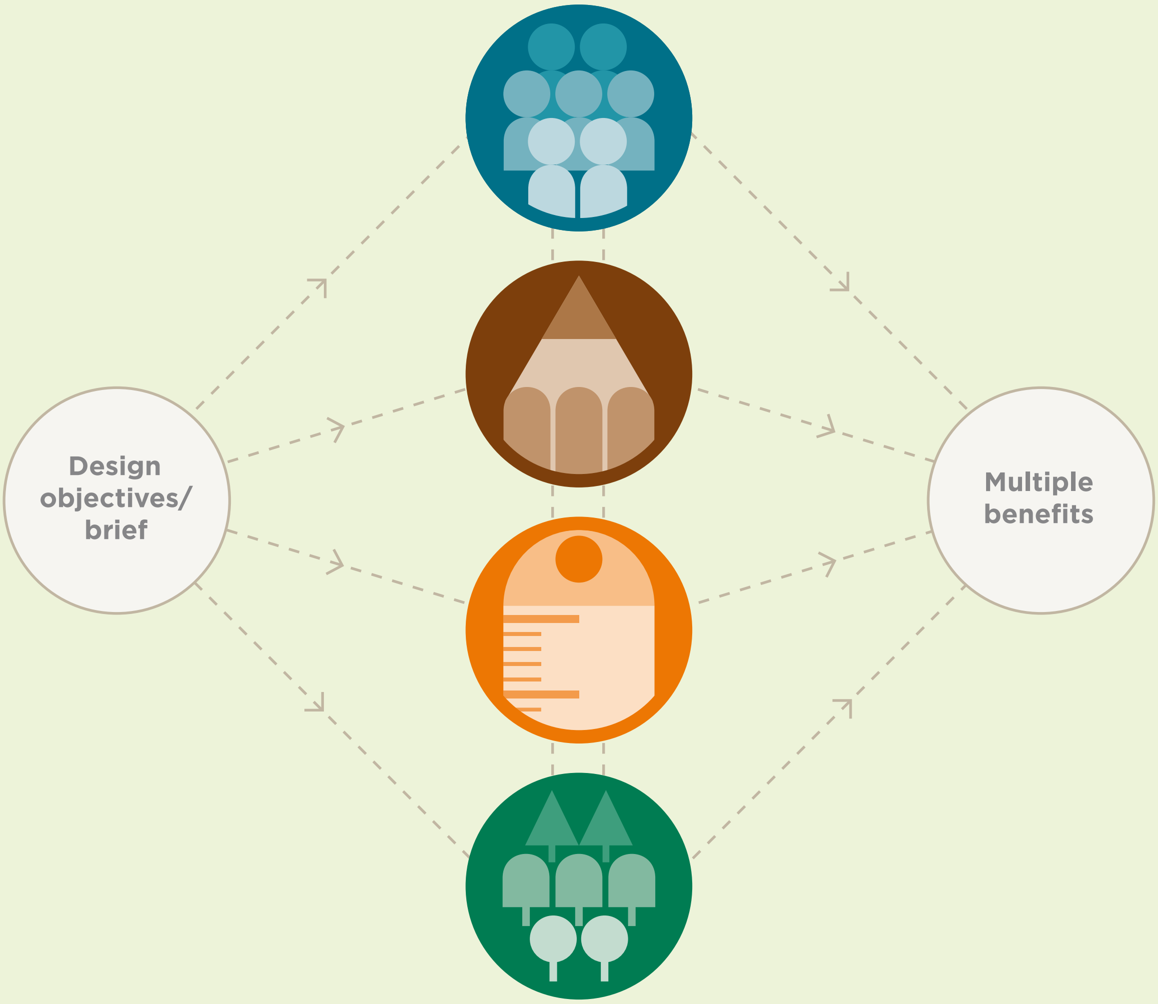
Starting from the point where the policy decision to retain or plant trees has been made, this guide explores the key building blocks to success through:

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.

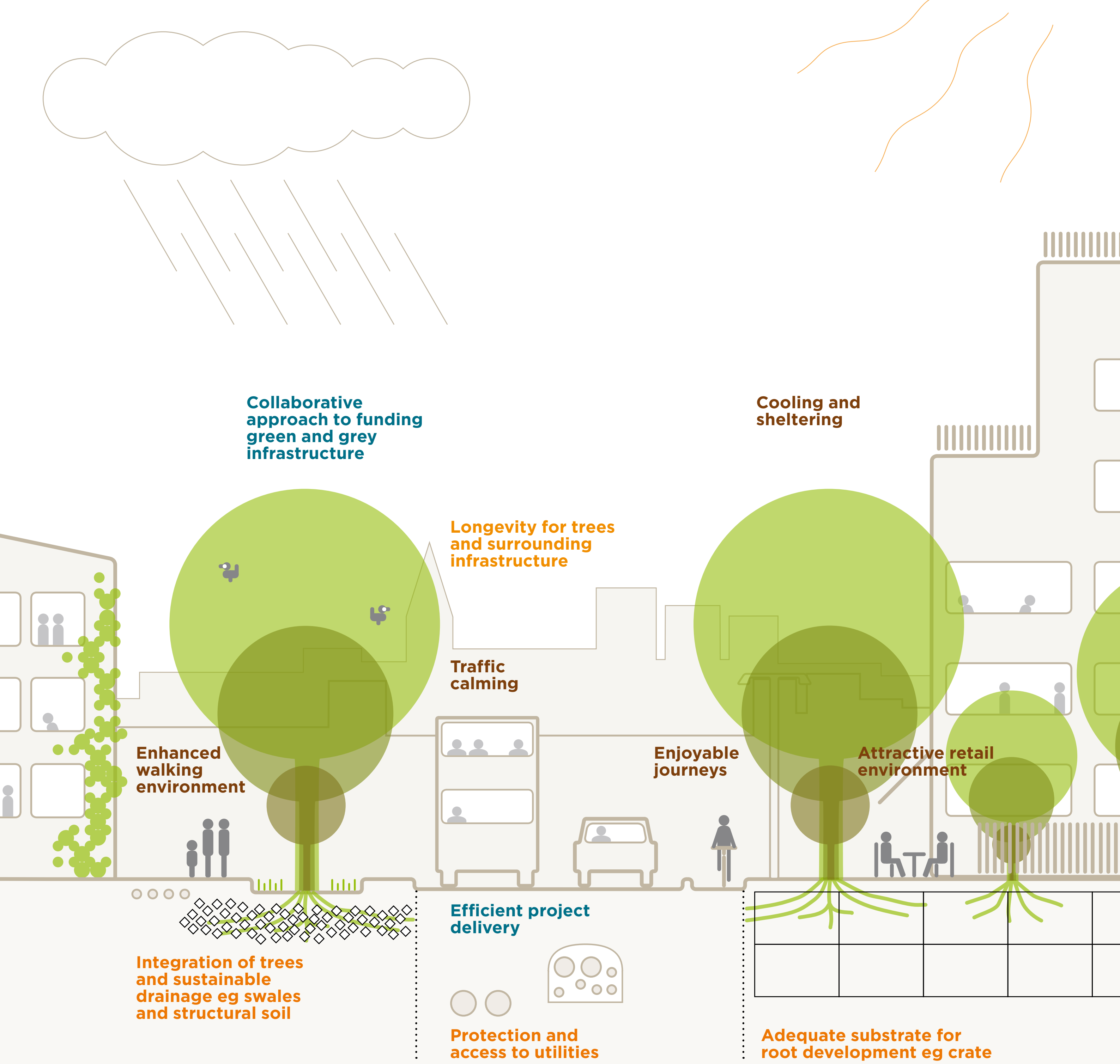
Technical Design Solutions
The available technical below-ground solutions to achieve lasting overall success.

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



Contents

21st century opportunities and challenges

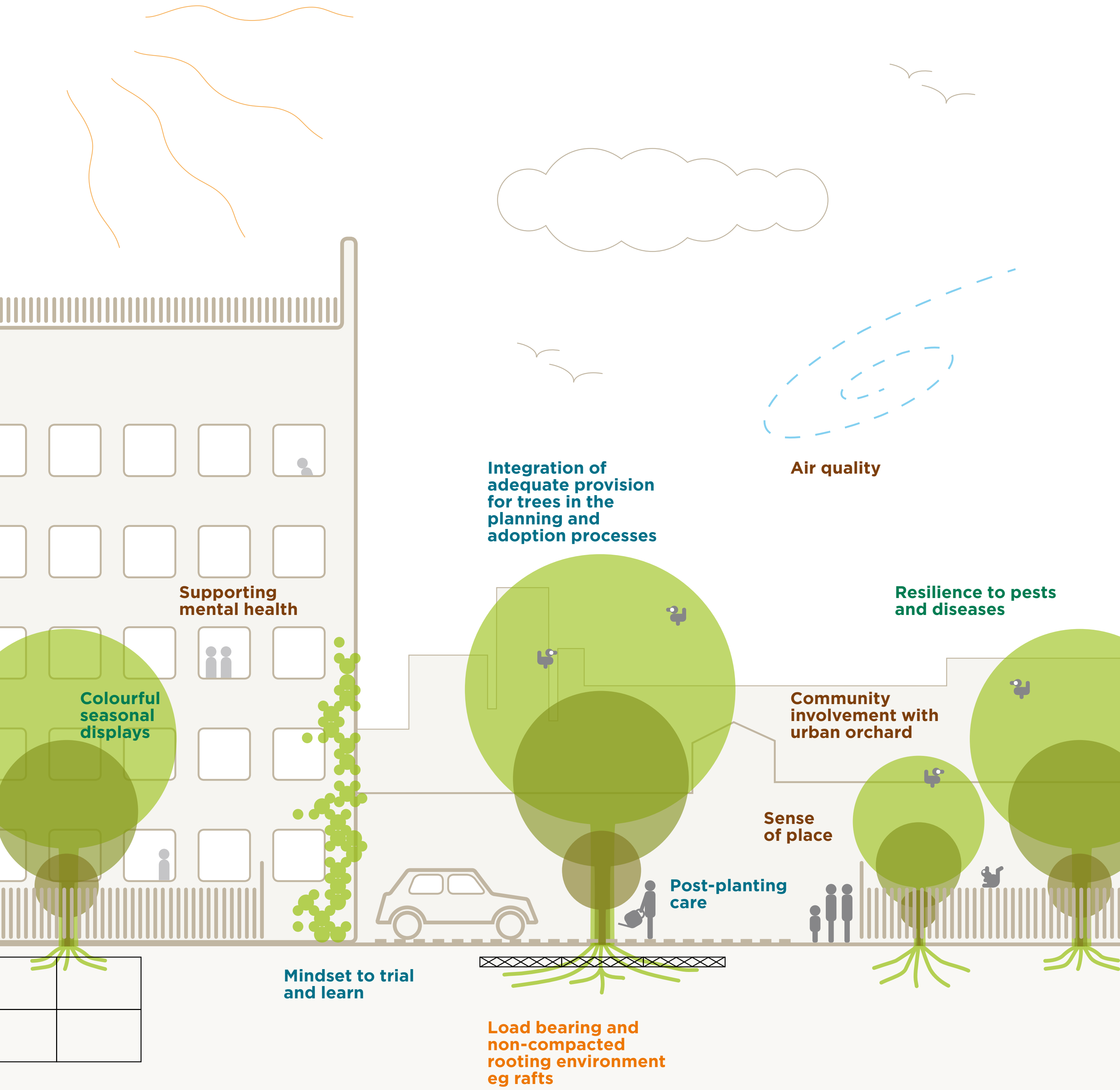


Collaborative Process

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

Achieving long-term benefits from trees requires a concerted strategy. This guide explores current evidence on the enabling factors for trees to bring value to the hard landscapes in which they grow.



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 and summary

Trees in Hard Landscapes: A Guide for Delivery is the companion document to *Trees in the Townscape: A Guide for Decision Makers*[1].

It explores the practical challenges and solutions for integrating trees in 21st century streets, civic spaces and surface car parks. These are arguably the most challenging environments for growing trees, but are also the areas that can derive great benefits from their inclusion.

Audience

Highway engineers, civil and structural engineers, highway contractors, construction site managers, project managers, designers and tree specialists are the primary audience for this guide. It will also be of value to developers, planners, elected members, local communities and all involved in hard urban landscapes and their design and management.

The need for a sustainable integrated infrastructure

Two themes are expressed throughout the guide. Firstly, the importance of innovation, an element of experimentation, so that improvements can be made in response to changes in available techniques as well as in constraints and expectations for the public realm. Secondly, the mindset to achieve multiple benefits. Both are essential for successfully integrating trees in high-performance hard landscapes in a 21st century context.

There is much evidence on the wide range of benefits that can be gained by integrating trees with other infrastructure. However research also shows that, while trees need to reach a degree of maturity to fulfil their potential and deliver returns on investment and benefits to their communities, many urban trees in hard landscapes are not living as long as they should[2].

The context in which trees can thrive in hard landscapes is in a state of flux, with new challenges and opportunities for success. Many urban trees, especially the larger growing trees, were planted from the mid-19th to mid-20th century when there was less crowding, complexity and compaction beneath our highways and public spaces.

There are now new uses and quality expectations for the public realm. Streets are increasingly regarded as 'places', not just as vehicular movement corridors. The same 'space' needs to accommodate cycles and a public transport system as well as private vehicles and better conditions for pedestrians to encourage walking. These challenges will need creative solutions.

Climate change and increasingly erratic weather patterns including heatwaves and extreme localised rainfall also put new pressures on the infrastructure of our towns and cities. Urban trees have a lot to offer towards urban cooling and surface water management. Modelling conducted for Manchester has shown that increasing the canopy cover by 10% would keep summer peak temperatures at their current level until the 2080s[3]. In terms of Manchester this would mean an increase in average canopy cover from about 15% to 25% but it is important that canopy cover is as evenly distributed as possible across the urban area.

How this guide works

Having established 12 principles of urban forestry good practice in *Trees in the Townscape*, this guide starts from the point where policy decisions have been taken to both protect existing and plant new trees. Successful delivery of these objectives is explored through:

1
Trees and Design Action Group (2012). London: TDAG

2
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

3
Gill, S., Handley, J., Ennos and A,. Pauleit, S. (2007) *Adapting Cities for Climate Change: The Role of Green Infrastructure*. Built Environment Vol 3, No. 1 pp 115-133

- Collaboration and the key players required from inception to delivery.
- Design choices that will ensure trees best contribute to project objectives.
- Technical solutions, mostly below-ground, to avoid conflicts between trees and the surrounding infrastructure.
- A framework for selecting and obtaining the 'right' tree(s).

Each section starts with a diagram showing an imaginary urban landscape illustrating some of the recommendations discussed. This is coupled with an outline of the 'Aims', 'Requirements' and 'Wider Benefits' described in the section.

The key actions –'what needs to be done' and 'who does it' is set out at the beginning of each main paragraph.

A checklist is provided at the end of each section summing up the tasks for each of the key players.

Case studies illustrating the points made with real-life examples from all over the UK and abroad are also provided at the end of each section. A case study finder on page 154 makes it easy to locate relevant examples based on topics of interest.

Terms defined in the Glossary (on page 156) are highlighted in green throughout the document

How this guide was developed

Trees in Hard Landscapes: A Guide for Delivery 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). It has been an exercise in collaborative working and 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 sponsors. Their profile can be found on page 160.

Collaborative Process

Collaborative Process
Securing value throughout the project lifecycle

Success with trees in hard landscapes requires a collaborative, cross-disciplinary process from project initiation through to design, implementation, maintenance and monitoring.

Such collaboration provides the foundation needed for other fundamental enabling factors such as access to funding and adequate expertise, resilient above- and below-ground design solutions, community support and competent delivery.

Aims

Examining the decision-making process of hard landscape projects, the aims of this section are to guide:

- Who to talk to and when.
- What information to get.
- What other actions to take and when to achieve the collaboration required to maximise the contribution trees can make.

Requirements

The main project requirements covered in this section are:

- The project brief.
- The scheme value assessment.
- The funding strategy.
- Tree-related policies and their enforcement.
- Surveys of utilities and of existing trees.
- The arboricultural method statement and tree protection plan.
- The tender documentation.
- The procurement strategy.
- The work sequence.

Wider Benefits

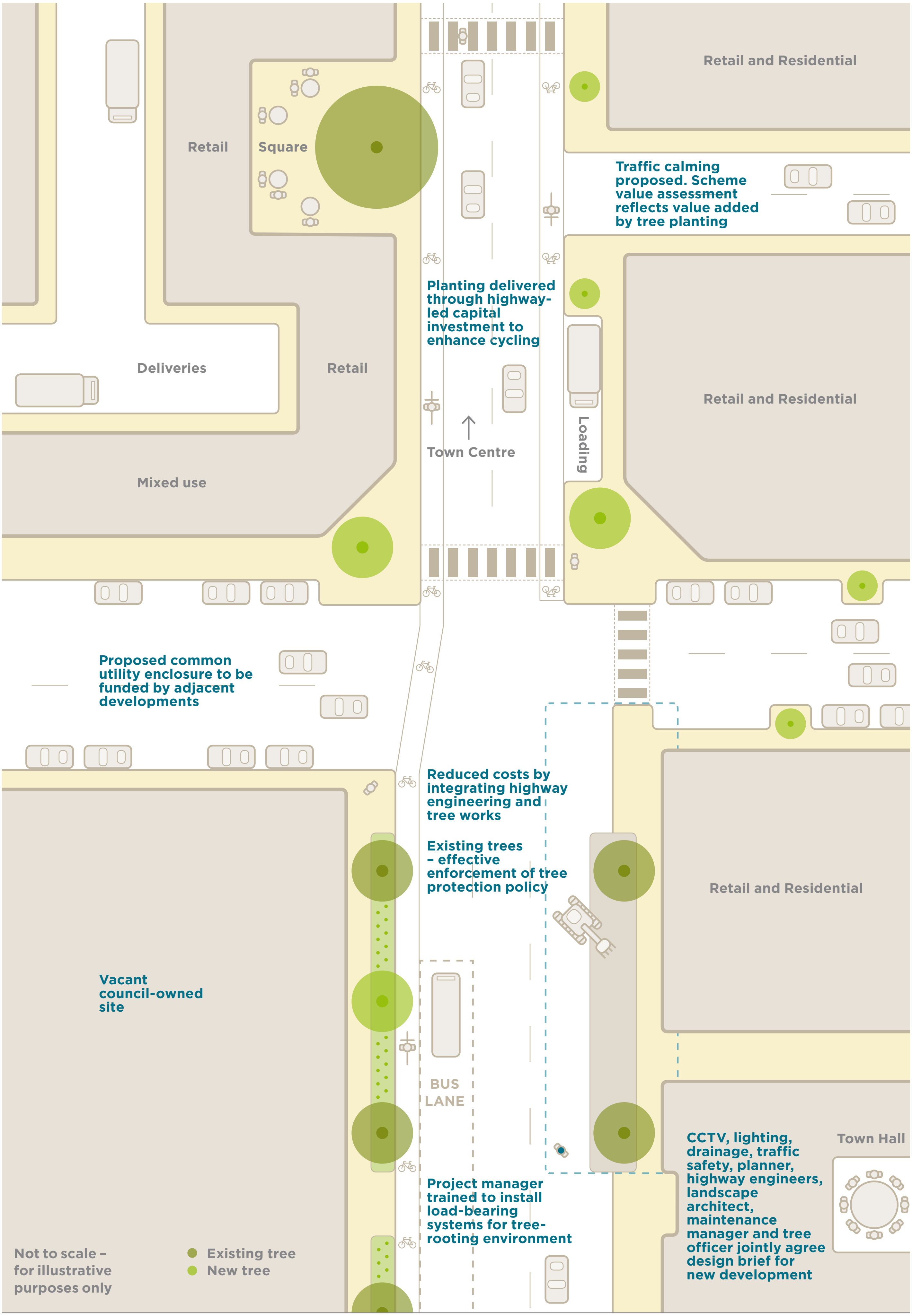
The wider benefits to be gained are:

- Better value for money from infrastructure investments.
- Enhanced ability for team members to learn and adapt to changing and complex local contexts and better anticipate potential issues and opportunities.

Gaining benefits through trees

The diagram opposite shows an imaginary townscape where there is a policy commitment to protect existing trees and create opportunities for planting additional trees to support other objectives such as the introduction of cycle tracks and traffic calming.

Meanwhile there is a meeting in the town hall to agree a design brief for the redevelopment of a council-owned site which will feature new office and retail space, as well as a 'Park & Ride' car-park. What will the outcome be? See Section 2.



Retail
Square
Retail and Residential
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
Town Centre
Loading
Mixed use
Proposed common utility enclosure to be funded by adjacent developments
Reduced costs by integrating highway engineering and tree works
Retail and Residential
Existing trees – effective enforcement of tree protection policy
Vacant council-owned site
BUS LANE
Town Hall
CCTV, lighting, drainage, traffic safety, planner, highway engineers, landscape architect, maintenance manager and tree officer jointly agree design brief for new development
Project manager trained to install load-bearing systems for tree-rooting environment
Not to scale – for illustrative purposes only
Existing tree
New tree

1.1
A good start: leadership, project team and funding

In brief: what needs to be done	Who does it
Have clear policies for the protection, care and planting of trees and commit to their enforcement.	– Planner/policy officer – Design champion/Client representative(s) – Tree officer/specialist – Project manager
Articulate the value of existing and proposed trees in the scheme value assessment.	– Design specialist(s) – Tree officer/specialist – Project manager
Articulate the benefits of existing and proposed trees bring to achieve the project vision and objectives.	– Design specialist(s) – Tree officer/specialist – Project manager
Secure access to the right skills for the team, including, where needed, expertise on soils, veteran trees, young trees, arboriculture, urban forestry.	– Design specialist(s) – Tree officer/specialist – Project manager
Incorporate five years of post-planting care in capital project costs.	– Project manager – Client representative(s)
Take a partnership approach to funding.	– Project manager – Client representative(s)

Terms defined in the Glossary found on page 156 are highlighted in green throughout the document

1.1.1
The need for vision and leadership

Whether in private or public organisations, establishing a culture of collaboration where there is pride in the inclusion and preservation of trees requires leadership and vision (see *Trees in the Townscape* Principle 9, pp56-61).

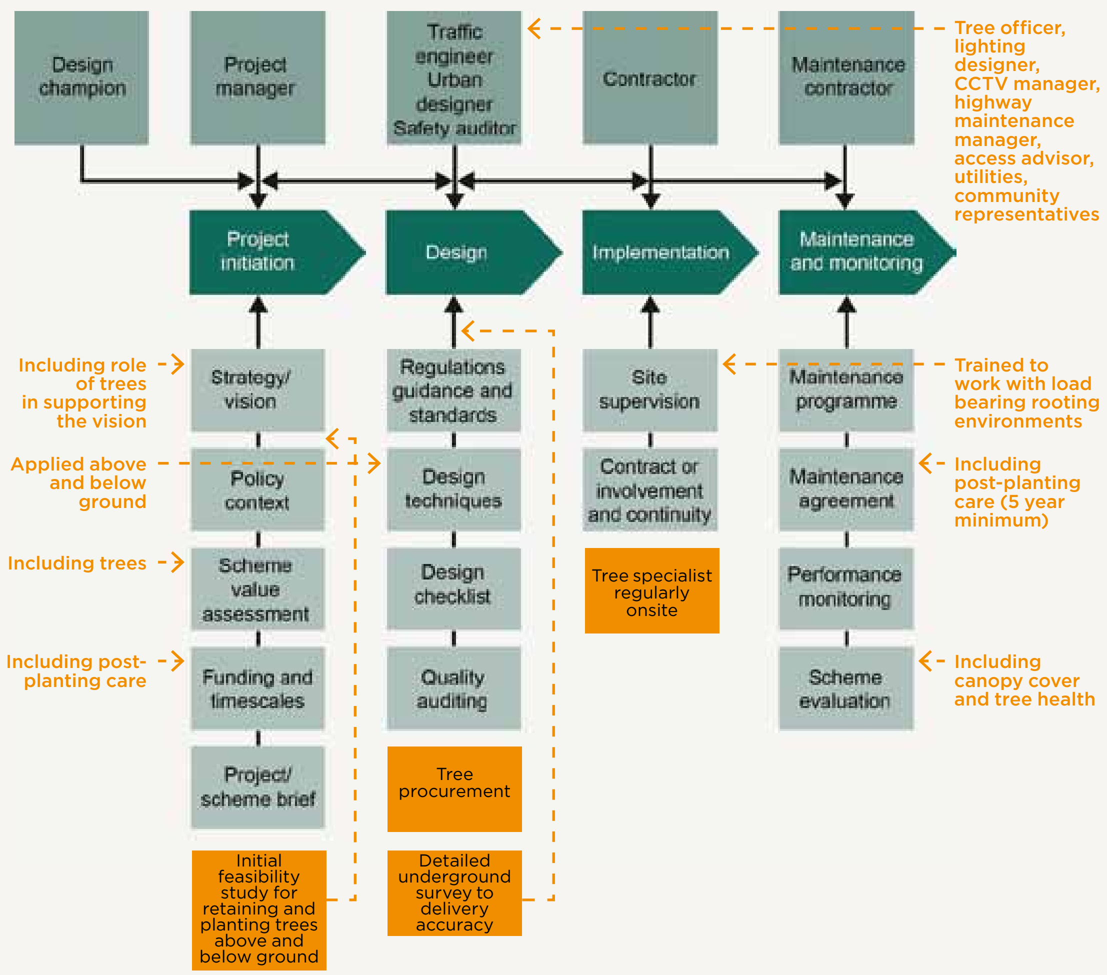
In practical terms, this requires:
- Clear standards for the protection, care and planting of trees in the local plan and/or other key policy documents, including local transport plans, highway design guides and supplementary planning documents addressing trees in new developments. Such standards may equally be set by private organisations in corporate policy documents (see the examples 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.

In high profile schemes to transform an area, top-level leadership will likely rely on the vision brought by local politicians. In standard schemes, the director of planning or the director of highways will have a key role to play. In all instances, ensuring the managing director or relevant account manager of the company building or overseeing construction will be critical. The top three messages to convey to them are:
- Include trees.
- Adhere to design and construction practices to facilitate successful tree growth and retention.
- Have funds available for post-planting care.

Beyond robust policies and executive commitment, integrating trees in hard landscapes also relies on leadership at staff level, including:
- Arboricultural or design staff who actively engage in policy work to articulate the relevance of trees within broader strategic policy or business agendas.
- Arboriculture and highway staff who are confident and collaborate in overseeing operational and construction work.
- Arboriculture and highway staff who share an interest in and appetite for innovation and learning. Flexibility in the use of specifications featured in local design guides in response to project circumstances and new techniques becoming available is critical. This ensures that contemporary approaches such as those designed to enhance the tree-rooting environment beneath load-bearing hard surfaces (see 3.2) can be explored and, if appropriate, trialled locally and accepted.

As the LTN1/08 diagram demonstrates, an important element in delivering successful projects is to have a single project champion who takes the project from concept to completion.

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



4
Found at:
www.gov.uk/government/uploads/system/uploads/attachment_data/file/3810/ltn-1-08.pdf

The Department for Transport's *Local Transport Note 1/08 Traffic Management and Streetscape* (LTN 1/08)[4] 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. Building upon the LTN 1/08 flows, inputs and links diagram, the orange annotations incorporated above demonstrate how to integrate trees into the design and implementation process.

Having the right people involved at the right time is of paramount importance. The titles shown in the diagram refer to the roles people have rather than to their professional background. A single person might take several roles. Definitions for some of these roles are provided below as they are used throughout *Trees in Hard Landscapes: A Guide for Delivery*.

The **Design champion's** role is to maintain design integrity throughout the project's life – from inception to maintenance. The design champion may be a senior and influential officer within the authority, perhaps a council member (see LTN1/08 paragraph 2.10) or appointed by a developer. To follow the language of LTN1/08 the term 'design champion' has been used although this role might also be described as the project leader.

Client representative(s) has the authority to give sign-off allowing the project to progress from inception to completion. The client representative might be a single individual (smaller schemes), a committee or a dedicated steering group.

Design specialist(s) such as urban designer(s), landscape architect(s), architect(s) and/or engineer(s) will help translate the vision in the brief and develop a design – in some cases the design specialist might also assist with the formulation of the brief.

Tree specialist(s) ensures that existing trees are retained in adequate conditions and that proposed trees can grow to fulfil the design intention (see 1.1.4).

Highway engineer(s) ensures that design details are safe, durable and are practical to construct.

Traffic engineer(s) makes certain that the transportation objectives are achieved for all road users.

Construction manager oversees onsite construction including highway contractors.

Project manager leads and coordinates the multi-disciplinary project team through the design and implementation process.

1.1.2
Integrating trees into the project brief and the value assessment

As shown in the LTN1/08 diagram, building a shared vision for the project is 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 purpose and intended outputs for the scheme. Existing policies on trees and the particular role trees can play in the scheme should be made explicit, together with the capacity and 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, HM Treasury's Green Book[5] 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 are now available to assess the value of existing trees, as well as estimate the benefits associated with new trees. These include CAVAT[6] and i-Tree Eco[7]. Case study 3, p32 provides a striking demonstration of the use of i-Tree Eco to demonstrate at design stage the return on investment to be realised from trees as part of a private development. Further details on valuation methods can be found under Principle 10 of *Trees in the Townscape*.

1.1.3
Adopting the right mindset for successful funding

A flexible and broad-based approach is needed to achieve adequate funding levels for trees. While dedicated "tree budgets" may be limited, the multiple benefits trees can deliver can justify access to funding and resources ranging beyond the 'green' sector. 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*[8], paragraph 11.2), are budgeted for as part of the capital investment sums.
- Taking a partnership approach to designing a funding strategy.

Examples of possible leads to pursue for schemes in England is provided below. The underlying mindset applies across the UK for both present and future funding schemes.

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 should cover the full planting costs. If not, a recognised alternative is for the highway fund to cover the excavation of the tree 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 effective 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 trees.

Complementary centralised transport funds are subject to rapid changes and

5
HM Treasury, *The Green Book: appraisal and evaluation in central government*. April 2014 update. London: TSO. Found at: www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-govertnent

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
The i-Tree Eco valuation method factors both the structural value of the tree (based on its replacement cost) and the value of the benefits it provides in terms of air pollutants removal, carbon storage and sequestration, and energy savings for surrounding buildings. More information can be found at: www.itreetools.org

8
British Standard 8545: 2014, Trees: from nursery to independence in the landscape. Recommendations. London: BSI

are structured differently across Britain. These funds often enable 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 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 £600m Department for Transport 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).

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 such as private squares, alleys and streets.

Highway or roads authorities may also rely on private finance initiatives, such as Design, Build, Finance and Operate (DBFO) contracts to secure investment in a particular road asset. DBFO are often used for the larger highways projects – which are mostly outside the scope of this guide, except in their urban sections. Under such contracts, which typically last for 30 years, the private sector assumes responsibility for the operation and maintenance of a length of existing road and for building specified improvement schemes for the life of the contract. It will be the responsibility of the contracting highway or road authority to include environmental enhancements within the criteria set for assessing bids, and carefully examine budget allocation, as well as the design and management approaches for trees in the proposed bids.

Funding and resources accessible through the planning process

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 developments. 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 drainage, underground services, lighting, carriageways, surface treatments and adjacent structures (see sections 2 and 3 of this guide). The use of planning conditions should ensure that the quality of materials, planting and aftercare used for new tree planting meet acceptable standards enabling long-term objectives to be met, 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 highway authority and a developer which describes proposed modifications to the existing highway network that are required,

with the public interest in mind, to accommodate the new 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 to mitigate its local impact, for example to fund improvements to the nearby highway that will be affected by the traffic generated by the new project. 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 3.1.2). 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 care. In Bristol, one of the street parties held in 2012 as part of TreeBristol[9], the local planning authority's community engagement programme around trees, raised £3,000 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 5, p34).
- *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[10] 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

9 www.bristol.gov.uk/page/environment/treebristol

10 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 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 16, p76).
- *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 28, p131). It is also not uncommon for energy companies and their alliances to fund tree planting as compensation for tree removal.

1.1.4 Securing early and substantial input from a tree specialist

Tree specialist input is essential for both new tree planting and working around existing trees. It should be built into the budget and make-up of the project team.

When planting new trees, expert input should be sought on:

- Sizing and design of the below-ground rooting environment.
- Tree placement and treatment of the tree surface opening.
- Tree species selection.

Expert input is equally important for hard landscape projects involving existing trees to:

- Conduct a tree survey compliant with *BS 5837:2012*.
- Produce a tree constraints plan.
- Produce an arboricultural method statement (AMS) and tree protection plan (TPP).

Two areas of expertise need to be covered:

- Arboricultural knowledge from professionally qualified specialists. This might be a consultant advisor and/or the local authority tree officer. Additional qualifications and experience in young tree establishment, tree protection or remedial work on tree roots and tree-rooting environments might also be required.
- Maintenance and management, which might be provided by the local authority tree officer or the estate manager. It is important to take into consideration constraints and resource limitations for long-term maintenance of hard landscapes trees prior to finalising decisions on approaches to tree retention or tree planting.

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 if:

- The context for decision-making is to support the whole urban forest and overall canopy cover. One essential dimension of the context that is often overlooked when making choices involving trees is the local tree population (see 4.3). It is the population as a whole that delivers benefits, rather than individual trees considered in isolation. All new planting, tree retention or tree loss contribute to the local tree population and affect its long-term resilience. Effective tree design therefore requires a good understanding of the greater whole to which any scheme contributes.
- There is a willingness to give and take, accepting that this may mean the loss, at times, of some trees – in which case adequate provision for replacements should be made in the local area affected by the loss, preferably using canopy cover or diameter at breast height as the point of reference (see *Trees in the Townscape* Principle 3).
- There is an understanding that, when planted in the right conditions, most trees have a longer potential lifespan than most of the hard infrastructure that surrounds them and that most

environmental benefits associated with trees in hard landscapes can only be realised if the trees reach and live through their mature stage (see 3.1.2). Efforts to retain existing large growing trees should be made a priority consideration, particularly when such trees are found in dense built-up setting where opportunities are limited and needs high.

- There is 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 22, p126) 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.

Collaboration between Highway Engineers and urban and landscape designers created space for people at an previous road junction. See Case study 11, p71. Image: City of London

1.2 Design: multi-disciplinary input and holistic above/below-ground responses

In brief: what needs to be done	Who does it
Engage with utilities at brief writing stage to gather asset data and find out about any planned refurbishment and upgrade.	– Project manager
Incorporate in the initial quality/site audit a tree survey compliant with *BS 5837:2012*, so as to provide the design team with a tree constraint plan at brief writing stage.	– Tree officer/specialist – Project manager
Provide the design team with soil characteristics data at brief writing stage.	– Project manager
Following PAS 128:2014 to conduct detailed underground utility survey to delivery accuracy at concept design stage. If the project is delivered through planning, require survey evidence that the scheme is deliverable.	– Planner/development control – Project manager
Integrate water-sensitive urban design principles from the inception of the design process – maximising benefits to and contribution of trees.	– Design specialist(s) – Tree officer/specialist – Drainage specialist
Use feedback collected from maintenance staff to improve the proposed design.	– Design specialist(s) – Tree officer/specialist – Project manager
Ensure consensus has been achieved between the tree specialist, the design specialist(s) and the engineers on detailed design solution for tree integration (reflected in final design, tree protection plan, monitoring procedure and arboricultural method statement).	– Project manager – Design champion/Client representative(s)
Consult with nurseries and factor in production and ordering lead-time to meet project programme.	– Tree officer/specialist – Project manager

1.2.1 Integrating trees into the site assessment process

For highway schemes, a quality audit is a process whereby a series of discrete evaluations of design conditions and how the space operates are collected and given due consideration within the design process[11]. Other development projects also require such an evaluation and trees are among the features that should be included in such assessments. This should include:

- *A survey of the trees present on site and immediately adjacent to the site*, as per the recommendations set out in *BS 5837:2012*[12]. The survey will consider species, location, current size, conditions and ultimate potential size of existing trees so as to determine their safe and useful life expectancy. This assessment should integrate information on existing statutory protections (tree protection orders, conservation areas). It is also important to analyse the contribution of existing trees to the streetscape or overall quality of the site, and any potential conflicts or nuisance trees might cause. This work will enable a balanced and evidence-based approach to decision-making on tree retention. It will also enable the identification of root protection areas, which, for projects integrating existing trees, will need to become a fundamental design parameter (see 1.2.2).
- *Wider context analysis of the treescape*, including the types of trees in private properties as well as the species, age profile and planting style found in the public realm in the neighbourhood affected by the scheme. Combined with information that might be available in a local landscape character assessment, this analysis will help better support local distinctiveness when making design choices on planting patterns and species choice (see 2.1.3). This analysis will also help to ensure tree population resilience issues can be addressed

11
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

12
British Standard 5837:2012, Trees in relation to design, demolition and construction. Recommendations. London: BSI

when making final decisions on tree species (see 4.3).

Some of the initial tree survey criteria should be used in ongoing 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
Designing below ground

Below-ground conditions are critical. Whether working with existing trees and or planting new trees in hard landscapes, the long-term success of both trees and the surrounding infrastructure will heavily rely on the ability to:

- Anticipate the below-ground impacts of above-ground objectives and choices (eg need for load bearing capacity for new or refurbished hard surfacing, need for below-ground services for a building, need for water infiltration, need for rooting space).
- Optimise the design of the below-ground in terms of space allocation, detailed technical design and delivery process. This requires a holistic understanding of available solutions to achieve good compatibility between all underground components (surfacing sub-base, utility pipe, sub-structure foundations, roots) – hence the need for a collaborative and cross-disciplinary approach to design.

Section 3 of this guide provides a more in-depth analysis of available design strategies and technical options for below-ground success. From a project and data management perspective, the holistic design approach advocated above will be greatly facilitated if information on utilities, soils characteristics and (for projects featuring existing trees) potential arboricultural impacts is made available to the design team at the right time.

Underground utilities

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 three 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 26, p129) and in Henley-on-Thames' public car park (see Case study 9, p38), or joint problem solving, as underway in Counters Creek (see Case study 28, p131).

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

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, utility records often do not reflect accurately the layout or conditions of the subsurface, and no single technology can detect in one single scan all types of underground utilities.

Addressing these challenges has been the focus of a comprehensive research programme called Mapping the Underworld led by the University of Birmingham[13] since 2005. One of the outcomes of this work so far has been the development of a silicon-free radio frequency (RF) tagging technology which precisely locates key elements of undergrounds assets (eg joints, junctions, valves, etc) and links this geographic information to a remote database. The creation of silicon-free tags, with a design life of 100 years (ie twice the design life of a modern plastic pipe), is an important

13 www.mappingtheunderworld.ac.uk

progress in radio-frequency technology since data in currently available silicon chips is not guaranteed by any of the global chip manufacturers for more than 10 years. This has the potential to greatly facilitate utility detection in the future if utility providers start tagging their assets as they carry out repairs, replacements or new installations. The Mapping the Underworld research programme is also exploring the development of a multi-sensor device to detect every utility without local proving excavations. The objective is to combine this with intelligent data fusion using existing utility records and British Geological Society (BGS) shallow surface soil data to create UK-wide accurate 3D geophysical property maps.

Until the promising outcomes of this work are adopted, when tree planting or enhancements to an existing tree-rooting environment are proposed, whether on an existing highway or in a new development, there is no certainty that the proposed tree works can be implemented unless specific site investigations are undertaken. The Institution of Civil Engineers (ICE) sponsored *PAS 128:2014*[14] 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) need(s) 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 the pros and cons of different techniques, is available at no charge from the Survey Association[15].

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 (see 3.4.1). 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.

Soils

Soil characteristics must be understood early in the design process.

As a matter of priority, confirmation should be sought on whether or not the subsoils are subject to shrinkage under moisture variation. Areas that are prone to subsidence require a careful approach to new tree selection as well as to the design of foundations and underground services in proximity to new or existing trees. More details on this can be found in 3.3.4 and 3.4.2.

It is also important to have a good understanding of:
- Soil compaction.
- Soil texture (soil particle size distribution).
- Soil pH.
- Nutrient and organic content.
- Salinity.

Depending on context, good knowledge might already exist within the team about the local soils and subsoils. Where such local knowledge is not available, specialist input should be sought to gather soil samples, conduct laboratory-based testing and provide an analysis with recommendations. This will also apply where contaminants might be present.

Arboricultural impacts

The tree survey will guide the development of a tree constraints plan identifying trees suitable for retention and those that should not be regarded as constraints. A tree constraints plan will also show the root protection areas[16] (RPAs) – formerly called tree protection zones – associated with each tree to be retained. Information on the location of RPAs should be made available to the

14
Publicly Available Specification 128:2014, Specification for Underground Utility Detection, Verification and Location. London: BSI

15
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

16
Refer to *BS 5837:2012*, paragraph 4.6

design team at conceptual design stage, prior to any decision on positioning of new above or below-ground structures is made, as illustrated in Case study 6, p35.

As an initial design develops, it will be important to get feedback from a tree specialist on the potential impact(s) of the proposal on existing trees to be retained and any mitigation strategies that may be needed. This should be captured in a tree protection plan (TPP) and arboricultural method statement (AMS). The TPP defines the location and type of protective barriers to be used (eg hoarding defining an exclusion zone), together with any ground protection measures (eg use of anti-compaction mat, oil trays, temporary raft, etc) required if some of the works encroach on the root protection area. The AMS will typically advise on the type and level of pruning required (eg crown lifting to accommodate machinery, crown reduction to accommodate a scaffolding), any complementary management regime required to enhance the ability of the tree(s) to cope with the works (eg irrigation) and potential enhancement to the conditions of the rooting environment that would help improve the longevity of both the tree(s) and the surrounding infrastructure. An initial draft of both the TPP and AMS should be made available to the design team at the early stages of detailed design. A collaborative and iterative approach will be required to come to mutually agreed final design, TPP and AMS.

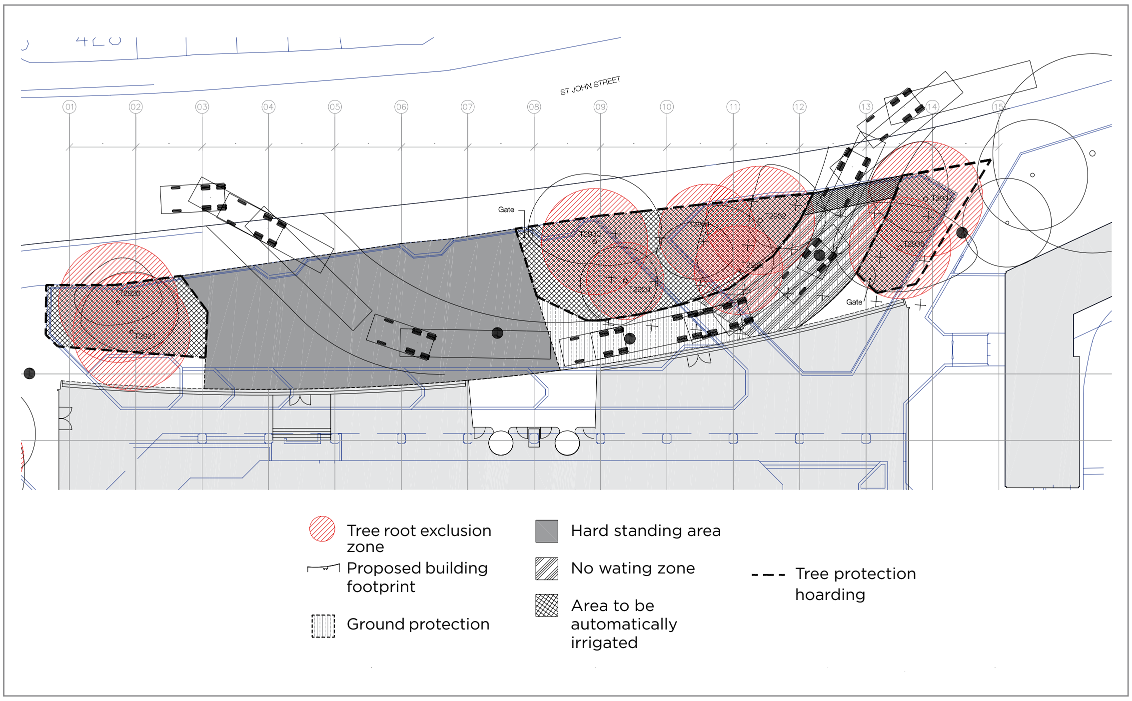
To complement project-triggered tree information sharing and in response to the growing use of load-bearing rooting environments (see 3.2), some local authorities[17] are also advocating:

- The integration of root zone data in the databases they maintain about the local tree population which are made available to highway contractors – this would particularly highlight were trees are planted with raft, crate or structural growing media requiring contractors to exercise particular care for access and repairs.
- The use of identification markers placed flush to the finished grade and directly adjacent to the tree to help further alert contractors.

1.2.3 Bringing water sensitivity into the design process

Access to water is an essential requirement for trees to survive. Recently planted trees rely heavily on root ball moisture because this is where most of the roots are located during the first growing seasons[18]. Young trees are therefore particularly dependant on provision of adequate watering (see 1.2.4 on post-planting care) and correctly designing for water entering the tree-planting hole. Available options to ensure the permeability of the tree surface opening and associated edge treatment are detailed in 2.6.2.

Opportunities might exist to enhance the permeability of the landscape surrounding trees, or make provision for some surface water runoff to drain



Tree constraints plan for the Angel Building (see Case study 6, p35). Image: J & L Gibbons

17
See for example p42 of the City of Toronto's *Tree Planting Solutions in Hard Boulevard Surfaces Best Practices Manual* found at: www1.toronto.ca/city_of_toronto/parks_forestry__recreation/urban_forestry/files/pdf/TreePlantingSolutions_BestPracticesManual.pdf

18
Watson G and Himelick EB (2013), *The Practical Science of Planting Trees*. Champaign, IL: International Society of Arboriculture

into the tree-rooting environment. With droughts becoming more and more common in the UK (and particularly in the south east of England), there is a greater need to avoid any possible wastage of water resources.

Opportunities might also exist for some of the drainage and water management needs of the site to be fully or partially involved through the integration of the tree(s) with sustainable urban drainage (SuDS) components. Full details on the role trees can play for surface water management and possible design options are respectively found in 2.4 and 3.5.

Exploring and realising these opportunities requires an integrated approach to the design of the soft landscape elements, especially trees, and the drainage strategy. This will need to be articulated as part of the project objectives in the project brief and initiated as soon as conceptual design starts.

1.2.4
Designing with maintenance and adoption in mind

Post-planting care is vital 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 but also formative pruning (see 1.4.1) and monitoring and adjustments to the support systems.

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.
- 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 aeration system and possibly an automatic irrigation systems.
- 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 project sign-off, 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, stimulating more positive responses to transport schemes and greater readiness to cope with disruptions associated with the construction period. In the minority of instances where trees raise concerns (see the Brislington Hill example in Case study 16, p76), 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. Another positive spinoff observed in Bristol has been the willingness of local community groups to assist with post-planting care (see 1.4.1).

For projects requiring planning permission, a positive approach towards trees can help facilitate the approval process. Such an approach will be demonstrated through:

- The conduct of a *BS 5837:2012*-compliant survey early on (eg prior to design starting, at pre-application stage) and the proactive adoption of design choices and protective measures facilitating the retention of existing trees, whether on-site, or immediately adjacent to the project area. The potential effect of development on trees is a material consideration to be taken into account in dealing with planning applications. Trees are considered as a part of the planning process whether statutorily protected (eg by a tree preservation order or conservation area) or not. The nature and level of detail of information required to enable a local planning authority to properly consider the implications and effects of development proposals varies between stages and in relation to what is proposed. Refer to *BS 5837:2012* Table B.1 for further guidance.

- Adequate replacement measures where the loss of one or more tree(s) cannot be avoided (see *Trees in the Townscape* principle 3 and associated case studies).
- The inclusion of new trees provided with sufficient space and sustainable growing conditions.
- Documentation of the value added by the retention and/or planting of trees through the use of tree valuation methods as well as graphics helping to visualise the canopy cover enhancements.

1.2.6 Ordering trees at the right time

Nursery production lead-times will greatly vary depending on existing available stock, required tree size(s), species, branch structure etc. This will need to be ascertained through early consultation with tree nurseries, preferably UK-based (for bio-security reasons) so that orders can be placed well in advance to meet project programme dates, as illustrated in Case study 2, p31.

See section 4 for further advice on tree selection, specification, storage and handling.

Multiple benefits and enhanced public realm in this retail street in Vancouver, Canada. Image: DeepRoot Green Infrastructure, LLC

1.3
Implementation: joined-up work sequence and site supervision

In brief: what needs to be done	Who does it
Set out in tender documentation the best practice to be followed (*BS 5837:2012*, *BS 8545:2014*, *BS 3998:2010* and Volume 4 of the NJUG Guidelines) and how compensation measures will be calculated and sought in case of breach.	– Tree officer/specialist – Project manager – Procurement officer
Ensure all contractors involved have adequate environmental awareness (ISO 9001 certification) – allow for additional training/briefing on trees when needed.	– Tree officer/specialist – Project manager – Procurement officer
Set out programme of work to correctly order tree works, tree protection and tree planting with other construction activities.	– Project manager
Train the construction site manager on tree protection and installation of load-bearing systems or low-compaction root growing environment.	– Tree officer/specialist – Project manager
Budget and secure regular on-site presence of the tree specialist(s) during implementation.	– Project manager

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).

Tender documentation should set out the best practice to be followed:

- All contractors working in the proximity of existing trees should comply with the relevant recommendations of *BS 5837:2012* and 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.*
- All contractors working near trees should also demonstrate adequate environmental awareness (eg ISO 9001 certification).
- All contractors involved in new tree planting should comply with *BS 8545: 2014*.
- Contractors working directly on trees should follow the relevant recommendation of *BS 3998:2010*[19].
- Contractors conducting specialised installations of load-bearing systems for tree planting (see 3.2) will need access to adequate engineering expertise.

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.

19
British Standard 3998: 2010, Tree Work. Recommendations. London: BSI

1.3.2
Optimising the work programme

Two important considerations require examination when designing a work schedule involving trees:

- *The timing of tree work*. Planting during the dormant season is always preferable. Ideally trees would be planted in the late autumn while there is enough warmth for some tree root development to take place. Root growth generally ceases in the winter. Some species of conifer benefit from being planted in the early spring. If using conifers, advice on the specific requirements of individual conifer species should be sought from the tree specialist. Such attention to detail will minimise maintenance, stress and the likelihood of failure. Where external constraints are such that planting has to take place at other times of the year then care is required in selecting an appropriate nursery production method which minimises the likelihood of root system exposure or damage.
- *The detailed sequencing of tree-related interventions and construction work*. Where works take place around existing trees, all tree protection measures must be in place prior to any demolition or construction is initiated. Where new planting is conducted, significant efficiencies can be realised through better integration of the work sequence between tree-related and other construction work, as demonstrated in the Bristol Bath Road (Case study 8, p37) and Henley Waitrose car park (Case study 9, p38) case studies.

Below: A place for people enhanced by existing and new trees at the Angel Building, Islington, London. See Case study 6, p35. Image: Sarah Blee, J & L Gibbons

1.3.3
On-site presence and supervision

The on-site presence of a tree specialist working closely with the construction site manager can make a big difference to effective implementation. For example:

- It will speed up the resolution of day-to-day issues for both existing trees and new tree planting. See Case study 16, p76 on how Bristol appointed a dedicated tree specialist to a large capital improvement scheme where extensive new planting has been successfully achieved within a tight deadline.
- It will maintain focus on the enforcement of tree protection measures, as illustrated in Case study 6, p35.
- Where/when less familiar techniques are used to provide load-bearing tree-rooting environments (see 3.2 for further details), results will greatly benefit from the construction site manager and the tree specialist having 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, one of the tree-rooting environment enhancement techniques detailed in this guide, are extensively used, training sessions for construction managers are regularly held to continuously improve the delivery of a sustainable integrated infrastructure.
- 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

In brief: what needs to be done	Who does it
Invest in and procure post-planting care as described in Annex G of *BS 8545:2014*.	– Tree officer/specialist – Project manager
Include indicators related to tree growth and health in the KPIs used to monitor the scheme.	– Tree officer/specialist – Project manager
Explore opportunities to share contracts across council departments as well as across councils to help facilitate access to lower unit rates and/or a wider range of tree expertise (eg young tree specialist, veteran tree specialist, soil specialist).	– Tree officer/specialist – Project manager – Procurement officer
Consider the role local communities can play in supporting the maintenance and monitoring activities.	– Tree officer/specialist – Project manager

1.4.1
Post-installation care 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. Recently transplanted trees rely heavily on root ball moisture because this is where most of the roots are initially located. 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. Specialist advice should be sought to help determine the frequency and volume of irrigation requirements.
- 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 street furniture do not damage or compromise the trees, taking remedial action where appropriate.
- Replenishing mulch at the base of the tree to a defined diameter and a depth (between 5 – 10 cm) so that it is measurable for quality audit purposes.
- 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 care of transplanted trees.

Post-planting care is an integral part of the installation process. It needs to be budgeted upfront, and preferably covered through the capital investment sums.

Engaging local communities with some of the post-planting maintenance will help reduce risks of vandalism and enhance survival rates.

Community involvement with newly planted care in Hackney.
Image: London Borough of Hackney

1.4.2
Monitoring and continuous learning

For existing trees, monitoring is vital to the successful implementation of tree protection measures. Regular site visits should take place to confirm that agreed tree protection measures are adequately implemented. Such visits should also confirm the effectiveness of the protective measures that are being implemented by checking the morphological (eg broken branches etc) and physiological conditions (eg signs of water stress) of the trees. Where ground protection measures are in place in the root protection area, compaction test(s) using a penetrometer should be conducted at least prior to work starting and after completion. For longer projects with high risks areas, testing the effectiveness of the anti-compaction measures mid-way through the project, as done for the Angel Building project (see Case study 6, p35), can allow corrective measures to be taken before too much damage is done. With trees having been exposed to extensive site works, extending the monitoring programme past completion of the works is also highly advisable. Such post-construction inspection should be planned for in the arboriculture methodological statement and tree protection plan.

For newly planted trees, a formal assessment of young tree health and development should be carried out annually, as recommended in *BS 8545:2014*, paragraph 11.5.1.

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 effective monitoring. In larger schemes, it might not be feasible to find the time and resources to monitor all trees (whether existing or new), but it is recommended that at least a representative sample is monitored and included in the key performance indicators (KPIs) used for reporting. Such indicators might include tree cover, tree health, as well as some qualitative dimensions, as recommended in LTN1/08 paragraph 4.2.

In some cases, local communities can be involved in the monitoring.

Monitoring can empower the project team through:

- Learning about what works well and what does not.
- Greater 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 regularly to ensure the best procurement route is secured for the services to be delivered. 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 31, p149) 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.

Trees and landscape create a civic place for people at Islington Town Hall, London. Image: Sarah Blee, J & L Gibbons

A place to step back from a busy street at Islington Town Hall, London. Image: Sarah Blee, J & L Gibbons

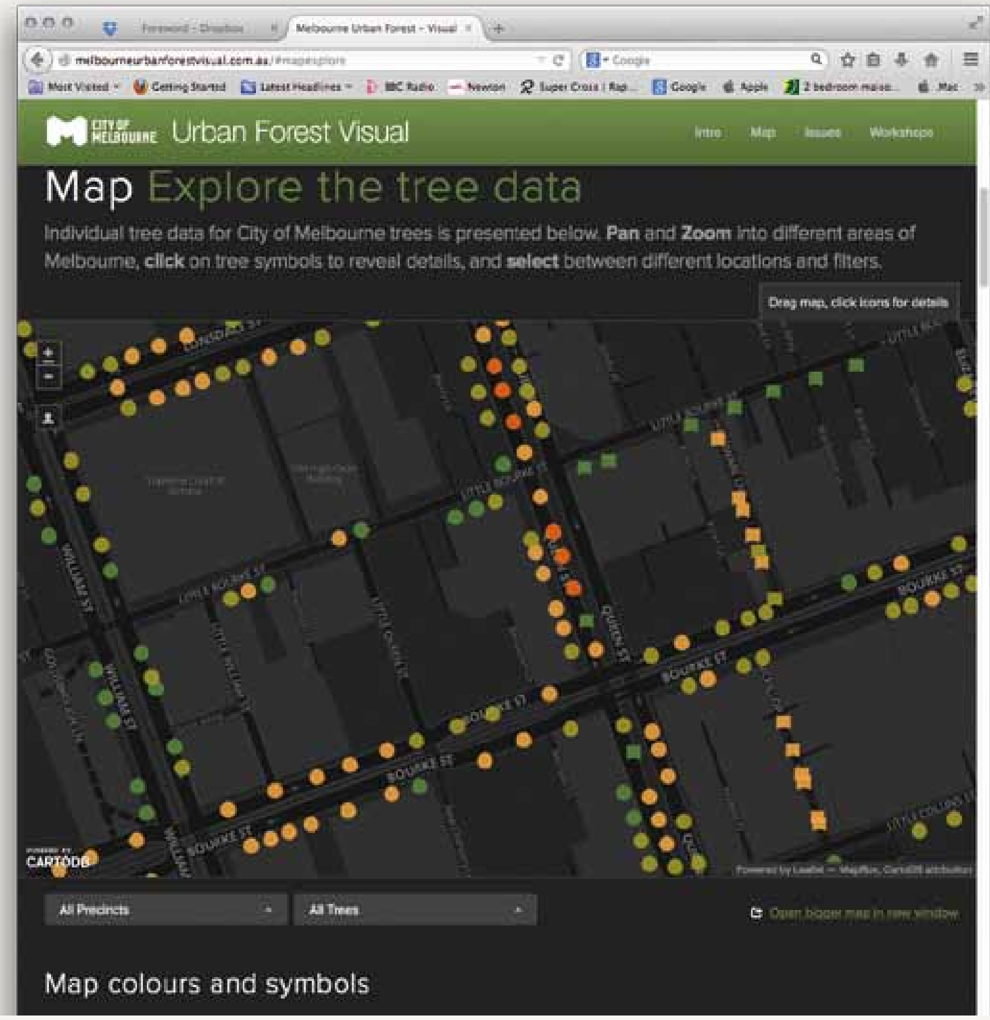
Case study 1
Melbourne's coordinated approach to streetscape projects to double canopy cover

Location
Melbourne, Australia

Project category
Highway

Melbourne is aiming to double its canopy cover from its current 22.5% to 40% by 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 condition to assess the safe useful life expectancy 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 over 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 will require planting trees into carriageways beyond existing kerb lines, where there is 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 called locally – 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.

Delivery of such an ambitious urban forestry programme will 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 landscape 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.



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

Case study 2
Strengthening the visitor and retail economy on South Shield's Ocean Road

Location
South Tyneside, England

Project category
Commercial

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 Ocean Road. This all-purpose urban A-road lined with restaurants, guest accommodation and some shops 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 had been scheduled for a simple refurbishment, became the focal point for enhancing the local distinctiveness of the public realm and the council's leadership team argued that the inclusion of trees would be one of the best ways to achieve this. Working as part of a multi-disciplinary 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 shopfront-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 salt spray. The cultivar chosen ('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 columnar trees maintains good visibility to shopfronts.
Image: South Tyneside Council

Case study 3
New trees at Chobham Manor Phase 1 expected to generate benefits worth over £1m a year

Location
Stratford, England

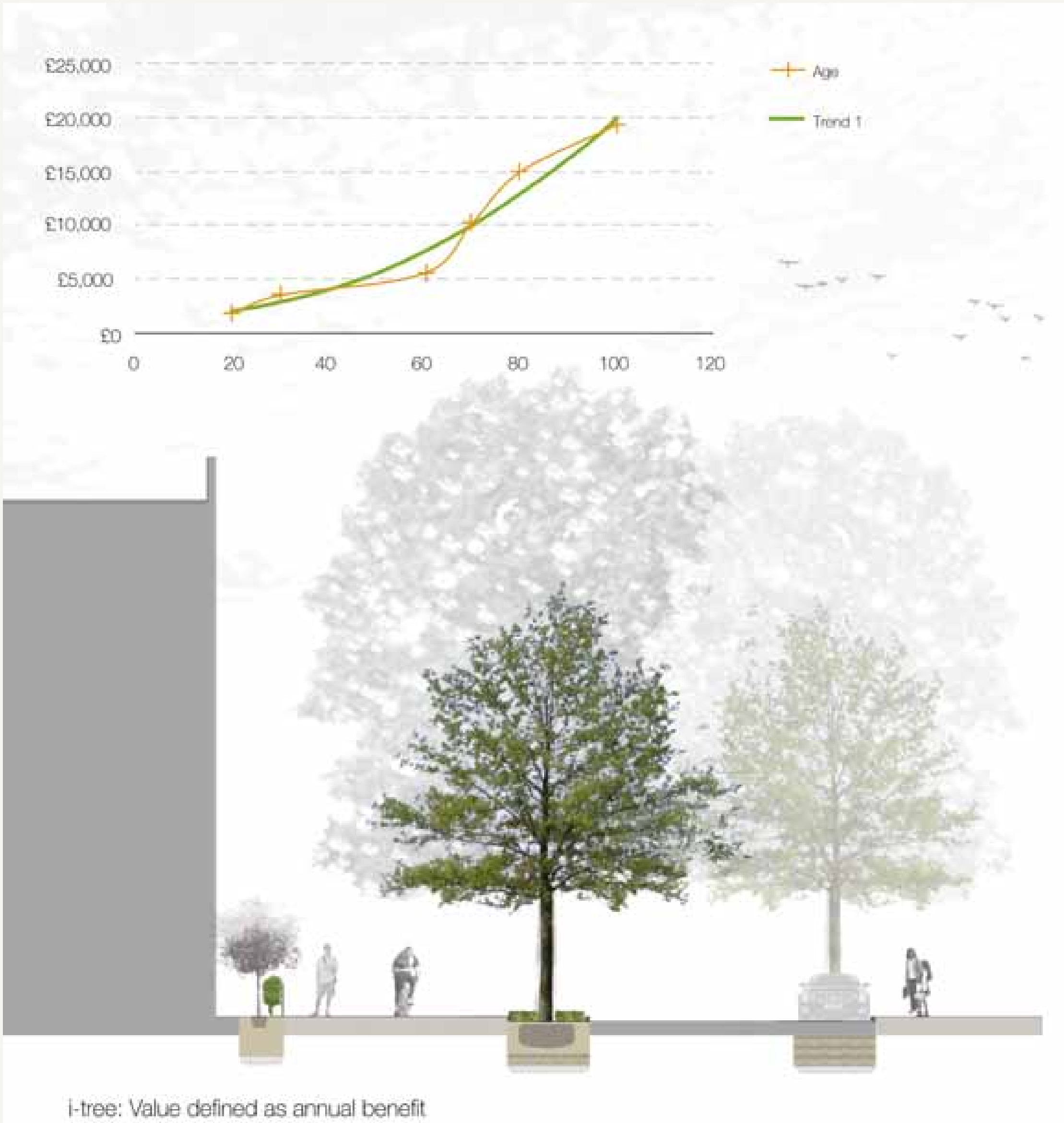
Project category
Residential

Chobham Manor is the first of five neighbourhoods to be created at London's Queen Elizabeth Olympic Park (QEOP). Phase one of the 259-home development was granted planning permission in January 2014. Given the proximity of the proposed development to parkland and iconic facilities such as the Velodrome, the Landscape Strategy and Green Infrastructure Statement supporting the application played an important role in the review process.
At the heart of the phase one submission is an ambitious planting scheme featuring over 150 trees. Pin oaks (*Quercus palustris*) and field maples (*Acer campestre*) are proposed along the new streets, while some English oak (*Quercus robur*) and multi-stemmed trees creating a wildlife-friendly layered landscape are proposed for the three garden squares at the heart of the masterplan.

The Landscape Strategy and Green Infrastructure Statement also pays particular attention to the below-ground conditions. It is proposed that street trees are planted using a crate system providing a good rooting environment below footways, while protecting hard surfaces from damage. This, the strategy argues, will enable large tree species to have a greater chance of reaching their mature size.

An evaluation of the monetary value of some of the environmental benefits to be secured from the planting should all the proposed trees enjoy good growing conditions provides a compelling case for investment in creating good below-ground conditions. Applying the valuation techniques underpinning i-Tree Eco to the proposed design has demonstrated that the yearly value of the carbon sequestration and air pollutants removal benefits 30 years after completion of phase one to be in excess of £1m.

Design proposal supported by annual tree benefits of *Quercus palustris* calculated with i-Tree Eco. Image: J&L Gibbons and Treeconomics



Case study 4
Third North Apartment's developer introduces the Stockholm system to the US

Location
Minneapolis, MN, USA

Project category
Residential

Third North Apartments is a new 204 unit housing development occupying half a city block in the North Loop area of Minneapolis, MN. The developer, Richardson-Schafer, insisted to the city of Minneapolis's Planning and Historic Preservation Commissions that the footways surrounding the development should feature some trees. Principal Kit Richardson of Richardson-Schafer explains: *"Some people on those commissions felt we should not be planting much to maintain the historic industrial look of the area. While the North Loop was a manufacturing district, it had no trees or plants for many years; all of the surfaces were hardscape. This desire to maintain a barren landscape has been quite controversial as many of the old industrial buildings have been converted to condominiums or apartments and people living in the neighbourhood now want trees and plantings."*

Kit Richardson was also keen to integrate street tree planting as part of the development to help with surface water management. As one of the business representatives on the Minneapolis mayor's Tree Advisory Committee, Kit had heard about the Stockholm system. He found strong support from the city's public works department's stormwater management specialist to trial the approach. Minneapolis is one of the pioneering cities in the US to introduce a stormwater management credit system[20] combining regulatory requirements and financial incentives to enhance the quality and reduce the quantity of surface water runoffs entering the public drainage and sewer systems. Adoption of SuDS and innovative green infrastructure solutions to address water management issues has been an explicit local policy objective since 2005.

Two local experiences gave Kit Richardson and the Minneapolis public works department confidence that planting street trees in a large rock-filled trench could yield success. Some of the hardiest forests in the Minneapolis region grow on slag hills left behind by former open pit iron ore mining. Emulating this natural precedent, the University of Minnesota, also represented on the mayor's Tree Advisory Committee, has been successfully experimenting for several years with a new growing medium for tree nurseries using pea gravel beds.

Armed with these local precedents, the design team working for Richardson-Schaffer sought advice from Sweden-based tree specialists on how to adapt the Stockholm system to the conditions found in the Twin Cities which has sandy subsoils, unlike Stockholm (granite bedrock), or Malmo (clay soil) – two cities where Stockholm-style skeleton soil has been extensively used. As water drains very quickly through sand, adjustments were required to enhance the water retention properties of the installation.

The trees planted within the 'Swedish' soil system were Accolade Elm (*Ulmus* 'Morton' Accolade), a type of elm which has been shown to be resistant to Dutch Elm disease. The tree has an historic arching form which adds to the urban streetscape character. The soil installed immediately around the root ball of the tree was a loam mix held in place by a cocoa fiber net that will hold soil moisture during dry spells as there was a concern that the surrounding native sandy soils would drain too freely and leave the tree with not enough water. Over time the fiber net will decompose, but by that time organic matter is anticipated to remain in the top zone and the tree's root system would be further developed.

Integrating trees and water management in this former industrial area.
Image: Urbanworks Architecture LLC

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More details found at: http://www.minneapolismn.gov/publicworks/stormwater/fee/stormwater_fee_stormwater_mngmnt_feecredits

Case study 5
Exemplar partnership for Dortmund Square gains a quality large canopy tree

Location
Leeds,
England

Project category
Commercial

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 street furniture and replace warn paving slabs, which would also 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's Centre, 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 large canopy growing tree would yield greater conflict-free benefits – particularly in terms of amenity value and shading – than a like for like approach to replacement.

To enable the new London plane tree (*Platanus x hispanica*) chosen for the site to reach over 100 feet in height (30 metres) and live well over 100 years, the below-ground design provided 28 cubic metres of non-compacted rooting environment supported by a crate system (Sylva Cell).

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's 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 (1,000 litres every week) was supplemented by St John 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.

Left: The long-term vision for the square.
Right: Summer 2014, second growing season.
Images: Leeds city council

Case study 6
Effective tree protection unlocks planning consent and letting success at the Angel Building

Location
Islington, London, England

Project category
Commercial

The Angel Building, a 250,000sqft office development by Derwent in Clerkenwell, in central London, was completed in 2010. In spite of a poor economic climate, two thirds of the building was let before completion, and full occupancy was reached very soon after opening. For Johanna Gibbons, landscape architect for the project, *"there is no doubt that the environmental quality afforded through the successful retention of mature trees all around the building was a key differentiator for this infill development."*

A tree constraints plan was developed early and became a primary driver for the design. The curved building façade on St John Street was positioned and shaped in response to the location of the root protection area. The strategy was to retain groups of trees, primarily limes (*Tillia spp.*) and Caucasian wingnuts, (*Pterocarya fraxinifolia*), at the corner of the project so as to create a microclimate facilitating building ventilation and energy conservation as well as the establishment of new tree and soft landscape around the scheme.

Spatial constraints were such that the access road for construction had to encroach upon the root protection area and deliveries needed to be conducted on a daily basis. To enable this, the TPP and AMS, developed by appointed tree specialist JCA, in coordination with the project landscape architect and the council tree officer, proposed the use of a porous load-spreading cellular confinement system (Geoweb) braced with timber frames. Waiting areas for delivery trucks were marked, and equipped with oil trays to avoid leakage of any potential pollutants into the ground. The 80-ton crane used for construction was set outside the root protection area, on a temporary concrete raft, which also helped to avoid compaction and contamination of the soils below. The trees to be retained were pruned prior to construction starting to avoid branches being inadvertently clipped by machinery and to help the trees conserve energy. All existing trees were irrigated during the two-year construction period following a sporadic pattern imitating rain. Because irrigation was fed with calcium-rich London tap water, the system was fitted with filters to avoid increasing the soil pH. Once the temporary access road was removed, and prior to final surfacing or landscaping being installed, earthworms were used to aerate the soils and help mix-in imported organic matter, without causing any disruption to tree roots.

Philip Wood, then tree officer for the council, emphasises that *"monitoring, and monitoring of the monitoring"* were critical to the project success. Soil compaction testing using a penetrometer was conducted before works started, mid-way through and after project completion to check that ground protection measures were effective. As Philip explains *"this showed that no significant changes had occurred in soil compaction in the RPA where the council had allowed for incursions to occur – but if deterioration had been detected, this approach would have enabled us to take corrective action"*. Further to this, the TPP required the tree consultant to submit monthly reports with photographs. Council officers had allocated time to review the reports, ask questions when needed, and conduct some site visits. This not only ensured the TPP was thoroughly adhered to, but also allowed for day-to-day issues to find easy (tree friendly) resolutions.

The new London plane trees (*Platanus x hispanica*) planted in front of the building entrance were ordered well in advance and hand-picked from the supplying nursery. To ensure good integration with existing bus traffic on St John Street, the specification required that a five-metre clear stem be achieved at least 18 months prior to planting. Below-ground conditions were optimised by integrating arboricultural advice prior to locating the main utility corridor – so as to retain an adequate rooting area for the new trees.

Retaining existing trees provided continuity and unlocked planning.
Image: Sarah Blee, J & L Gibbons

Case study 7
Wirral Green Streets programme supporting regeneration

Location
Birkenhead, England

Project category
Commercial and Residential

Over the next 20 years, Peel Holding's Wirral Waters regeneration scheme aims to bring to Birkenhead's derelict docklands 420,000 square feet of new office space, some goods handling facilities, and 13,000 new residential units alongside leisure and retail facilities. By April 2015, in advance of the scheme, over 1,200 trees along 10km of streets and green spaces will have been planted within and around the Wirral Water area.

This ambitious scheme is part of The Mersey Forest's Wirral Green Streets programme designed to create green walking and cycling links between residential areas and places of employment or training, as well as public transports hubs, so as to maximise the impact of the Wirral Waters regeneration scheme on both public health and inward investment. Pre-project evaluation showed that 25% of local residents believed that Green Streets would encourage them to cycle to work more regularly, and 15% said that they would walk more. Delivered in partnership with Wirral Council, Peel Holdings and a range of local stakeholders, the project is also intended to ensure that local people in this most deprived area feel a sense of ownership of the work. Funding sources to meet the £1.46m total cost are:

- The Local Sustainable Transport Fund (LSTF) through Merseytravel, part funded by the Department of Transport.
- The Forestry Commission's Setting the Scene for Growth programme supported by the Department of Business, Innovation and Skills (BIS).
- ForestClim, a European Interreg project demonstrating the role of trees in climate change adaptation through cooling, shading and water interception.

For Richard Mawdsley, development manager at Peel Holdings, there is no doubt that the green infrastructure investment underway in Birkenhead 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".*

The funding secured covers not only the planting costs but also the consultation and engagement process with local residents and businesses, as well as post-planting care for the first five years. Applying environmental economic evaluation techniques accounting for the anticipated impact of trees on local physical activity, labour productivity, property value, etc, The Mersey Forest has estimated that the 400 trees planted in the first year of the programme could have a gross value added (GVA) benefit to the local economy of £2m.

Top images: Before and after implementation of the Green Streets programme, Birkenhead.
Before image: McCoy Wynne
After image: The Mersey Forest

Bottom left: Liquidambar add seasonal colour to Beckwith Street.
Image: Griff Evans, Ombler Iwanowski Architects

Bottom right: Trees lining Hoylake Street.
Image: The Mersey Forest

Case study 8
Bath Road's integrated delivery co-ordinating tree planting and road improvements

Location
Bristol, England

Project category
Highway

When elm trees (*Ulmus* 'New Horizon') were planted in a newly built central reservation on the Bath Road/A4 corridor, Bristol's highway 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 come 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: City Design Group, Bristol City Council

Case study 9
Joint working with Waitrose to retrofit trees in public car park

Location
Henley-on-Thames, England

Project category
Commercial

When the time came to refurbish a council-owned car park adjacent to a large Waitrose store and extensively used by its customers, South Oxfordshire Council and the retailer decided to work together. The public car park 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 aucuparia.*), 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 its 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 (*Plantanus x hispanica*) and a load-bearing crate system (Sylva Cell) 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 to be 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.

Replacement tree, two years after planting. Image: Steve Parker

Case study 10
Research and development in the Greater Lyon Authority

Location
Lyon,
France

Project category
Highway

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 integrated green-grey-blue infrastructure solutions which are only being rediscovered today. This prompted the Greater Lyon Authority's (GLA) arboriculture team to take action to ensure project delivery would also help retain and build upon existing knowledge. As a result, inclusion of an element of research and development (R&D) in each major highway project is one of the key commitments written in the tree charter agreed by the 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 17, p77) explores the last two themes.

As part of the Garibaldi Street refurbishment, an old underpass that had allowed cars to avoid ground level intersections has been converted to a rainwater collection cistern. Water from the cistern is used for, among other things, the irrigation of the new planting areas. Existing and newly planted trees feature prominently in the new streetscape created. Beyond the first three growing seasons, irrigation of newly planted trees 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. Sensors installed within and around the newly planted trees and vegetation strips, as well as around existing trees, will quantify the cooling effect of vegetation at different stages of maturity and under different irrigation regimes. Sensors have also been installed further down the street, where the refurbishment is to be completed in later phases, to provide control data. The cost of the monitoring equipment installed is 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 p60

Quick Check

Are all key parties engaged in the collaboration required for success?

Design champion/Client representative(s)

Have you...

- ○ Got clear policies for the protection, care and planting of trees and are committed to their enforcement?
- ○ Communicated to the team the importance of the inclusion of environmental improvements, especially trees, for your vision of the project?
- ○ Ensured the project brief, the team composition and the budget allocations will effectively support this vision?
- ○ Before signing off design, checked that a consensus has been reached among the team on a detailed solution for successful integration?

Local authority planner

Have you...

- ○ Sought expert guidance (from both a tree specialist and relevant references, such as *Trees in the Townscape*) to draft/update tree policy?
- ○ Communicated tree protection, planting and care policies as well as associated site-specific requirements right from pre-planning meetings?
- ○ Put conditions in planning approval to require survey proof confirming that the planting scheme is deliverable?
- ○ Ensured effective enforcement of tree-related requirements?

Project manager

Have you...

- ○ Ensured the vision for the contribution trees make to the project objectives is well articulated as well as the value of using i-Tree Eco during consultation with members, other decision-makers and the wider public for project sign-off – making use of tree valuation and visualisation techniques, as appropriate?
- ○ Ensured the right tree specialists and soil scientist have been commissioned?
- ○ Facilitated a collaborative approach to funding tree-related enhancements, exploring all potential sources as described in this guide?
- ○ Budgeted five-year aftercare for newly planted trees as part of the capital investment programme?
- ○ Explored advanced procurement with the design specialist(s) (in this case the landscape architect) to secure precisely the right tree species and specification?
- ○ Ensured the team composition includes the right tree expertise – this might mean a short-term dedicated post for larger projects?
- ○ Conducted the right underground surveys at the right time: initial survey from site visit and utility asset database at project initiation, and delivery accuracy survey at the beginning of the design phase?
- ○ Ensured all necessary negotiations with statutory authorities have been carried out?

- ○ Invited the tree specialist to schedule training/briefing sessions on critical tree issues (eg tree protection, installation of load-bearing system tree-rooting environment)?
- ○ Ensured a landscape management and maintenance plan has been commissioned?

Design specialist(s)

Have you...

- ○ Articulated clearly in the brief the overall relevance and specific role(s) of trees to help achieve the project objectives?
- ○ Engaged with the local community to stimulate enthusiasm for the project?
- ○ Engaged with the tree officer to ensure the scheme meets strategic and local ambitions?
- ○ Adequately integrated trees in the site assessment process and given diligent attention to below-ground conditions (ie utilities, existing soils)?
- ○ Negotiated with the statutory authorities on location of trees in relation to services and any specific rooting zone detail requirements related to easements?
- ○ Coordinated the entire below-ground infrastructure in association with the highway or civil engineer?
- ○ When working with existing trees, anticipated the implications (work staging, preventative tree care) to ensure effective tree protection through and sustained tree health through the construction process?
- ○ Secured cross-disciplinary input on the integration of trees in the design including lighting, CCTV, access, biodiversity, water harvesting and drainage, arboriculture and maintenance?
- ○ Made the most of valuation and visualisation techniques to communicate the impact of trees in the proposed design?
- ○ Ensured that the tree specification reflects functional, aesthetic and programme requirements?
- ○ Advised the client of the opportunities for advanced procurement?

Tree officer/specialist

Have you...

- ○ Actively contributed to tree and green infrastructure policy development upstream of individual projects?
- ○ Helped the design specialist(s) articulate the relevance of trees to the project objectives?
- ○ Provided the design specialist(s) with the policy wording and tree-related requirements to be included in the project brief and tender documentation?
- ○ Obtained a *BS 5837:2012*-compliant survey of existing trees supporting a tree constraints plan and made this available to the design team at project brief/pre-application stage?

- Agreed with a design specialist a satisfactory tree protection plan and arboricultural method statement at design stage?
- Organised training/briefings for highways and civil engineering colleagues on rooting environment design and load bearing as well as on tree protection measures?
- Liaised with nurseries and informed the design specialist(s) and project manager of availability, production lead times and best time for tree works in the implementation schedule?
- Made tree specialist expertise available on-site during construction of major and (tree) sensitive schemes?
- Arranged an effective set up to actively enforce tree protection measures and contractual requirements associated with tree works and works around trees?
- Regularly reviewed opportunities to improve contractual arrangements (eg sharing of framework contracts across department or across councils)?

Highway engineer

Have you...

- Checked and agreed the project objectives?
- Ensured the public realm and highways quality audit methodology factors trees?
- Used both the advice provided in this guide (section 3) and input from a tree specialist on the tree-related criteria for highway adoption used in your local authority in particular relating to rooting zones and structural soils?
- Established a good communication process on planned highway works, to ensure opportunities for tree-related enhancements or retrofit can be planned accordingly?
- Confirmed to the design lead and project manager whether the proposal is on adopted public highway?
- Coordinated with the tree officer on project objectives?
- Provided the design lead with any local knowledge or particular, site specific, criteria for street tree planting?
- Sought to include the tree planting as part of the capital and revenue costs?

Drainage engineer

Have you...

- At conceptual and outline drainage design stages, liaised with the lead designer and the tree specialist on provision of water to trees and the potential contribution trees can make to water management?
- Factored the presence and role of trees in the detailed drainage design?
- Factored prevailing soil conditions in relation to attenuation and the conveyance of surface water?

References

Non-technical publications and resources

Professional publications and resources

Academic 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.

Designing with Trees

Designing with Trees
Using trees as positive assets

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

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.

Fully realising all or any of these benefits requires a concerted approach that both exploits enabling factors and devises solutions to potential conflicts.

Aims

Focused on project objectives and the above-ground design choices available to achieve success, this section aims to ensure:

- The inclusion and/or retention of trees fully supports the identity, place-making and any movement objectives for the project.
- The inclusion and/or retention of trees also enhances local climate resilience, public health and wildlife.
- Risks of conflicts arising from interruption to visibility splays are prevented or managed.

Requirements

The main project requirements described in this section are:

- Conceptual and outline design (above ground).
- Detailed design (above ground).
- Surface water drainage concept proposal.
- Landscape management proposals.

Wider Benefits

The wider benefits to be gained are:

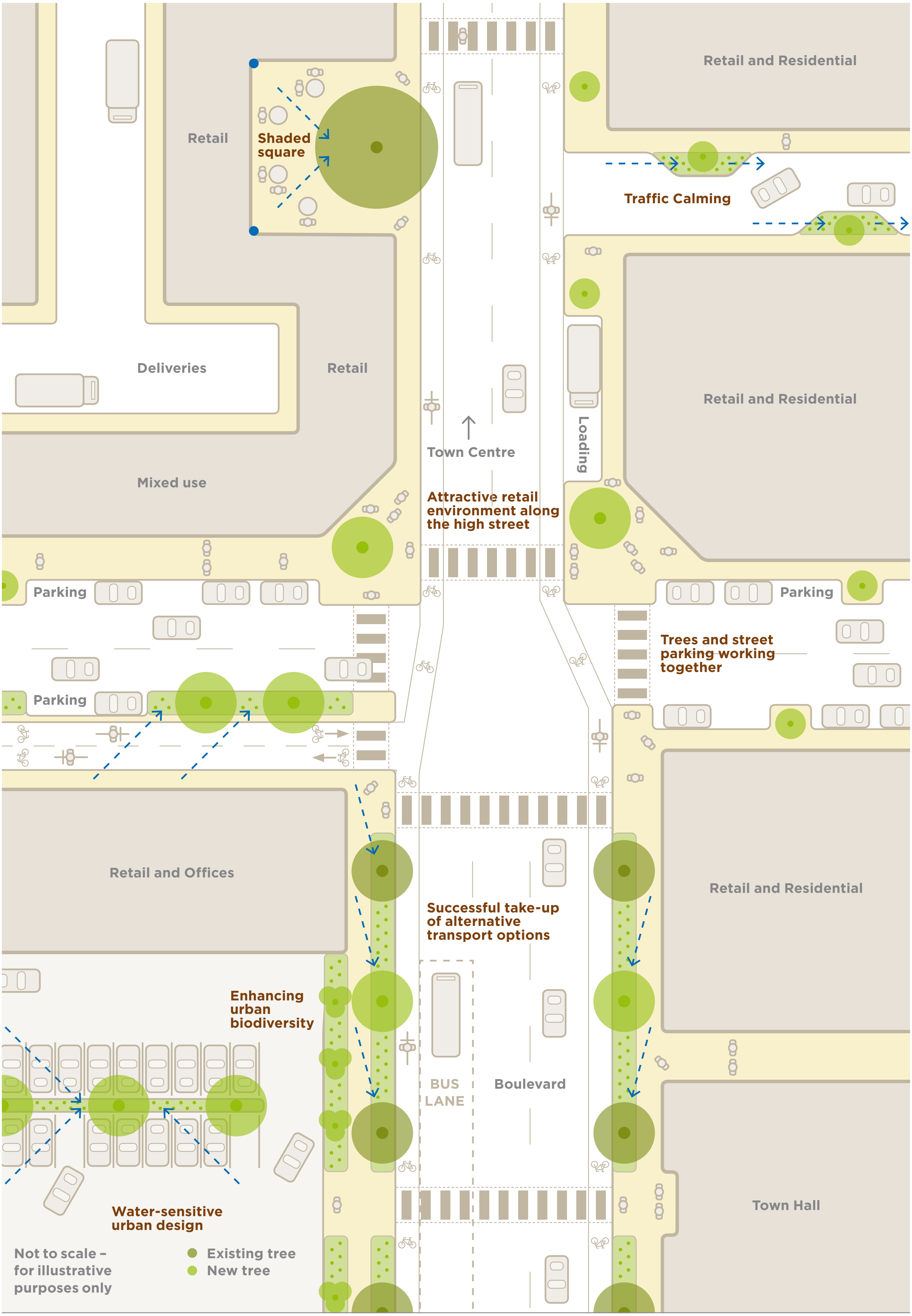
- High performing and liveable places.
- Good community and end-user buy-in.
- Resilient urban forest.

Designing with trees for multiple benefits

In the diagram opposite, much enhanced high street patronage has been achieved. The vacant site has been successfully redeveloped with sustainable urban drainage and trees along with an improved access road for all users. What were the below ground environment implications for achieving this? See Section 3.

● **Downpipe directing roof runoff to tree-rooting environment**

-> **Surface water runoff directed to tree-rooting environment**



Retail and Residential
Retail
Shaded square
Traffic Calming
Deliveries
Retail
Retail and Residential
Town Centre
Loading
Mixed use
Attractive retail environment along the high street
Parking
Parking
Trees and street parking working together
Parking
Retail and Offices
Retail and Residential
Successful take-up of alternative transport options
Enhancing urban biodiversity
BUS LANE
Boulevard
Water-sensitive urban design
Town Hall
Not to scale – for illustrative purposes only
Existing tree
New tree

2.1
Effective use of space and sense of place

In brief: what needs to be done	Who does it
Examine the potential for reallocating carriageway or car parking space to accommodate new or improve conditions for existing trees.	– Design specialist(s) – Highway engineer – Tree officer/specialist
Use existing trees as assets for the proposed design.	– Design specialist(s)
With new planting, explore several options for tree arrangements, spacing, species diversity.	– Design specialist(s)
With new planting exploit all available strategies to achieve impact (where required), year-round effect and address age-balance.	– Design specialist(s) – Tree officer/specialist
Ensure consideration of large species trees for long-term impact and benefits.	– Design specialist(s) – Tree officer/specialist – Highway engineer

2.1.1
Making space for trees: a shared responsibility

Principle 4 of *Trees in the Townscape: A Guide for Decision Makers*[21] advocates creating places where trees can thrive and deliver their full range of benefits without causing harmful nuisance. 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 that the design of the surrounding infrastructure allows for trees – whether existing or new – to thrive. The guide argues that the latter ought to be considered first where possible because it largely predetermines the very possibility of having and retaining trees in the urban landscape.

With an agreed objective to include trees but competing demands for space, design teams sometimes adopt one or both of the following flawed strategies:

- Give priority to replacement planting, without carefully exploring opportunities for retention. When planted in the right conditions, most trees have a longer lifespan than most of the hard infrastructure that surrounds them. Town centres are typically refurbished every 15 to 20 years while large canopy trees in hard landscapes have the potential to live 100 to 150 years (see 3.1.2). Replacing trees at the same rate as the surrounding infrastructure results in a situation where urban trees never mature. Most environmental benefits associated with trees in hard landscapes are only accrued once the trees reach their mature state. Systematic loss of maturing trees, even when accompanied with replacement planting, therefore does not make up for the associated loss. From an asset management perspective, this is like a financial investor who constantly withdraws invested sums prior to the minimum period required for dividend payments to start.
- Resort to planting trees in above- or below-ground containers with insufficient growing space for longevity. This often yields high financial and environmental costs for relatively little 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 section 1 of this guide and 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 11, p71), finding space for planting new or retaining existing 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 –

21
The Trees and Design Action Group (2012), *Trees in the Townscape, A Guide for Decision Makers*. London: TDAG, pp30-33

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 trees to the context is explained in Principle 5 of *Trees in the Townscape*. The starting point of any site analysis for choosing tree species should be the key constraints determining whether the trees can survive (eg how much light is there? How much water? What is the soil pH? What is the level of exposure to pollutants and salt?). Other constraints to ensure good compatibility between trees and the surrounding infrastructure (eg are there shrinkable subsoils?) should come next, before any aesthetic considerations.

A decision-making framework for tree species selection detailing the criteria to consider and prioritise is provided in section 4.

2.1.3 Quality of place and local distinctiveness

> *"Of all the natural aids to townscape the tree is surely the most ubiquitous (...). For just as trees have different characteristics, fastigiate or drooping, geometric or fluffy, polished or velvet, so these qualities may be used in dramatic conjunction with buildings, either to extend the conception or to offset it as a foil."*
>
> Gordon Cullen[22]

Trees have an architectural and place-making role as well as being natural features. Tree planting or retention 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, local distinctiveness and overall quality of a place requires particular attention to:

- *The final canopy size of the tree(s)*: 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 impact in the townscape. A positive design aspiration is to aim for the inclusion of larger trees. The density and characteristics of the urban form will affect opportunities and decisions: suburban contexts can offer ample scope for extensive planting of large growing trees. In tighter locations, the inclusion of large-canopy growing trees might still be possible by planting a smaller number. Correct use of tree specifications (see 4.5) can ensure enhanced compatibility between buildings or high-vehicles and large growing trees from the outset.
- *Arrangement of planting*: the possibilities are endless and will depend on the particular site and the design objectives. Planting formation choices should reflect the local setting: a linear arrangement will support a strong urban frontage while individual accent planting might be more suited to market town settings and public squares. Where widths allow, double rows of planting are possible. The historic context should be an important consideration.
- *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.
- The shape, colour, texture and seasonal variation(s) of the tree(s): this will have a strong impact on the amenity value of the tree(s). However, aesthetic considerations should not override other important criteria for long-term success when selecting tree species (see section 4).

22
Cullen, G (1961), *The Concise Townscape*. Oxford: The Architecture Press

Top and bottom 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)

Above: Halving tree numbers retains townscape impact while improving light for residents, Saône Embankment, Lyon. 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

BS 3936-1:1992[23] Nursery stock specification for trees and shrubs		Barcham Trees' guidance on approximate tree height when planted
Standardised classification	Corresponding tree girth size measured at a height of 1m	
Light Standard (LS)	6-8cm	
Standard (S)	8-10cm	7-9ft (2.1-2.7m)
Select Standard (SS)	10-12cm	9-11ft (2.7-3.3m)
Heavy Standard (HS)	12-14cm	11-13ft (3.3m-4.0m)
Extra Heavy Standard (EHS)	14-16cm	13-15ft (4.0m-4.6m)
Advanced Heavy Standard (AHS)	16-18cm	15-17ft (4.6m-5.2m)
Semi-mature	18-20cm+	17-19ft (5.2m-5.8m)

23 *British standard 3936 – part 1:1992, Nursery stock. Specification for trees and shrubs.* London: BSI

yield good results. In urban settings such an approach might be suitable 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 illustrated on p50). This planting strategy is unlikely to be suitable for trees in hard landscapes where competition for space is fierce, where high investment in providing good quality rooting environment or load bearing is needed, and/or where progressive felling of young trees to achieve adequate mature spacing is impractical and likely to generate a public outcry.
- Exclusively planting larger diameter or semi-mature trees. Older, semi-mature trees (as described in the table on page 50 on tree sizes) are less adaptive than their younger, smaller counterparts. Not all sites will have sufficient available space to accommodate the planting hole required for the (large) root ball of a semi-mature tree. Achieving success when planting semi-mature specimen also requires a higher quality of tree stock sourced from specialised suppliers, careful specification limiting the number of times the tree(s) purchased will have previously been transplanted, scheduling the planting early in the winter dormant season, and good post-planting care. This needs to be reflected in the budget and procurement process.

Alternative strategies to secure instant impact include:
- 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 20, p124).
- Considering the use of multi-stem trees (if compatible with the design intent) as these could be planted alongside smaller diameter trees until the latter have grown sufficiently.
- Combining species that have different growth rates, as pictured below in the former Sathonay military. In this 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.

2.1.5
Tree strategies for year-round impact

Trees, whether deciduous or evergreen, have a year-round visual impact. Deciduous trees also provide seasonal variation and even in winter the branch forms can provide visual interest.

Increasing species diversity not only

Summer and winter views with combined species at Sathonay, near Lyon.
Images: Anne Jaluzot (winter) and Frédéric Ségur (summer)

supports better resistance to pests and diseases and improves resilience to climate change, it also helps enhance the range of visual impacts trees might have throughout the year. Consider:

- Incorporating flowering trees and/or trees with striking autumnal colour displays, mixing species with different or concomitant timing for such seasonal changes.
- Mixing in species that shed their leaves early or late in the season. As pictured below in the new neighbourhood being developed in the former Sathonay military base near Lyon, France, in the middle of January oaks (*Quercus spp.*) still carry their dry leaves, making a pleasant contribution to what would otherwise be a barren new street.
- 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.

Reflecting the seasons with a variety of trees in Cambridge. Image: Michael Murray

2.2
Safe movement for all

In brief: what needs to be done	Who does it
Plant new street trees outside the dynamic kinetic envelope, making adequate specification for clear stem height and/or pruning programme as trees grow.	– Design specialist(s) – Highway engineer – Tree officer/specialist
Seek to retain existing trees, taking a flexible, accommodating approach to pavement and kerb design.	– Design specialist(s)
Use trees for traffic calming: highlighting intersections, reducing physical and optical width.	– Design specialist(s) – Highway engineer
Use trees to enhance the cycling environment – providing aesthetic, traffic calming, physical separation and cycle parking	– Design specialist(s) – Highway engineer
Use trees to enhance the walking environment – greening islands for easier crossing, attractive footways with adequate clearance and access creating green links.	– Design specialist(s) – Highway engineer

"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)[24] 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"*[25].

Whether in the *Manual for Streets* (MfS)[26] and *Manual for Streets 2* (MfS2)[27] in England and Wales or *Designing Streets* in Scotland[28], 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.

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.

Below: Planting placed in carriageway to support its alternative transport strategy, Rue de La Part-Dieu, Lyon.
Image: Frédéric Ségur (bottom left), Sophie Barthelet (bottom right)

24
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

25
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

26
Department for Transport (2007), *Manual for Streets*. London: Department for Transport. Found at: www.gov.uk/government/publications/manual-for-streets

27
Full references provided in note 25 above

28
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

2.2.1
Are trees allowed on the highway?

There is a compelling case for trees on the highway, but what does the legislation say? 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 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)[29].

2.2.2
Urban road safety

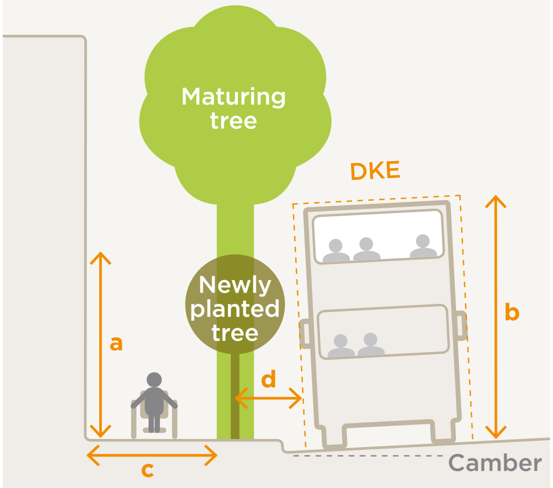
The inclusion or retention of trees in central reservations or on footways sometimes gives rise to safety concerns. Comparative analysis of crash data in the United States shows a difference between urban and rural settings. Within built-up areas, the presence of trees is not associated with an increase 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[30].

Looking at the fatality statistics in the table below, there are a total of 435 fatalities of which 302 are identified as 'none'. In this case 'none' refers to collisions between pedestrians, cyclists etc and moving traffic. If we take this figure out and focus on the remaining 133 fatal one-vehicle collisions, trees represent about 20% of the actual off-road object's struck and lamp posts 17%.[31]

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 maximum lateral overhang (ie mirrors) and the carriageway camber. As shown in the diagram above, newly planted trees should be positioned and specified (eg clear stem height at time of planting[32]) and/or managed (eg progressive crown lifting) so as not to encroach upon the DKE.

On shady or windy streets, additional allowances might be required. Exposed trees can lean due to prevailing wind;

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)

One-vehicle accidents in 2012 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	435	6,820	25,269	32,524

29
Legislation is subject to change. For full details and most recent editions, the respective acts of parliament can be found at: www.legislation.gov.uk

30
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

31
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

32
To achieve a five-metre clear stem at time of planting, semi-mature trees will need to be used, which require greater amount of space and care (see 2.1.4)

33
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

34
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

35
Found at: www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/footway2/footways209.cfm

36
Found at: http://ciht.org.uk/en/media-centre/news.cfm/free-to-download-from-ciht-traffic-calming-guidelines-

37
Foltête, JC and Piombini, A (2007), *Urban layout, landscape features and pedestrian usage*. Landscape and Urban Planning 81, 225-234

38
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

39
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

40
Lee, C (2007), *Environment and active living: The roles of health risk and economic factors*. American Journal of Health Promotion 21(4), 293-304

41
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

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 might be hazards to passing high-sided vehicles.

In parking areas, trees need to be planted so that drivers will not accidentally damage them while manoeuvring.

In terms of reducing risks, urban trees can directly and indirectly help create settings which lead people to take more account of potential dangers as they move through a street. One study found a 46% decrease in crash rates across urban arterial sites after landscape improvements were installed[33]. Another study found that placing trees and planters in urban arterial roadsides reduced mid-block crashes by 5% to 20%[34].

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
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 to better gauge their speed.

The use of vegetation, particularly trees, is featured as one of the three main types of approaches to traffic calming in the US Department of Transportation Federal Highway Authority's Design Guide[35]. The guide observes that *"trees, when located on both sides of the street, create a sense of enclosure that discourages drivers from speeding"*. Tim Pharoah's 1991 Devon county council Traffic Calming Guidelines[36] conveys a similar message. 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
Encouraging walking and cycling

The quality of the outdoor environment, including the presence of street trees, can increase levels of physical activity, such as walking and cycling (Foltête et al 2007[37]; Forsyth et al, 2008[38]; Larsen et al, 2009[39]; Lee, 2007[40]).

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"*[41].

Alongside the Hackney example on p56 (and see Case studies 14, p74 and 15, p75), 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 Green Streets programme (see Case study 7, p36) in Birkenhead and the refurbishment of Cheapside (see Case study 30, p148) 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 3.3). Strategies to deal with existing trees causing surface disruption are covered in 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 pedestrian- and cycle-friendly hard landscapes. Species and cultivars that are prone to develop basal trunk suckers are best avoided in narrow footways as they can cause obstructions (pedestrians, sight lines for vehicles) 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 the likelihood of obstruction issues caused by overhanging branches (see 2.4.1).

Concerns might also arise in relation to trees and physical access. Footways that work for those who have impaired vision or mobility are better for all users, although clear routes are more critical for those with impairments[42].

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.

42
Department for Transport (2005), Inclusive Mobility. London: Department for Transport

Shared space allowing movement for all at Leonard Circus, Hackney. Image: London Borough of Hackney

2.3
Unobstructed splays and light

In brief: what needs to be done	Who does it
Take a context-sensitive approach to occasional minor obstructions trees may create at traffic junctions.	– Design specialist(s) – Highway engineer
Use trees to enhance the retail environment, whether in high streets or malls.	– Design specialist(s)
Work with local shop keepers on the positioning of new trees in retail settings, using visits to demonstration sites.	– Design specialist(s) – Tree officer/specialist
Take an integrated approach to the design of trees, lighting and CCTV – bearing in mind that trees have greater potential longevity.	– Design specialist(s) – Lighting engineer – CCTV manager – Tree officer/specialist

2.3.1
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[43].

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[44].
- 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[45].

2.3.2
Commercial signs and shop window visibility

Studies conducted in the US[46] have established that the presence of trees in retail areas positively affects both shoppers' perception and behaviour (in the form of increased dwell time and increased product pricing). 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 (see Case studies 2, p31 and 16, p76).
- Making adequate provision for formative pruning and crown lifting: in a high street, formative pruning to achieve four metres of clear stems over time is advisable in order to achieve good visibility of signs. If four metre clearance is required from the outset, this will require planting a larger girth tree prepared in advance by the supplying nursery and a larger planting whole. Funding for capital and/

43
Designing Streets, p35

44
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

45
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

46
See: Wolf, KL (2014), City Trees and Consumer Response in Retail Business Districts (pp. 152-172). In: Musso, F and Druica, E (eds) *Handbook of Research on Retailer-Consumer Relationship Development*. Hershey, PA: IGI Global. See also the articles on trees and consumer environment found at: www.naturewithin.info/consumer.html

or maintenance and available planting space will determine which approach is best.

2.3.3 Daylight, lighting and CCTV

The adverse impact trees can have when overshadowing nearby buildings is often raised during planning applications when tree planting requirements are raised. This challenge can be addressed through good design and species selection. Location and choice of trees must be based on a sound understanding of the future canopy size, growth habits (eg trees with a lateral spreading canopy form such as English oak (*Quercus robur*) 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 fact that constraints in man-made environments, such as cities, are largely self-imposed. Relocating a lamp column might be worth considering.

Good coordination is also paramount for ensuring good compatibility between CCTV and urban trees. Effective strategies for this start very early in the design process: the Department for Communities and Local Government[47] as well as the Home Office and the Design Council[48] have all emphasised 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[49].

Where CCTV is used, research has shown that CCTV managers and tree specialists or tree officers rarely design together – a situation that both professions agree needs to change[50]:

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

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

47
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

48
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

49
Kuo, FE and Sullivan, WC (2001), *Environment and Crime in the inner city: Does vegetation reduce crime?* Environment and Behaviour, 33(3), 343-367

50
Body, S (2012), *Investigation into the interactions between Closed Circuit Television and urban forest vegetation in Wales.* In: Johnston, M and Percival, G (eds.) Trees, People and the Built Environment. Forestry Commission Research Report. Forestry Commission: Edinburgh. Found at: http://www.forestry.gov.uk/forestry/INFD-8BVE4R

2.4
Water-sensitive design

In brief: what needs to be done	Who does it
Ensure the design allows for some precipitation to reach the tree-rooting environment.	– Design specialist(s) – Drainage engineer
Take full advantage of the capacity of the tree and its rooting environment to help manage stormwater runoff.	– Design specialist(s) – Drainage engineer
Explicitly integrate trees in the surface water drainage plan and strategy for the site in accordance with SuDS best-practice.	– Design specialist(s) – Drainage engineer

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 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. Adopting WSUD principles when working with trees in hard landscape might translate into:
- Designing the surface opening and tree-rooting environment to ensure adequate water supply to the tree from surface water runoff (see Case study 20, p124 and p26, p129).
- Preserving existing large canopy trees to assist with the reduction of volume and rate of surface water runoff entering the drainage system. See Case study 28, p131.
- Designing the tree-rooting environment to assist with the reduction of volume and rate of surface water runoff entering the drainage system. See Case study 4, p33.
- Designing the tree-rooting environment to assist with removal of pollutants from surface water runoffs. See Case study 4, p33 and 27, p130.

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. This should be reflected in drainage proposals. Quantifying this impact has been the focus of significant research work in the past ten years. A summary is provided below.

Trees can also be a source of damage to water-carrying infrastructure (eg root ingress into water pipes) or to structures in areas of clay and silt subsoil that expand and shrink under moisture variation. Solutions to prevent and/or address these issues are provided in 3.3.4, 3.4.2 and 3.4.3.

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[51] 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

51
Herrera Environmental Consultants (February 2008), *The Effects of Trees on Stormwater Runoff*. Seattle: City of Seattle Public Utilities. Found at: www.psparchives.com/publications/our_work/stormwater/lid/clearing_grading/Effect of Treeson Stormwater LitReview-Herrera.pdf

52
Metro (2002), *Trees for green streets: an illustrated guide*. Portland, OR: Metro. Found at: www.oregonmetro.gov/index.cfm/go/by.web/id=26337

53
See for example the Recarga Model. Found at: http://dnr.wi.gov/topic/stormwater/standards/recarga.html

54
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

55
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

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[52]. This is now being factored into models used to design SuDS components[53].

Infiltration

Tree root growth and decomposition 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. 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 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 laboratory and field studies of bioretention pollutant removal have concluded that bioretention systems are highly effective at pollutant removal[54]. High concentration and load reductions are consistently found for suspended solids, metals, polycyclic aromatic hydrocarbons (PAH), and other organic compounds[55]. 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 3.5.

Top: Phase one of Garibaldi Street refurbishment nearing completion in January 2014. See Case studies 10, p39 and 17, p77.
Middle: 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

2.5
Safety, health and comfort for people and wildlife

In brief: what needs to be done	Who does it
Audit and mange trees as recommended by the National Tree Safety Group's Common Sense to Tree Management.	– Tree officer/specialist
Avoid creating concentrations of allergenic tree species.	– Design specialist(s) – Tree officer/specialist
Consider the positive and negative impacts trees can have on air quality.	– Design/ Project leader
Use trees for cooling and sheltering buildings and public spaces from dominant and turbulent wind.	– Design specialist(s)
Use tree species and designs that foster urban biodiversity.	– Design specialist(s) – Biodiversity officer/specialist

2.5.1
Public safety

Trees that have become infected by a pest or a disease or lost their structural integrity due to harsh weather events, collisions or other sources of damage (eg poorly conducted excavations) might, over time, drop branches or fall down completely and create safety hazards. However, as the statistics compiled by the National Tree Safety Group[56] in the table below show, such risks are low.

Risks associated with tree safety are best managed through:

- Enforcing the adoption of best practice for works in proximity to existing trees (eg *BS 5837:2012* and *NJUG guidelines volume 4*).
- Avoiding planting in high use areas those species that are known to have a propensity for premature whole-tree or limb failure, or for rapid deterioration of condition when damaged or infected.
- 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, requiring 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 pests or diseases will be detected (see 4.4).
- 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 trees showing structural faults as well as diseased trees, ensuring infected cuttings are adequately discarded.
- Following the guidance issued by the National Tree Safety Group on *Common Sense Risk Management of Trees*[58].

2.5.2
Public health

A large body of academic research demonstrates[59] 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 quality), alleviating chronic stress, encouraging physical activity and protecting people from

Trees and public safety[57]		
Annual risks of death		**Basis of risk and source**
Cancer	1 in 387	England and Wales 1999
All forms of road accidents	1 in 16,800	UK 1999
Trees	1 in 10,000,000	UK 1999-2009
Number of non-fatal injuries (average number of A&E cases per year)		
Leisure-related injuries	2.9 million	UK 1999-2009
Tree-related injuries	55	UK 1999-2009

56
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

57
The data was sourced from Watt, J and Ball, DJ (2009), *Trees and the Risk of Harm. Report for the National Tree Safety Group*. Hendon: Middlesex University. Found at: http://www.forestry.gov.uk/pdf/NTSG-Report-1_Trees-and-the-Risk-of-Harm.pdf/$FILE/NTSG-Report-1_Trees-and-the-Risk-of-Harm.pdf

58
See note 56

59
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/

harmful UV. The positive impact trees can have on public health and the overall comfort and liveability of towns and cities has 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 (OPM – *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[60].

2.5.3 Air quality

Nitrogen dioxide, ozone, and microscopic particulate matter are the three air pollutants of principal concern in the urban environment in the UK[61] due to their measurable chronic and acute health effects[62]. Carbon dioxide is not normally considered an air pollutant in the same sense. In other countries, especially those with significant coal burning for domestic heating and/or electricity generation, sulphur dioxide is also a pollutant of concern in urban areas.

All of these air pollutants land on surfaces, including the surfaces of trees. Because trees present a large surface area to the air and can take up gaseous pollutants via their gas-exchange apparatus, trees have the potential to mitigate urban air pollution. The cooling effect of trees can also limit ground-level ozone formation.

However, the impact of trees on urban air quality is not always positive. Trees can contribute to ozone pollution by releasing volatile organic compounds[63]. This negative effect is only associated with some species and is felt downwind of the trees, rather than where the trees are located.

Where mitigation of localised air pollution is an important objective, care is therefore required in the selection of tree species used. Trees which do not emit the most reactive volatile organic compounds (VOCs), but do have large leaf surface areas have the best effect on air quality. Examples include Scots pine (*Pinus sylvestris*), common alder (*Alnus glutinosa*), larch (*Larix spp.*), Norway maple (*Acer platanoides*), field maple (*Acer campestre*), ash (*Fraxinus excelsior*) and silver birch (*Betula pendula*). Further advice is available from Lancaster University and the Centre for Ecology and Hydrology[64]. As with any other tree selection criteria, this should be balanced with other considerations, as described in section 4.

Trees can also negatively impact local air quality by reducing the dispersion of air pollution especially from busy roads under dense tree canopies[65]. This is sometimes called the "street-canyon effect", as shown in the diagram on p63. Using trees to help mitigate urban air pollution therefore also requires a context-sensitive approach, considering the location of the source of the pollutants to be removed, and the characteristics of the surrounding built form (street height-to-width ratio):

- In a dense inner-city context with street canyon height-to-width ratio above 0.7 and ground-level pollution sources (eg local traffic exhaust), a continuous tree canopy can prevent air circulation. Care is therefore required in such contexts on the chosen arrangement and spacing of planting.
- In dense urban environments with no in-canyon pollution sources (eg a pedestrianised street), trees can produce "filtered" avenues, in which

60
www.forestry.gov.uk/opm

61
The *Air Pollution in the UK* annual reports published by the Department for Food and Rural Affairs can be found at: http://uk-air.defra.gov.uk/library/annualreport/

62
As summarised for the UK in the Committee for the Medical Effects of Air Pollutants' reports found at: www.comeap.org.uk/documents/reports

63
Donovan, RG, Owen, SM, Stewart, HE, MacKenzie, AR, and Hewitt, CN (2005), *Development and application of an Urban Tree Air Quality Score using the Birmingham, United Kingdom, area as a case study*, Environ. Sci. Technol., 39(17); 6730-6738. DOI: 10.1021/es050581y

64
Stewart, H, Owen, S, Donovan, R, MacKenzie, AR, Hewitt, N, Skiba, U and 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

air is cleaner than on the regional scale.
- Similarly, in a low density context where the building frontage will not cause a canyon effect, trees can remove air pollutants, especially particulate matter, although the size of this removal effect is still the subject of research[66].

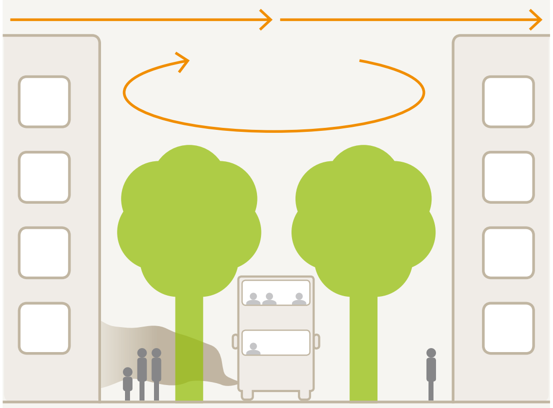
2.5.4
Temperature and wind control

The cooling effect of trees has long been established[67]. 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 aiming to quantify this benefit suggest that evapotranspiration is a direct result of the photosynthetic activity and hence the growth rate of trees[68]. This has important implications regarding the conditions required to maximise cooling benefits from trees. These will be of particular value for projects in city centre locations where urban heat island issues are most likely to occur. Cooling urban temperatures with trees will be best achieved through:

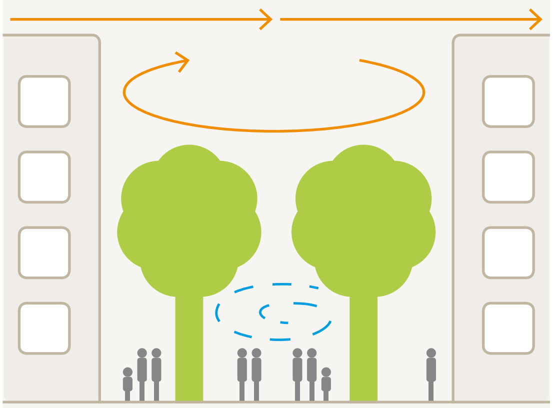
- Setting canopy cover targets rather than driving design and management decisions on the basis of a number of trees.
- Providing non-compacted rooting environment(s) of sufficient size to achieve and sustain the desired canopy cover target.
- Ensuring a good supply of water, particularly during extended 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 inner city planting scheme as recently done in Lyon, France, Garibaldi Street (see Case study 17, p77).

Impact of trees on air quality in street canyons

Street canyon effect



Filtered avenue



The impact of cooling by trees on building energy consumption and human health are also widely evidenced. The details provided below focus on building energy consumption, as public health considerations are covered is 2.5.2.

Trees placed close enough to directly shade buildings (called shade-effect trees) can lower summertime energy demand to cool a building. Care is then required to avoid blocking warm radiation during winter months, while shading sun-exposed walls during the summer. At UK latitudes, this is best achieved by positioning trees along the west-facing side of a building. Identical trees positioned on the south-facing side of a building will cast relatively more shade in winter. However, a taller tree in the same 'south' location with a higher clear stem will cast relatively more shade on the building in summer and relatively less shade in winter than an unpruned specimen.

Trees located such that they do not provide shade but are close enough to influence the local microclimate are termed climate-effect trees. As described above, these trees cool the local microclimate through evapotranspiration, leading to summertime air-conditioning energy savings. Climate-effect trees, particularly evergreen species, can also reduce heat loss from buildings in winter by reducing wind speed and, thus, air infiltration into the building. A study[69] 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.

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

65
Pugh, TAM, MacKenzie, AR, Whyatt, JD, and Hewitt, CN (2012), *The effectiveness of green infrastructure for improvement of air quality in urban street canyons*. Environmental Science & Technology, 46 (14), 7692-7699. DOI: 10.1021/es300826w; Vos, PEJ, et al. (2012), *Improving local air quality in cities: To tree or not to tree?* Environmental Pollution

66
Litschke, T and Kuttler, W (2008), *On the reduction of urban particle concentration by vegetation – a review*. Meteorol. Zeit. 17: pp229-240

67
Doick, K and Hutchings, T (2013), *Air temperature regulation by urban trees and green infrastructure*. Forestry Commission Research Note. Found at: www.forestry.gov.uk/pdf/FCRN012.pdf/$FILE/FCRN012.pdf

68
Ennos, R (2012), *Quantifying the cooling benefits of trees*. In: Johnston, M and Percival, G (eds.) Trees, People and the Built Environment. Forestry Commission Research Report. Forestry Commission: Edinburgh. Found at: www.forestry.gov.uk/forestry/INFD-8BVE4R

69
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

of wind speed and turbulence to help enhance pedestrian comfort.

2.5.5 Wildlife health

Trees support wildlife in built-up environments in many ways. They provide food, shelter, nesting and roosting sites. For example, as cities are warmer than the countryside in the winter, some birds, such as pied wagtails, can choose evergreen trees in city centres to roost in. It is the volume of this canopy that is the best predictor of species use, as most animals require a minimum amount for survival. A secondary consideration is the spatial arrangement of the canopy, as some species cannot cross large gaps readily or rely on tree lines for navigation – as is case for some bats[70].

Strategies to enhance the wildlife benefits associated with trees in hard landscapes include:

- Selecting species for their habitat value – considering nectar, fruit and seeds, as well as the density, structure and seasonality of the tree canopy.
- Maximising the total volume of tree canopy.
- Creating several layers by using shrubs and smaller trees such as hazel among taller trees and planting the tree openings with ground cover. This will, however, increase competing demands for water which will need to be compensated when the trees are young.
- Choosing tree location and planting patterns in the wider landscape context so as to increase habitat connectivity to vegetated areas, parks or groups of trees.

70
Limpens, HJGA and Kapteyn, K (1991), *Bats, their behaviour and linear landscape elements*. Myotis, 29, 39-48

A place for people and nature, West Smithfield, City of London. Image: City of London

2.6
Surfacing, cleaning and de-icing

In brief: what needs to be done	Who does it
Understand tolerance for droppings – based on feedback from users and maintenance staff.	– Design specialist(s)
Balance tree needs, use, and maintenance capacity for choosing the tree opening surface treatment and edging – review all options.	– Design specialist(s) – Tree officer/specialist – Highways maintenance coordinator
Establish good communication channels with staff responsible for de-icing on best practices in proximity to trees and local problem areas.	– Tree officer/specialist – Highways maintenance coordinator
Take remedial action after a bad winter to reduce risks of salt pollution damage to trees.	– Tree officer/specialist – Highways maintenance coordinator
Use species tolerant to saline soils in areas exposed to high risk of contamination by de-icing salt and mitigate through design detail.	– Design specialist(s) – Tree officer/specialist

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 need to clean 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[71]. 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 (*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 environments around its root ball. It will also need water. To achieve this, the surface immediately around the trees needs to be permeable and non-compacted.
- Depending on context, the use of the space around the tree (including pedestrian movement patterns) will determine the degree to which accessibility will need to 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 kerbs or low protective railings) will also have 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 – so long as this soil is not compacted. 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

71
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

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.

Pervious 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.

Pervious bound aggregates will accommodate higher footfall level, maximising accessibility to the space around the tree. Available products broadly fall into two categories: flexible pervious rubber surfacing and pervious resin-bound gravel. Pervious 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 and size of aggregate used) on long-term porosity and wearing of resin-bound aggregate tree surrounds. Flexible pervious rubber 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 ductile 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 grille 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* by the

London Tree Officers Association to be published in October 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. See overleaf for illustrations of working solutions for surface opening treatment.

Surface opening 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
Porous paving 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
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
Porous paving 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
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

Working Solutions:
Surface opening treatment examples

In a kerb buildout, woodchips provide a good surface opening treatment in 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.

Planting beds protect existing mature trees and provide seating. St John Street, Islington, London. Image: Liz Kessler

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.

Well-maintained loose gravel provides porous surround for trees at 30 St Mary Axe, London. Image: Capita

Simple loose gravel, laid slightly below the surrounding asphalt to avoid spilling in Bern, Switzerland.

Porous self-binding aggregate surrounds trees near bus stop in Rouen, France.

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

All non-credited images: Anne Jaluzot

Grate with watering inlet and resin-bound infill and watering/aeration inlet on Ocean Road (see Case study 2, p31). 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 grille with limestone infill at 90 degrees to pedestrian flow to reduce slipping, aids water infiltration and gas exchange. Place de Bellecour, Lyon, France.

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

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

Grate with removable rings in resin-bound gravel and watering/aeration inlet on Swansea Boulevard (see Case study 17, p77). Image: Sue James

Substructure and completed conditions of the bespoke tree grate installed at Apeldoorn Station Square, The Netherlands (see Case study 24, p127). Images: Ron van Raam (left) and Jeremy Barrell (right)

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 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 Group[72].
- 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 pictured below.
- 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[73] of the soil salt tolerance of common species in the UK. This list is non-exhaustive, and complementary advice should be sought from a tree specialist 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.

Metre-high black units installed during the winter months only to protect trees from the effects of salt spray on busy traffic routes. Image: Anne Jaluzot

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

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

Case study 11
Lyon and London reclaim road space for trees

Location
Lyon, France.
London, England

Project category
Highway

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 more than 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 Corporation has pursued similar trade-offs enabling it 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: Tree and alternative transport strategies go hand-in-hand in Lyon.
Image: Anne Jaluzot

Bottom left and right: Before and after – reclaiming road space on Old Bailey, London.
Image: City of London

Case study 12
Trees in the middle of Bristol's Whiteladies Road enhances road safety and bus journeys

Location
Bristol,
England

Project category
Highway

Whiteladies Road is a shop-lined strategic route into Bristol. As part of the DfT grant-funded Greater Bristol Bus Network (GBBN) project, close to 15 trees, including Elms (*Ulmus* 'New Horizon'),Limes (*Tilia cordata* 'Greenspire') and London planes (*Platanus x hispanica*) were planted in new islands in the middle of the carriageway. The design was initially controversial, raising fears of worse traffic congestion and more conflicts between motorised vehicles and cyclists. Others saw in the proposal an effective way to address night speeding issues, enhance the pedestrian street experience – particularly in relation to crossings – and smooth traffic flows by facilitating right turns. Since completion in spring 2012, the scheme has unarguably won the popular vote. Feedback to Bristol city council from local residents has been very complimentary. The new streetscape was recognised with a Bristol Civic Society Environmental Award in 2013. An enthusiastic local driver issued an online video[74] celebrating the traffic calming impact of the scheme.

2014 saw the release of the first set of post-installation monitoring data. A comparison between "before" (2007) and "after" (2013) accident records along the refurbished segment of Whiteladies Road shows a marked drop in total collisions. Cyclist counts increased by 13% for the period of 2007-2012 and collisions involving cyclists have slightly reduced. While the total number of casualties has reduced more significantly than across the city as a whole (excluding GBBN routes), the number of killed or seriously injured (KSI) casualties slightly increased (from 12 to 15). However, this variation is based on such a small sample size it is difficult to draw any conclusions from it. The amount of people using the buses along this GBBN corridor has significantly risen: bus patronage has increased by more than 40% between 2008/09 – 2013/14 (FirstGroup's main GBBN services) The overall quality of the bus service has improved showing exceptional increases in bus user satisfaction rising from 28% in 2007 to 81% in 2012.

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

GBBN Whiteladies Road bus user satisfaction survey results[75]

Criteria	2007	2012
The overall quality of the bus service	28%	81%
Whether buses arrive on time	24%	78%
The frequency of the buses	28%	86%
The journey time to your destination	37%	98%
How easy buses are to get on and off	54%	97%
The quality of bus stops and shelters	35%	92%
The availability of timetable and route information	34%	88%

74
Found at:
www.youtube.com/watch?v=purZUFopnqE

75
Based on 613 responses on bus services 1 and 54 in October 2007 and 372 responses on bus service 1 in February 2012

Case study 13
Glen Innes's "self explaining roads" project

Location
Auckland, New Zealand

Project category
Residential

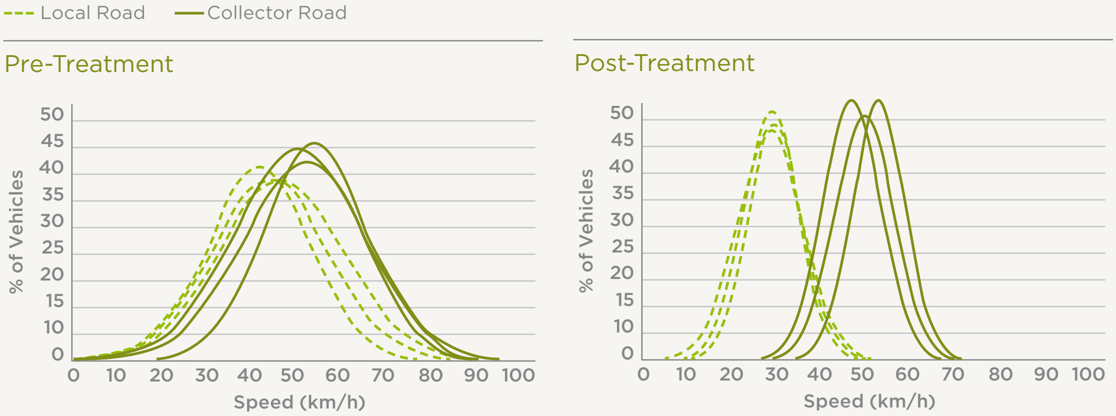
Back in 2007, the flat street grid of Glen Innes, a low-income residential suburb of Auckland, New Zealand, boasted crash rates that were twice the level of Auckland's seven other wards. This prompted the New Zealand Foundation for Research, Science and Technology to award Transport Engineering Research 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



Case study 14
Linear orchards for attractive cycling

Location
Hackney, London, England

Project category
Highway

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 communis* ‘Conference’ ‘and *Pyrus communis* ‘Doyenne du Comice’) and plum (*Prunus domestica* ‘ 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 where traffic flow needed to be reduced to improve cycle and pedestrian safety.

Both schemes are to feature 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 15
Trees for Dutch-style shared space in Leonard Circus

Location
Hackney, London, England

Project category
Highway

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.

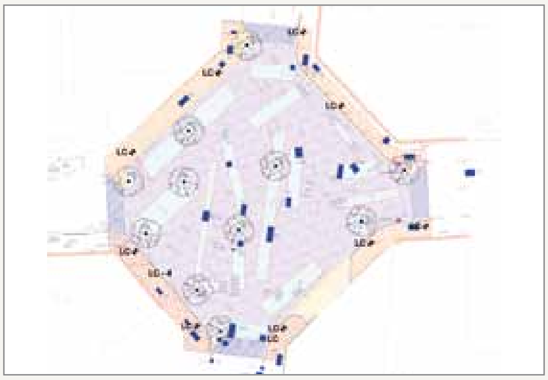
The art piece has been moved to a more suitable location and the area between the buildings has been paved at a single level in unglazed brickwork, broken up by an irregular pattern of panels using contrasting grey granite, York stone and Italian porphyry. Kerbs, signs and carriageway markings are absent 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 Scots 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 pollutants). Around the space are also Maidenhair trees (*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 (Stratacell).

Top left: Leonard Circus before.

Top right: Layout for finished scheme.

Bottom: Leonard Circus in July 2014, as completed.
Images: London Borough of Hackney



Case study 16
Trees for revitalised retail and attractive bus routes

Location
Bristol,
England

Project category
Commercial

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 a grant from Department for Transport, 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: *"We knew we had to take a different, more holistic approach. 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 English 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 mall entrance, removing guardrails preventing pedestrians from crossing and creating a green gateway with nine small leaved lime trees (*Tilia cordata* 'Greenspire'). One year on, 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 planting 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!)

Such holistic outcomes from what was initiated as a bus route improvement scheme was made possible by the creation of a dedicated project tree specialist role 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 answer 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.
Images: City Design Group, Bristol City council

Case study 17
Using rainwater cisterns for tree-based cooling on Garibaldi Street

Location
Lyon, France

Project category
Highway

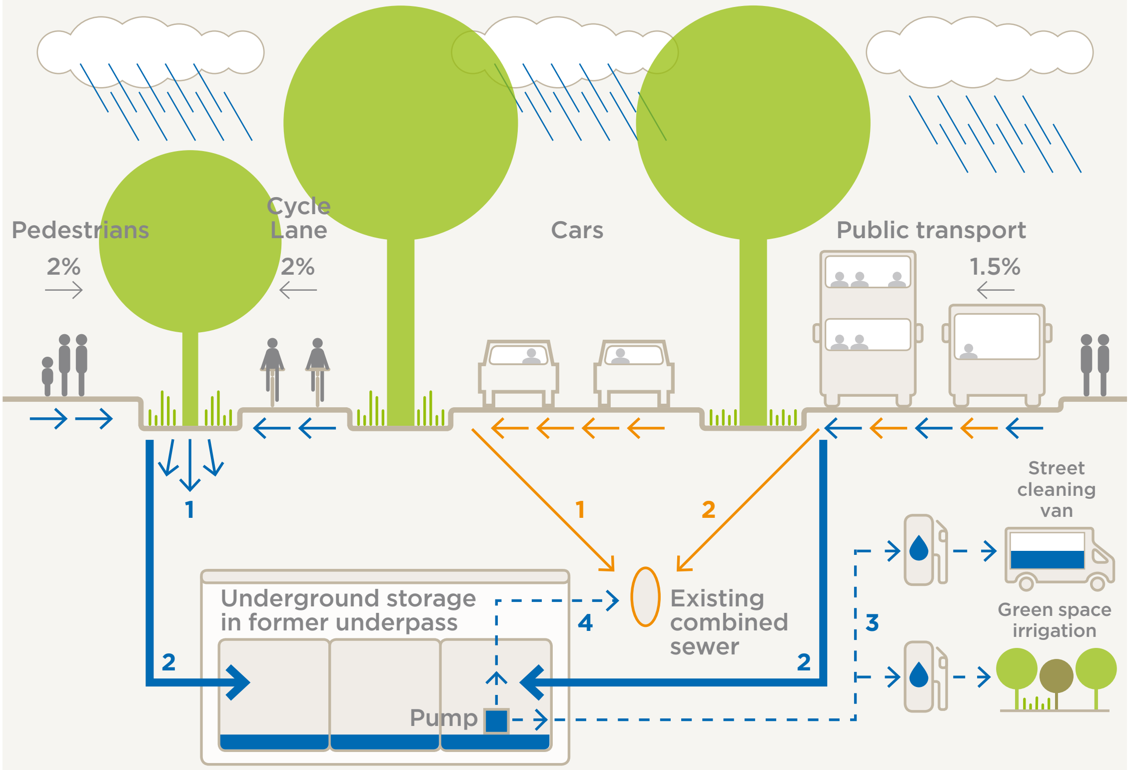
Garibaldi Street is a major arterial road running through Lyon's city centre. Designed as an "urban motorway" in the 1960s, the oversized road no longer serves contemporary needs for development and quality of space. Refurbishment was initiated in the 1990s, and is now entering into a second, more ambitious phase expected to turn the six-lane road into a people-friendly green street 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 paths. 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 repurposed 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 (as shown in the diagram below). 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 p39 and p60

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

Quick Check

Is the best potential outcome being achieved from trees?

Project manager

Have you…

- ○ Managed coordination of inputs and outputs between all team members?

Design specialist(s)

Have you…

Explored all opportunities to make space for trees ie:

- ○ In new development situations, ensured that the inclusion or retention of large trees is considered in parallel with the siting and dimensions of buildings, roadways, utilities and drainage?
- ○ In retrofit situations, reviewed carriageway and car parking allocations or considered planting (or enhancement to the rooting environment of existing trees) on the road side of the kerb where footway width is too limited?
- ○ Considered using or retrofitting a common utility enclosure or shared trench?

Fully exploited tree benefits, whether existing or new, to:

- ○ Help to achieve the desired operational vehicular speed?
- ○ Enhance the walking and cycling environment?
- ○ Receive and manage surface water runoff, while also considering how this can benefit the tree?
- ○ Enhance people's health and wellbeing?
- ○ Enhance and support urban wildlife?
- ○ Provide microclimate control (eg shading, shelter from wind, reducing overheating on glazed frontages) and associated impacts on buildings?
- ○ Enhance or conserve cultural and historic amenity?

Ensured above ground compatibility, ie:

- ○ Factored tree growth over time in the positioning of new trees in respect to surrounding buildings and other infrastructure?
- ○ Followed guidance to achieve good visibility for road users, commercial signs and shop windows, street lighting and CCTV?
- ○ Reviewed all options to make informed and context sensitive choices for the surface and edge treatment around new or existing trees?

Tree officer/specialist

Have you…

- ○ Collaborated with highway design lead to explore opportunities to plant new trees on the roadside of the kerb where footways are too constrained?
- ○ Collaborated with the design lead to enhance the growing environment of existing trees that might be part of a scheme?
- ○ Ensured not only species diversity, but also associated nursery, planting and management specifications will secure adequate vertical and horizontal clearances?

- Ensured the surface treatment and edging for the immediate surround of the tree provides for adequate gas exchange and water infiltration?
- Ensured that above- and below-ground detailing for soil volumes and soil specifications so that rooting environments are coordinated with civil engineering performance and service runs?

Highway engineer

Have you...

- Made best use of vegetation, particularly trees, for clutter-free traffic calming?
- Resolved potential urban road safety issues?
- Sought design and tree specialist advice on the contribution trees can make to the success of shared space and pedestrian priority areas?
- Sought design and tree specialist advice on the contribution trees can make for enhancing the cycling environment?
- Sought design and tree specialist advice on the contribution trees can make to a public transport improvement project?
- Communicated clearly the vertical and horizontal clearance to be achieved at project completion and over time to the design team and tree specialist responsible for designing, specifying and developing the maintenance plan for trees?
- Liaised with the tree specialist/officer on possible tree or highway management responses to existing trees growing into the dynamic kinetic envelope?
- Sought feedback on the impact of road de-icing on the local tree population – amending highway winter maintenance practices where salt-inflicted damage has been observed?
- Shared feedback with the tree specialist and in-house design lead on ease of cleaning and durability of different tree surface opening treatments in different context?
- Reviewed the project programme with lead designer to establish the best construction procedure for successful tree planting establishment?

Drainage engineer

Have you...

- Made provision for trees to access water?
- Explored opportunities to use trees and their growing environment for attenuating, storing and/or cleaning surface water runoffs?
- Considered the geotechnical characteristics of the site?
- Coordinated with the lead designer on drainage runs and surface water conveyance strategy in accordance with SuDS best practice?

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Technical Design Solutions

Technical Design Solutions
Building in sustainable success

A rich and evolving body of research findings and technical solutions are available to better understand the needs of trees and the infrastructure that surrounds them, and how they can sustainably and successfully be made to work together. Choices made in the design of the below-ground environment are vital to this success.

Aims

Focused on technical and primarily below-ground design solutions, this section aims to:

– Enhance design teams' understanding of some of the fundamental needs and behaviours of urban trees and tree roots.
– Communicate the evidence-based pros and cons, relevant context, and success factors of a wide range of design approaches.
– Enable informed analysis and decision-making for the design of the below-ground environment around trees in hard landscapes.

Requirements

The main project requirements covered in this section are:

– Concept design: principles for utility specification in proximity to trees, drainage strategy, meeting load-bearing requirements.
– Detailed design: tree-rooting environment.
– Programme of works.
– Maintenance specifications.
– Drainage strategy: options to be explored in detailed design.

Wider Benefits

The wider benefits to be gained are:

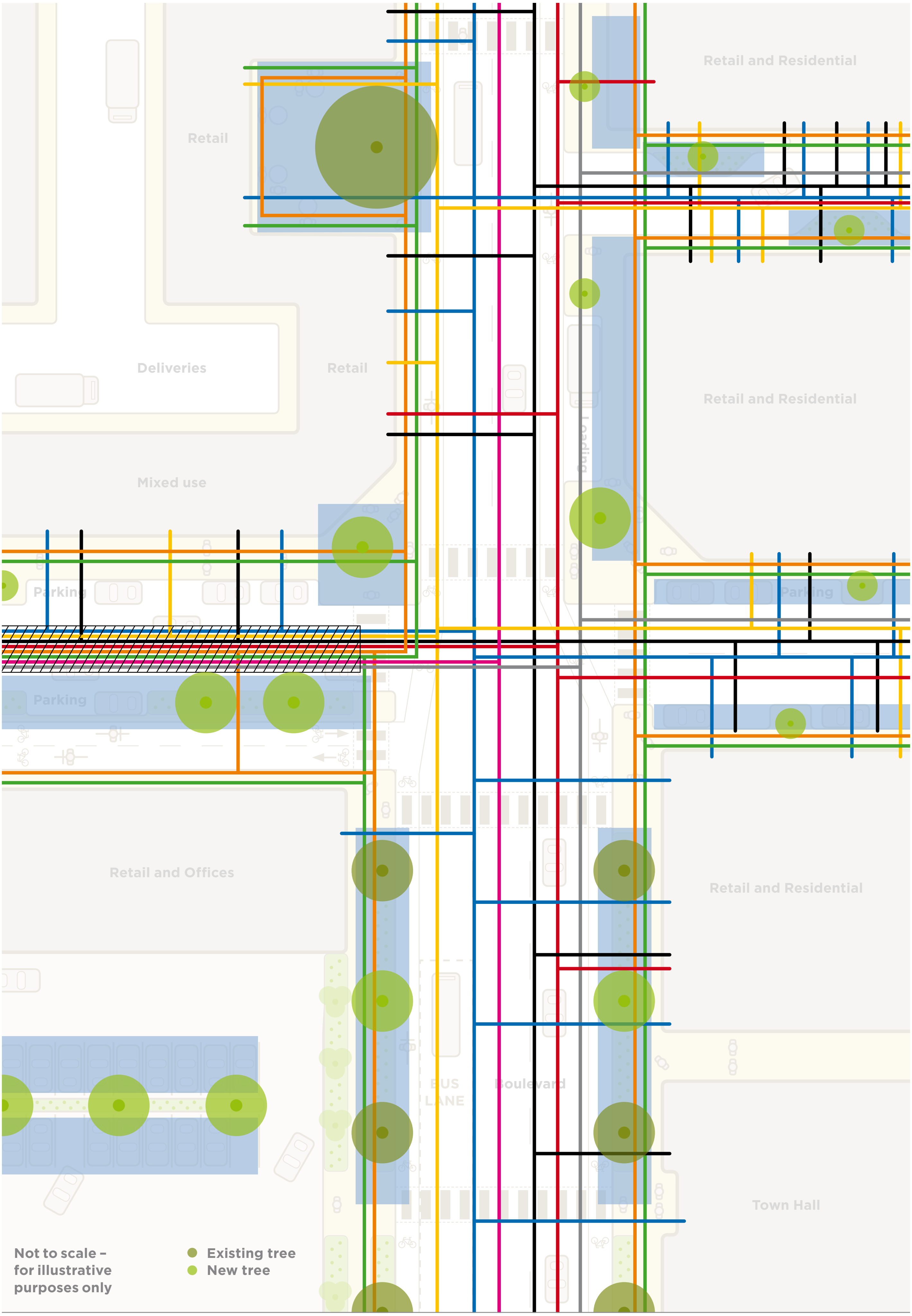
– Better performing infrastructure – successfully combining 'green' (natural) and 'grey' (engineered) components.
– Lower infrastructure maintenance costs.
– Greater capacity to trial innovative solutions.
– Greater resilience to stormwater surges.
– Longevity in the urban forest for future generations.

The complex world below ground

The diagram opposite shows that the new development rationalised the use of space for and improved access to utilities. Lasting compatibility between trees and structures has been achieved with context sensitive use of load-bearing designs for tree-rooting environments. What was the rationale for species selection? See Section 4.

Load-bearing solutions to suit location and long-term project objectives

Gas
Sewer
Water
HV Electricity
Lighting
Cable
CCTV
Other telecom
Common service enclosure


Retail and Residential
Retail
Deliveries
Retail
Retail and Residential
Loading
Mixed use
Parking
Parking
Parking
Retail and Offices
Retail and Residential
BUS LANE
Boulevard
Town Hall
Not to scale – for illustrative purposes only
Existing tree
New tree

3.1
Basic tree knowledge for success

In brief: what needs to be done	Who does it
Establish a shared understanding in the project team of what trees need to grow and mature successfully in hard landscapes.	– Tree officer/specialist
Establish a shared understanding in the project team of the requirements of the above and below-ground infrastructure surrounding trees, especially footways and utilities.	– Design specialist(s) – Highways maintenance – Utility representatives

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 enabling good compatibility with the surrounding infrastructure.

Understanding the "tree fundamentals" covered below does not remove the need to involve the right professionals throughout the decision-making process, but will make collaborative 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. It is 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 design and management need to recognise 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 urban tree population (urban forest) will consist of a diverse range of trees – large growing, medium sized and small trees. The trees will peak at different times. For example, a long-lived, large-growing tree such as a London plane (*Platanus x hispanica*) has the capacity to deliver significant benefits over a long period of time. The ability of trees to deliver these benefits should be factored into value assessments as explained in 1.1.2 and demonstrated in Case study 3, p32.

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

- Select species that have the genetic capacity to survive in harsh urban conditions (see 4.1).
- To provide an adequate type and

volume of growing substrate (see 3.1.3).
- To provide suitable above-ground protection (see 3.1.6).
- To provide for adequate post-planting care, including adequate formative pruning which addresses the correction and adjustment of branch structure when it is least expensive to do so (see 1.4.1).

Long-lived plane tree, Victoria Embankment, London. Image: Sue James

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)[76].

In hard landscapes, soil aeration can be severely compromised:

- 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. There are a number of methods available for assessing rooting volume requirements[77], but the final decision is context and species specific. Guidance should be sought from a tree specialist, preferably with knowledge and/or qualification in young tree establishment.

Strategies to achieve adequate rooting volumes include:

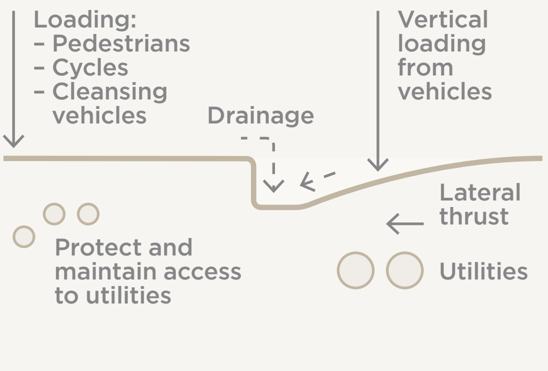
- Estimating rooting volume requirements early in the process – if brought in as an afterthought, too many parameters will have already been set for enhanced rooting condition and volume to be provided cost effectively.
- Expanding as much as possible the rooting environment beneath the paved surface, 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 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.

76
Kozlowski, TT (1985), *Soil aeration, flooding and tree growth*. Journal of Arboriculture 11:85-96

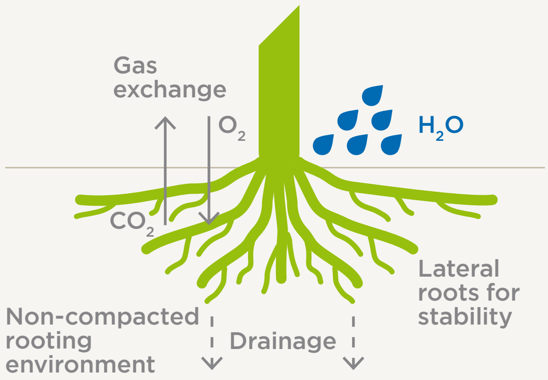
77
Published estimates of required (soil) rooting volumes are usually of two main types. Some are empirically based on observations of existing urban trees. Others are based on calculations of soil volumes required to meet the water demands of the tree. Resulting estimates vary widely due to differences in soils, climate and assumptions regarding tree species and size. A summary of available methods can be found at: http://stormwater.pca.state.mn.us/index.php/Studies_analyzing_minimum_soil_volume_needed_by_trees

Key points for success with trees in hard landscapes

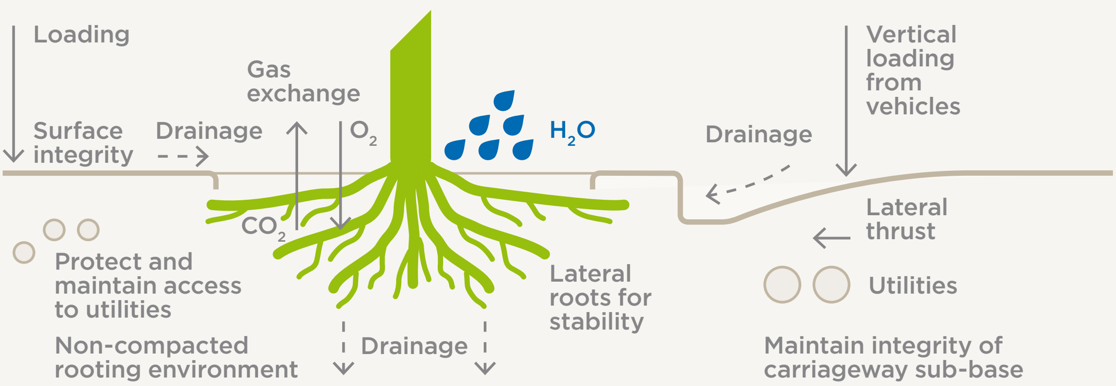
Highway needs



Tree needs



Setting the brief



Planted at the same time, the available rooting volume and soil compaction have effected the tree growth rates in this carpark in Gelsenkirchen, Germany. Image: Johan Östberg

3.1.4
Dispelling the topsoil myth

What is topsoil?

Topsoil is often 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. Therefore, if imported soils are used, the most appropriate mix for the site condition should be used[78]. 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[79].

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[80].

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 (see 1.2.2) and seeking expert advice at the outset of a project can bring significant savings if spoil can be used on site[81].

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 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 leads to 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 shown on p91. As demonstrated in *Sustainable Water Management: Trees are part of the solution*[82] 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 gas exchange, water movement and root extension beyond the tree planting hole, which will all limit the ability of trees to access water.

78
Refer to *BS 8545:2014*, paragraph 10.2.8

79
Refer to *BS 8545:2014*, paragraph 10.2.2

80
Refer to *BS 8545:2014*, paragraph 10.2.5-10.2.6

81
Refer to *BS 8545:2014*, paragraph 6.3

82
Published in 2013. Found at: www.trees.org.uk/aa/news/LTOA-Sustainable-Water-Management-Trees-are-part-of-the-solution-200.html

3.1.6
Protection above ground

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 gas exchange 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 and edge treatment choices play an equally important role in allowing water infiltration, facilitating moisture retention and gas exchange for the soil below. Surface and edge 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[83]

It will take newly planted trees a few years to establish stabilising roots and adequate anchoring. Some support is therefore necessary for young trees. A degree of continual movement stimulates root growth and is essential for the tree to develop adequate rooting structure, anchorage and strength. The support provided therefore 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. 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 need to be removed and can remain in the ground for as long as the tree.

83
Refer to *BS 8545:2014*, paragraphs 10.3.1-10.3.6

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

84
Refer to *BS 8545:2014*, paragraphs 10.3.11-10.3.13

85
Found at: www.ltoa.org.uk/resources/dog-damage-to-trees

Protecting the tree bark from injury[84]
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.

Careful handling by the staff or contractor responsible for the delivery, storage and planting of the tree is therefore an important consideration (see 4.6) and should be reflected in the tender and contract documentation. Care is needed when using street cleaning equipment, particularly machinery, near young trees. Maintenance staff should briefed not to damage tree bark and consideration should be given to protective measures.

In tight spaces, high traffic areas and hard landscapes cleaned with machinery, providing protection for the tree bark might 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 cane wrapping, 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.
- Street furniture (seating, bicycle racks) adequately positioned around or on each side of a tree. This 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.

Dog damage and other forms of vandalism (eg graffiti, intentional destruction, etc) are probably best dealt with through education, community engagement and enforcement as shown in *Better Bark than Bite – Damage to trees by dogs*, the Best Practice Note published by the London Tree Officers Association in 2010[85]. See over page for examples of working solutions for tree protection.

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 circumstances are more demanding and some more sophisticated designs will be required to secure the successful integration of trees 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.

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). Image: Anne Jaluzot

Working solutions:
Tree protection examples

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

Bicycle hoops mounted on tree grilles in Stockholm, Sweden.

Popular circular benches in Norwich.

Low-level multipurpose protection in central Stockholm, Sweden.

Rural timber frame protects tree and biodiversity along this Parisian boulevard.

3.2
Load bearing

In brief: what needs to be done	Who does it
Provide an adequate rooting environment, as described in *BS 8545:2014*.	– Design specialist(s) – Tree officer/specialist
Consider designing in or retrofitting the tree-rooting environment with a load bearing system. Review pros and cons of all available systems, and anticipate implications on training needs and sequencing of works.	– Design specialist(s) – Tree officer/specialist – Product manufacturers

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.

Where load bearing is needed, the sub-surface may need to be engineered to aid tree root growth. Techniques to alleviate the tree-growing media from compaction while providing adequate support to hard surfaces have been used for highway tree planting since Victorian days. Percy J Edwards[86] clerk of the Improvement Committee which oversaw the planting of Northumberland Avenue in London between the Thames and Trafalgar Square in the 1870s describes the care taken to ensure the survival of the tree in a load-bearing, hard surfaced context as follows:
"To secure the well-being of the trees, pits were formed and filled with proper soil, and the footway surrounding the tree was covered with an open grating to admit the rain and air to the soil, and to enable it to be stirred and kept loose on the surface. The grating and footway were supported independently by girders over the tree pits, so as to prevent settlement of the paving and hardening of the ground around the roots of the tree."

The technical solutions currently available to enhance the load-bearing capacity of tree root growing environments broadly fall into three categories:
- Structural growing media.
- 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 interviews with experts and users of the different techniques and a review of the limited available published and peer-reviewed academic research. It should be noted that, at the time of publication of this guide, there is neither the research nor the criteria by which the different load-bearing growing media can be compared with each other. This is a first attempt at such comparison.

The systems described might encompass both patented and unpatented techniques and 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 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

86
Quoted pp242-243 in Lawrence HW (2008), *City Trees: A Historical Geography from the Renaissance through the Nineteenth Century.* Virginia: University of Virginia Press

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 (also called tree soils).
- Medium-size aggregate substrates.
- Large-stone skeleton substrates (also known as the Stockholm system).

This categorisation is, to a degree, a simplification as a wide range of solutions has been developed to suit local circumstances, including 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. Over 10,000 street trees have been planted across greater Lyon over the past 20 years in this locally defined stone-soil mix.

Good in-house expertise on (young) tree requirements together with a capacity and willingness to experiment in order to fine tune implementation specifications are two paramount success factors with structural growing media.

Sand-based substrates (also called tree soils)

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[87].
- 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) limits species choice.
- 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 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

87
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

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 300mm. 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 planting hole is required, then geotextiles that prevent root extension should not be used.

Working solutions: Sand-based substrate installation process

Site excavated and aeration system in place.

Filling with 100% recycled sand-based structural soil in 30 cm layers, well compacted with a vibrating (wacker) plate.

Trees planted, geotextile in place to prepare the foundation for the concrete block pavers.

A completed scheme in The Netherlands.

Images: Joris Voeten

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[88].
- 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

- Increased tree vulnerability to drought conditions: structural soil does not hold water in the same way as a normal soil and drains quickly. This will need to be factored in the species choice.
- The type of stone used in the mix will affect the soil pH. For best results, this will need to be factored in the species selection and therefore narrow available choices.
- 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

- Good technical site supervision from the beginning to the end of the works is critical. Training the construction manager is an important first step to enable this. Thorough quality control needs to be exercised to ensure all tips listed below are not only translated into specifications but also well adhered to.
- The stone aggregate used in the mix has to be angular and consistent in size. As with sand-based structural substrates, good specifications 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%) and larger voids for root growth.
- 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 150-300mm deep – depending 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.
- Species choice needs to factor the impact of the stone used on the pH of the growing media (eg using limestone will result in a somewhat alkaline

88
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
See also Bühler, O (2007), *Below the Surface: In-depth Investigation of Tree Development, Root Growth, and Soil Conditions in Structural Soils in Copenhagen, Denmark*. Copenhangen: University of Copenhagen

conditions with a pH of about 7.8-8.2 whereas granite, as in Stockholm, is less likely to have an impact on soil pH).

Stone skeleton substrates (also known as the Stockholm system)

How it works

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

> *"What is the Stockholm system? Tree-rooting environments built with large stones where we infiltrate stormwater and ensure that the gas exchange works. Strong control over both construction work and maintenance programme is key to success."*
>
> Björn Embrén, arboricultural manager, City of Stockholm

Emulating the conditions found on 15+ year-old railroad embankments (ie once some organic matter has formed in-between rocks as a result of the presence of low vegetation and allows tree seedlings to grow into full trees), the system prioritises good gas exchange 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.

The system consists of an extensive base, made of large angular stones (granite, recycled concrete blocks, etc – 100-150mm in grade size), covered with an aeration layer (washed granite 63-90mm in grade size). Soil is flushed into the stone base after it has been compacted, and prior to the installation of the aeration layer. Slow release fertiliser is included to support the growth of the tree for the first couple of growing seasons. 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 are also 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. The aeration wells are equipped with a sand/silt collector to allow for periodic cleaning. The 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[89].

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

Limitations

- The system is only nine years old and, as explained above (see 'How it works'), challenges common wisdom on the importance of soil and tree requirements to access nutrients. Good results have been observed so far in Sweden (see Case studies 20, p124 and 26, p129), as well as in the United States (see Case study 4, p33), but 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

- In hard landscapes with strong load-bearing requirements, where continuous trenching is feasible: plazas/squares, streets where narrow footways

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

require expansion of the root zone beneath the carriageway.
- In hard landscapes with existing trees showing premature signs of decline.
- In hard landscapes where both surface water management and tree planting are to be provided.

Cost
Expensive.

Tips for success
- The Stockholm system is not technically complicated but it requires rigorous implementation. Good technical site supervision from the beginning to the end of the works is critical. Training the construction manager 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 that 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 specifications, great attention should be paid to the stone grading. If stone fractions of inconsistent size are used, there are no voids left for roots to spread once the soil is flushed in. Checking upon delivery that the specification is met is of paramount importance.
- Care should be taken to avoid using a soil mix with too high a clay or organic matter content as this leads to issues with watering the soil down into the system during installation. In Stockholm, fines (soil particles of less than 0.02mm) are kept under 8% of the whole mix, while organic matter is no higher than 2-4%. Initially, organic matter was not included in the soil mix flushed at the bottom of installations and included only in the top 400mm of the stone base. However, trials have revealed that, combined with the aeration system, the presence of voids in the stone base enables effective gas exchange deeper down than 400mm. The municipality of Stockholm therefore uses the same soil mix (including a small amount of organic matter) used throughout the stone base profile.
- 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. This process needs to be carried out layer by layer.
- A geotextile membrane needs to be placed between the aeration layer and the carriageway or footway subgrade above 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. See over page for working solutions showing the skeleton soil installation process.

The joys of trees without traffic along London's South Bank. Image: Sue James

Working solutions:
Skeleton soil installation process for existing trees

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.

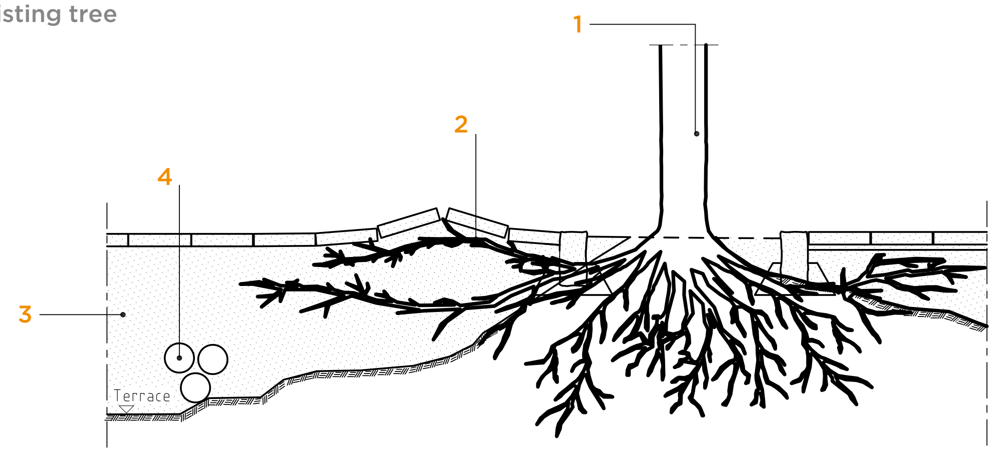
Root balls with new soil under protective cover and irrigation (notice the green watering bag around each tree). More soil is being flushed into the skeleton soil.

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.

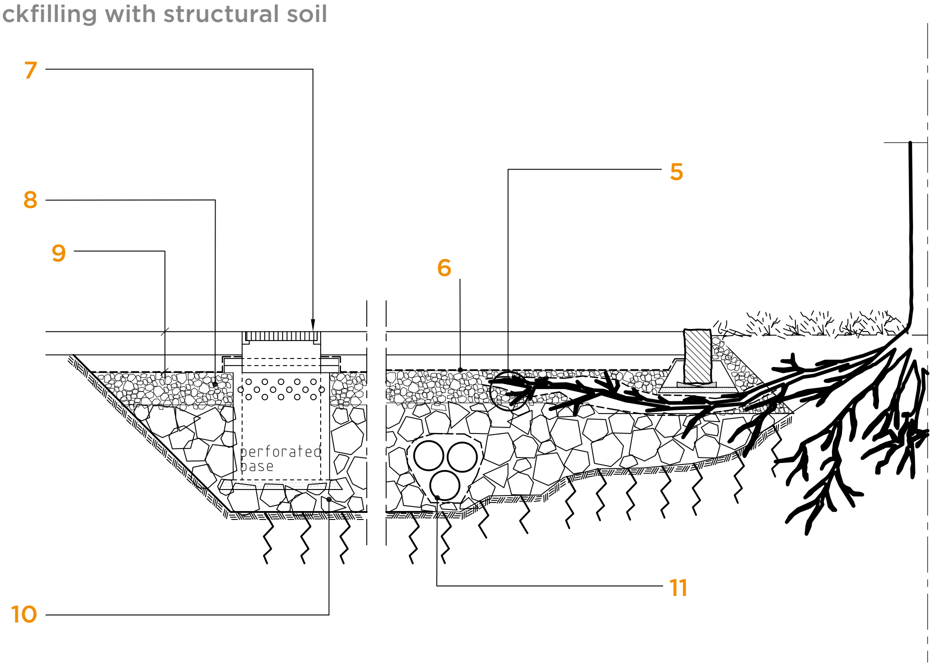
The limes show signs of vigorous growth the following spring. Notice the aeration/water inlet between the two foreground trees.

Images:
Björn Embrén

Section for excavation around an existing tree



Section backfilling with structural soil



1. Existing tree
2. Vacuum excavation 2-3 m radius from tree trunk
3. Existing superstructure excavation to 1m
4. Existing pipes
5. Pruning tree roots:
   - big roots protected with crushed rock 32-90mm
   - roots in structural soil protected with crushed rock 4-8mm
6. Geotextile
7. Air and water supply
8. Aerated bearing layer
9. Surfacing superstructure
10. Structural soil with planting soil and fertiliser
11. Pipes in structural soil protected with geotextile

Typical sections for retrofitting skeleton soil around an existing large tree with shallow roots as shown in the *Stockholm Handbook*. Unlike 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 for new trees

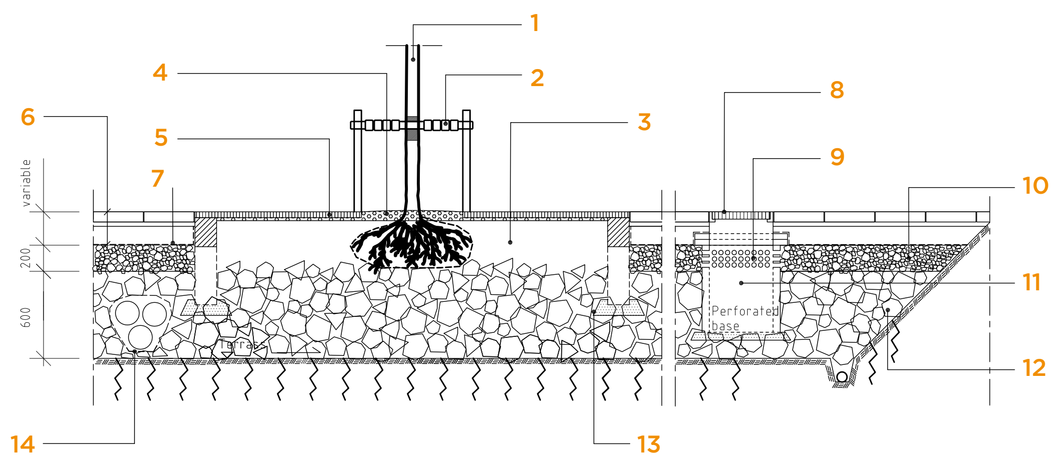
Positioning of concrete frame in continuous planting trench with large stones for skeleton soil along Hornsgatan, Stockholm (see Case study 25, p128).

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.

Section for new tree planting



1. New tree size 20-25 cm
2. Tying in tree support
3. Planting soil.
4. Crushed rock at grid 4-8mm thick c. 50 mm
5. Surface grid 1400 x 2800 mm
6. Surfacing superstructure
7. Geotextile
8. Stormwater cover, dished for laying by gutter
9. Air hole placed at level of aerated bearing layer
10. Aerated bearing layer
11. Air and water supply
12. Crushed rock structural soil with planting soil
13. Fertiliser at each structural soil level
14. Pipes in structural soil protected with geotextile and gravel surround.

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

Images: Björn Embrén

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. The manufacturer will typically provide performance criteria and warranties.

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. An aeration system is typically fitted at regular intervals in the installation to allow for effective gas exchange.

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 and durability of such systems depends on the material used for the cells. Plastic crates are usually made of glass-reinforced polymer. Some manufacturers offer concrete crates.

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, polymer-based, 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, polymer-based 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. Concrete cantilevered systems have been in use for longer (about 40 years), with good results.
- 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. Check with product manufacturers to assess their operations, maintenance and repair protocols before deciding which system to use.
- 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 hard landscapes 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.
- In hard landscapes where both surface water management and tree planting are to be provided.

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.

Working solutions: Installation process for various crate systems

Placing the crates, accommodating the water main (see Case study 9, p38).

Filling the crates with tree soil.

Two above images: Martin Gammie

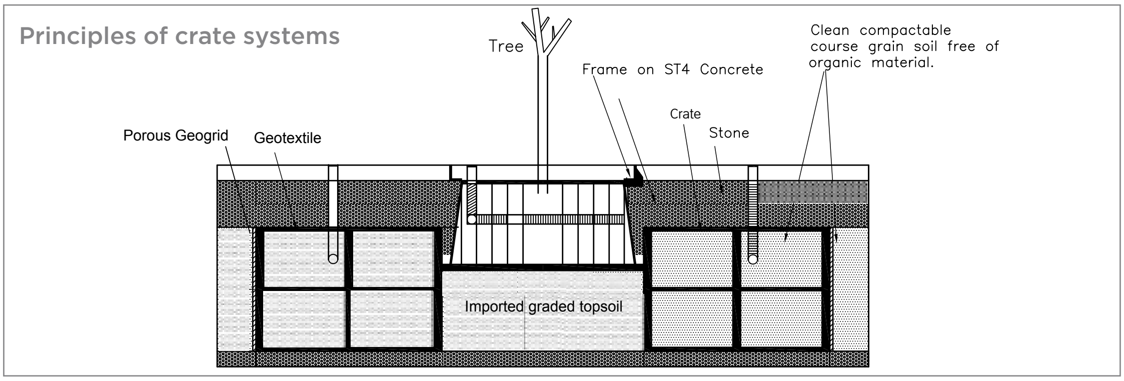


Image: Monson and DeepRoot

Excavation is starting along Ocean Road (see Case study 2, p31).

Compacting base and placing crates.

Crates with aeration/watering tubes being filled with soil.

Tree planted.

Four above images: South Tyneside Council

Positioning concrete crates on prepared island base at Apeldoorn station square (see Case study 24, p127).

Placing cellular units around concrete crates.

Island ready for soil fill.

Filled islands topped with geotextile.

Protective covers are placed over planting holes.

Images:
Ron van Raam

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. The manufacturer will typically provide performance criteria and warranties.

Raft systems broadly fall into two categories:

- Plastic honeycomb-shaped mattress systems (also sometimes called anti-compaction mat, geocell or cellular confinement systems) that are stretched over the root zone and pinned to the ground. This might be used as a temporary protection or permanent protection measure.
- Shallow plastic tiles (80-150mm in depth) that are mounted together, either through pre-assembly or onsite, and anchored into the ground. This tends to be used more exclusively as a permanent solution. The 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.
- Possibility to combine the system with sustainable drainage strategy.
- Ease of installation in retrofit situation around mature trees, without having to dig out the rooting zone.

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 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.

Trees nine years after planting in 2004. St Paul's, City of London. Image: GreenBlue Urban

Working solutions: Raft system installation process

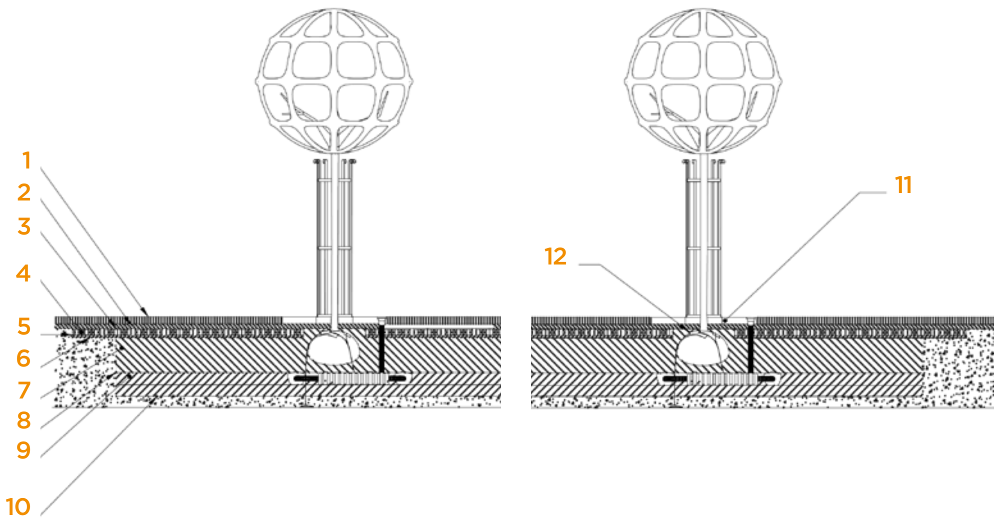
Drainage layer and root ball anchoring system.

Root barrier lining.

Soil and irrigation system.

Permavoid units over geotextile membrane. Image: South Tyneside

Generic section through raft system



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 grille including vent for irrigation
12. Anchor system

Image adapted from: GT Specifier, Landscape Solutions

All non-credited images: Barry Browne

3.3
Integrity of surfaces and above-ground structures

In brief: what needs to be done	Who does it
Use both tree- and infrastructure-based solutions to ensure surface integrity.	– Design specialist(s) – Highway engineer
Appraise all available options in light of objectives and site constraints before taking remedial actions to address existing root-inflicted surface damage.	– Highway engineer - Tree officer/specialist
Seek structural engineering advice on designing foundations in subsidence-prone area so as to accommodate existing and future trees.	– Design specialist(s)
Make careful choice of tree species in areas prone to subsidence.	– Design specialist(s) – Tree officer/specialist

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 solutions. 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.

3.3.1
Tree-based solutions for surface integrity

Species selection

Root damage to hard surfaces around trees often occurs where water-demanding species with fast-growing shallow roots are planted such as willow (*Salix spp.*) and poplar (*Populus spp.*). *The Design Manual for Roads and Bridges*[90] on footway design recommends that new developments give preference to trees that have deep rather than shallow roots. It also emphasises, and this is perhaps more critical, 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 upheaval. 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.

Rooting volume and aeration

If the rooting environment provided is not rich in oxygen-rich voids for roots to grow through, roots will exploit voids and oxygen wherever it is available in their immediate surroundings, such as in footway sub-bases. Planning for and providing ample, well oxygenated, void-rich growing medium for roots is one of the most important considerations in any comprehensive strategy for avoiding damage (see 3.1.3).

3.3.2
Infrastructure-based solutions 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 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

90
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

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 avoid damage. 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 surface upheaval. Root damage mainly emerges in lightly constructed hard surfaces that are laid on a base layer of compacted sand. Research[91] 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 (ie supported from underneath so as to 'float' above the soil and the tree roots) 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.

No-dig surfacing

Where new surfacing close to existing trees is unavoidable, it has to be designed so that there is minimal disturbance to the tree roots and to the tree-rooting environment. In such circumstances, it is important to:

- Limit digging, since a large proportion of the roots are likely to be in the top layer of soil.
- Limit soil compaction.
- Make sure that water can still get through.
- Make sure that gas exchange can continue to take place.

Where hard surfacing is being retrofitted around existing trees, as recommended in Arboricultural Practice Note 12 (APN12)[92], no-dig surfacing provides one possible solution to achieve all the above, while also helping to prevent risks of surface upheaval by roots.

A no-dig surfacing installation typically involves first laying a robust yet permeable geotextile membrane over the existing ground, then laying and securing a cellular confinement system (see 3.2.3) on top of this, and then filling the cells with no-fines angular stone of 20–40mm. On top of the confinement system, a permeable sub-base is laid with a permeable surface on top of the sub-base to complete the installation. Pavers over sand are one example of permeable sub-base and surface.

From an accessibility and drainage perspective, successful implementation of no-dig surfacing requires good anticipation how the new surface level, once the installation is completed, will fit with existing hard surfaces.

From a tree health perspective, there is to date no research available on the long-term impacts of no-dig surfacing on the longevity of trees, particularly in respect to soil contamination and microbial life. As the installation should involve no digging, the new surface could be higher than the surrounding levels.

Root deflectors

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

91
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

92
Patch, D and Holding, B (2007), *Through the Trees to Development. Arboricultural Practice Note (APN) 12*. Farnham, UK: Tree Advice Trust

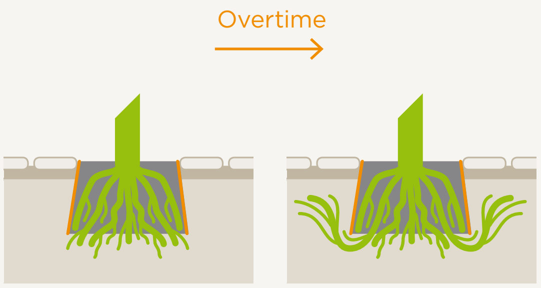
also allow remedial root pruning that might be conducted as a last resort to address surface distortion to be carried out with much-reduced impacts on tree health and structural integrity.

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[93].

93
Morgenroth, J (2008), *A Review of Root Barrier Research*, Arboriculture & Urban Forestry 34(2):84-88

Root deflectors are commercial products and manufacturers can advise on performance criteria and any warranties.

Root deflector and impact on roots



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 may occur (see no-dig surfacing in 3.3.2), combined – or not – with retrofitting of a load-bearing solution in the rooting environment (see Working solutions: Skeleton soil installation process pp100-104) or applying non-invasive soil decompaction techniques.
- 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 surrounding hard surface) and enhancing the quality of the rooting environment immediately around the root ball of the tree (applying non-invasive soil decompaction 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 3.2.2) and stone-based structural substrates (see 3.2.1) 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, p126. It should only be considered as a last resort before removal and conducted under expert supervision.

Regardless of the strategy chosen, it is important that:
- All excavations around the root ball of an existing tree are conducted by trained operatives with non-invasive excavation tools (eg vacuum or pressurised air powered excavators).
- Care is taken to avoid suffocating roots with additional soil build up or reducing root volume by lowering soil levels (see no-dig surfacing 3.3.2).

3.3.4 Trees and subsidence

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

94
NHBC (2014). Standards. Milton Keynes: NHBC.

95
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

96
Hipps, N, Atkinson, CJ (2014), *Pilot study to determine the feasibility of using existing claims data to determine the impact of tree pruning on subsidence incidents on swelling clay soils*. London: The Subsidence Forum.

97
Found at: www.ltoa.org.uk/resources/joint-mitigation-protocol

98
Found at: www.ltoa.org.uk/resources/risk-limitation-strategy

Shrinkable clay and silt subsoil are present throughout the UK, although they are more prevalent and more shrinkable in East Anglia, Greater London and the surrounding counties, and the South East. The best way to assess the ground conditions is by referring to the British Geological Survey (BGS) maps of the UK showing surface drift, as opposed to bedrock. BGS surface drift maps detail where the high risk soils outcrop and they should be consulted whenever assessing risks of subsidence.

Minimising future risk of tree-related subsidence requires:

- Fit-for-purpose special foundation design for buildings and structures, as advised by a structural engineer, bearing in mind the nature of the subsoil and the proximity of existing or proposed trees and shrubs, as well as the potential additional risks from climate change and the possibility of trees or shrubs that may be planted or grow nearby in the future. For further details, see the references provided at the end of this section pp134-135 under 'Subsidence'.
- 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 (x *Cuprocyparis leylandii*). Appendix 4.2A of the NHBC Standards sets out species risk according to soil plasticity index and water demand[94].

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[95] 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[96] 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[97] to manage claims.

For further information on how to handle occurrences of tree related subsidence, refer to the London Trees Officers Association's Risk Limitation Strategy[98].

Careful detailing for surface integrity around trees in Bonn Square, Oxford. Image: Michael Murray

3.4
Underground utilities

In brief: what needs to be done	Who does it
Follow the recommendations found in the National Joint Utility Group publication volume 4.	– Design specialist(s) – Local authority planner – Utility representatives
Maximise the use of common utility enclosures in new large or green field developments and of shared trenches in smaller, infill regeneration and existing situation.	– Design specialist(s) – Local authority planner – Utility representative(s)
Use root-intrusion resistant pipe technology whenever possible, particularly in green field developments.	– Design specialist(s) – Local authority planner – Utility representative
Choose tree species carefully, as well as carefully designing the tree-rooting environment in proximity to sewer pipes.	– Design specialist(s) – Tree officer/specialist

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[99]. This was produced in collaboration with the arboricultural profession and Defra. 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
Rationalising space allocation and access

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 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"*[100].

3.4.2
Avoiding indirect damage

In areas with a high risk of vegetation-related subsidence (see 3.3.4), 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 and expanding due to moisture variations 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 paragraphs 2.1.1 and 3.1.4 of NJUG's publication volume 4 – NJUG *Guidelines for the Planning, Installation and Maintenance of Utility Apparatus in Proximity to Trees*.

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[101] and further developed through Swedish

99
Both can be found at: www.njug.org.uk/publications

100
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

101
Stål, Ö (1998), *The interaction of tree roots and sewers: the Swedish experience*. Arboricultural Journal 22, 359-367

and British collaboration[102] has shown that roots have a penetration force of 15 to 20 bar per square cm, whereas the commonly used rubber joints only withstand six 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*[103] 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 (see 3.1.3).
- Choice of tree species with slower root growth, as described in 3.3.1.
- Use of welded polyethylene (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.
- Where a high number of side connections exist, lining does not remove the weak point associated with the pipe connection. Using 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.

102
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 and 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: Ridgers, D, Rolf, K and Stål, O (2008), *Management and planning solutions to modern PVC and concrete sewer pipes' lack of resistance to root penetration*. 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

103
Found at: http://wales.gov.uk/docs/desh/publications/121001sewerdrainstandardsen.pdf

3.5
Sustainable drainage systems (SuDS)

In brief: what needs to be done	Who does it
Create an open forum to discuss and address the concerns the integration of trees and SuDS might generate.	– Design specialist(s) – Project manager
Seek out and make the most of opportunities to integrate trees and SuDS components.	– Design specialist(s) – Tree officer/specialist – Drainage engineer

As demonstrated in 2.4, the simple integration and/or protection of trees in hard landscapes reduce(s) and attenuate(s) 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 (see 3.1.3).

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 water management 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 (WSUD) principles (see 2.4).

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 subsoil.
- 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. The only context where such provision of an overflow system connecting the tree-growing medium to the local drainage or sewer system may be counter-productive is in areas with high water tables. In such circumstances, the overflow could create an entry point for ground water to leak into the drainage or sewer system.

- *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* [104]. 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 around the surface 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, ten 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

104
The 2007 edition of *The SuDS Manual* (Ciria C697) is found at: 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)

105
The 2007 edition of *The SuDS Manual* (Ciria C697) is found at: 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)

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 17, p77.

3.5.2
Design options for surface water runoff management systems with trees

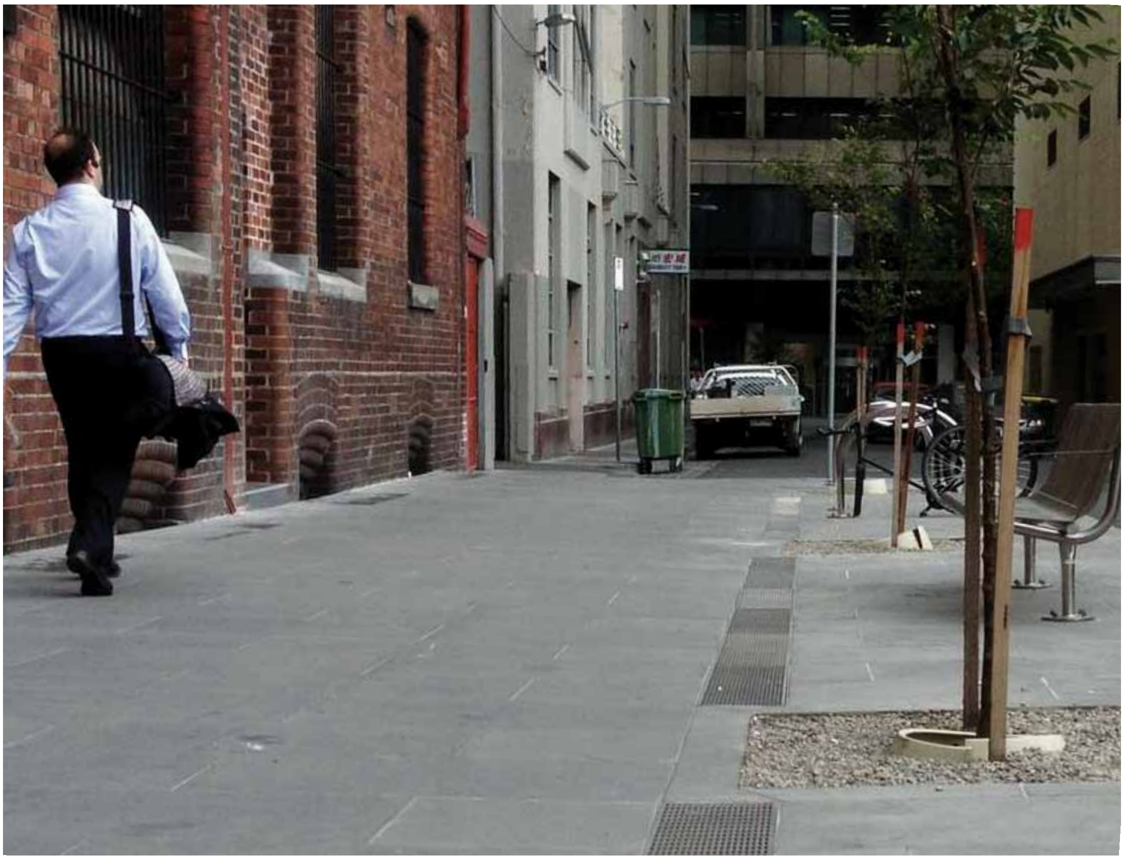
As mentioned above, provision of a large canopy tree, with an adequate rooting environment will in itself already significantly contribute to water management. This can be further enabled through the use of pervious surfacing over all or part of the rooting zone of the tree or by otherwise facilitating 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*[105] 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.

For all design options outlined below, the involvement of a tree specialist for the selection of a species that is adapted to the drainage characteristics of the growing medium is essential.

Pervious surfacing

Pervious surfacing refers to a wide variety of surfaces, including porous concretes, porous bound gravel, porous grit jointed pavements 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.



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

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.

The most prevalent maintenance concern with pervious surfacing, and particularly porous asphalt, is the potential clogging of pores[106]. Proper design, construction, and maintenance is required to limit the reduction of infiltration rates over time 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.
- Regular vacuuming instead of sweeping of debris.

106
Bean, EZ, Hunt, WF and Bidelspach, DA (2007), *A Field Survey of Permeable Pavement Surface Infiltration Rates*, ASCE Journal of Irrigation and Drainage Engineering, Vol. 133, No. 3, pp. 249-255

Crate systems and structural growing substrates

While a small crate installation (see 3.2.2) or a few strips of structural soil (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 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 species 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

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

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 100-400mm/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.

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.

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.

Swale between carriageway and footway in Sathonay near Lyon, France.
Image: Richard Barnes

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

Case study 18
Building a long-lived maritime boulevard treescape

Location
Swansea, Wales

Project category
Highway

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.

Funding secured from the Welsh government, the Wales European Funding Office and its own budget allowed Swansea council to launch in 2010 an ambitious refurbishment programme aimed to turn Quay Parade, Victoria Road and Oystermouth Road into a tree-lined boulevard.

Traffic signals have been modernised, key junctions reconfigured, the number of turning points restricted, footways widened and close to 120 elm trees (*Ulmus spp.*) have been planted. Elms were selected for their longevity, capacity to withstand maritime exposure, compact habit, small seeds and leaves that decompose quickly. A licensed cultivar resistant to Dutch elm disease was procured.

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.

A 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.

To grow healthy, long-lived, conflict-free, elms in this context, sand-based tree soil was used to backfill the tree planting holes. Given the high level of the local water table, the sand-based tree soil helps provide good drainage and prevent waterlogging, while also allowing percolation to keep the trees well supplied with water. Where utility constraints allowed, the dimensions of each tree-planting hole were extended to enable roots to access the good growing environment found in adjacent landscaped areas. The surface opening around each tree is covered with an adaptable grille made of incrementally removable concentric rings of aluminium in-filled with 10mm resin-bound red granite chippings, except in the ring closest to the tree trunk where matching unbound clean red granite chippings is used. The grilles are level with the surrounding footways, thus maximising pedestrian access while allowing for some of the surface runoff to enter the root growing environment.

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

Case study 19
Structural soil for resilient footways in Slaney Road

Location
Walsall, England

Project category
Residential

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

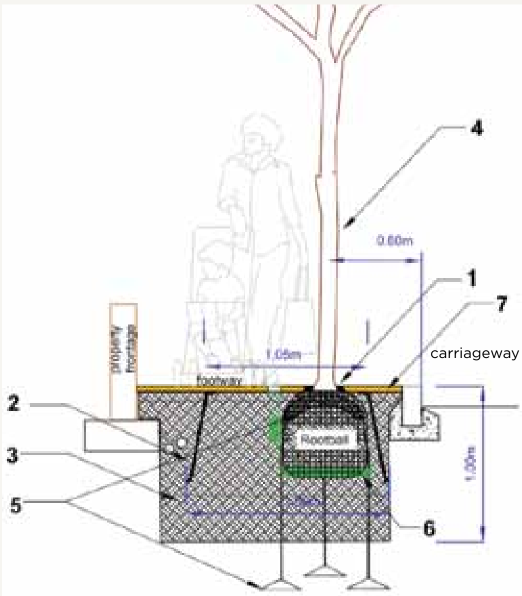
Following consultation with local residents and representatives, it was decided that approximately 60% of the trees would be removed in the narrowest portion of the street and replacement planting would take place. While consensus was reached, there were conflicting views, including strong dissatisfaction 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 adopted a collaborative approach to the 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: Tree planting detail used on Slaney Road.
Image: Adapted from Walsall Council

Below right: Sweet gum trees planted to replace mature limes that had overgrown their location.
Image: Anne Jaluzot



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

Case study 20
Skeleton soil breathes new life in trees in Erik Dahlbergsallén

Location
Stockholm, Sweden

Project category
Highway

The results of central Stockholm's first full street tree inventory asset prompted dramatic change. The survey showed that approximately one third of the trees were dead, another third were in very poor health, and the remaining third were healthy. 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 abundant oxygen and water supply to the roots to promote good tree health, prevent the risk of surface upheaval and guarantee good load-bearing capacity. It also only required 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* 'Baumannii' – double-flowering sterile variety) 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 wells. 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 every autumn through the diameter at breast height (dbh) at one metre above ground, has been as follows:

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

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

Case study 21
Coed Aber – creating a tree-lined gateway to Aberystwyth

Location
Aberystwyth, Wales

Project category
Highway

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 of 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 aesthetic and sense of place. This was deemed a real obstacle to enhancing the economic prospects of this university town, administrative centre and seaside resort.

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[107] 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 tight delivery deadlines.

107
Found at:
www.youtube.com/watch?v=ePodgfip2EQ

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 specimen trees and a more formal avenue planting. This approach also helped to diversify the species being planted and make 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 system and a crate system (Stratacell) 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 the 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

Case study 22
St George's Street where trees and seats create a plaza

Location
Norwich, England

Project category
Commercial

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 (Stratacell) 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 tree specialist 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 tree specialists, four landscape architects and four engineers from Norwich city council took part and commitment to trial the crate 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

Case study 23
Haaksbergerstraat cycle lane retrofit

Location
Hengelo, The Netherlands

Project category
Highway

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 a 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

Case study 24
A pine forest for Apeldoorn station square

Location
Apeldoorn, The Netherlands

Project category
Public realm

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 easy and inclusive access to the train platforms and 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 meet 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 save time and money, 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

Case study 25
Lidl's New Milton car park manages roof runoff with trees

Location
New Forest, England

Project category
Commercial

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, together with five plane trees (*Platanus x hispanica*) and all that was needed for them to become long-lived specimens. Right from the first pre-planning meeting, the New Forest district council tree officer made a firm request to the prospective applicant 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 (Silva Cell) in the design of the rooting environment underneath the car park and connection of the installation to the downpipes collecting surface runoff from the 800m2 store roof. The request was translated into robust, enforceable planning conditions associated with the landscaping schemes attached to the planning permission. Time was allocated for the officer to conduct regular site visits during construction to ensure that 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 left: Completed installation, with permeable paving.
Image: Liz Beckett

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

Case study 26
Hornsgatan's environmental remediation

Location
Stockholm, Sweden

Project category
Highway

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, airborne 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 redesign 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 features 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 species first proposed was Scots pine (*Pinus sylvestris*), which is particularly effective in removing airborne particles. As the primary drivers for the scheme evolved, so did the choice of species to be planted. Maidenhair (*Ginkgo biloba*) was selected for its tolerance to air pollution (Hornsgatan still has rather poor air quality levels, even though the concentration of certain airborne 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. Maidenhair was also selected for its 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 ginkgoes between carriageway and cycle track where space allows.
Image: Björn Embrén

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

Case study 27
Creating green links through East Walworth

Location
Southwark, London, England

Project category
Mixed-use

The East Walworth green link project is an experiment in retrofitting rain gardens with trees in the residential streets of East Walworth, a neighbourhood located just south of Elephant and Castle in Southwark, London. The project evolved from a community-initiated proposal to create safe and enjoyable walking and cycling routes across the borough. Once Southwark council had bought into the green links idea, its delivery team seized the opportunity to trial, on a modest scale, the retrofit of rain gardens in streets.

In East Walworth, the green link route 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 21 p125) and Minneapolis, MN (see Case study 4, p33). However, the installation does not feature the “aeration layer” typically used as part of the Stockholm system 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 month after planting in November 2013 was not 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 28
Thames Water sponsors green in Counters Creek

Location
London, England

Project category
SuDS

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 £250m 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 sensors 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: Thames Water

Quick Check

Is the below-ground design adequate to ensure long-term success?

Local authority planner

Have you...

- ○ Adequately considered the need to include planning conditions for the use of load-bearing systems for new developments involving trees in hard landscapes?
- ○ Adequately considered the need to include planning conditions for the use of root intrusion resistant pipe technology as well as common utility enclosure for new developments?
- ○ Enforced planning conditions related to trees?
- ○ Ensured that existing trees are protected during construction to an approved methodology that is monitored regularly and reported?

Project manager

Have you...

- ○ Facilitated effective communication in the project team to secure a shared understanding about what trees need to grow and mature or be successfully retained in hard landscapes?
- ○ Facilitated effective communications between the project team to ensure a shared understanding of the requirements for load bearing, footway accessibility and access to utilities around trees?
- ○ Anticipated the training, contracting and works sequencing implications if the design integrates load bearing into the rooting environment?
- ○ Checked that enforcement of tree protection zones and other agreed tree and soil protection measures is taking place throughout implementation?
- ○ Ensured that adequate provision is made in the cost plan to deliver the entire proposal above and below ground?

Design specialist(s)

Have you...

Sought to provide or maintain quality rooting environment by:

- ○ Following *BS 8545:2014*?
- ○ Investigating whether the inclusion or retrofitting of a load-bearing system is required?
- ○ Making yourself familiar with all available load-bearing systems before making a final choice, seeking expert advice as necessary?
- ○ Anticipating the training, contracting and works sequencing implications?
- ○ Anticipating the implications of tree protection zones and other relevant tree and soil protection best practices (eg oil tray, temporary rafts, etc) in the staging and organisation of the works?
- ○ Specifying the use of non-invasive excavation techniques around existing trees to be retained?

Planned for trees and infrastructure together by:

- ○ Making careful choice of tree species in proximity to existing sewer pipes or in areas prone to subsidence?
- ○ Following the NHBC standard for the design of building foundation next to an existing tree in subsidence-prone areas?
- ○ Following the advice provided in this guide to avoid or remedy surface upheaval by tree roots?
- ○ Referring to *NJUG Guidelines* and maximise the use of common utility enclosure (new large or green field development) or shared utility trenches (smaller infill or retrofit situations)?
- ○ Maximising opportunities to integrate trees and SuDS components?

Tree officer/specialist

Have you...

- ○ Followed *BS 8545* to guide specifications on the sizing and quality of the rooting environment?
- ○ Provided access to adequate expertise on available techniques to enhance the load-bearing capacity of tree-rooting environments?
- ○ Defined adequate tree and soil protection or management measures for existing trees in close proximity to works?
- ○ Checked the enforcement of tree protection zones and other agreed tree and soil protection measures during construction?
- ○ Checked the enforcement of *NJUG guidelines*?
- ○ Collaborated with the design leader to ensure design, details and implementation are feasible?

Highway engineer

Have you...

- ○ Reviewed and communicated the load-bearing capacity required for surfaces over existing or future tree-rooting areas?
- ○ Sought advice on available technical solutions to enhance the load-bearing capacity of tree-rooting environment and maintaining the integrity of hard surfaces over tree roots?
- ○ Ensured the Local Planning Authority’s Highway department is satisfied that the proposals are adoptable?

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i Non-technical publications and resources | P Professional publications and resources | A Academic publications

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Species Selection Criteria

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

While tree species selection alone cannot make up for poor design or inadequate underground growing conditions, choosing the right tree for the right place is an essential final ingredient for success.

The temptation is strong to 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.

All those involved with the urban forest today are concerned to achieve species diversity. A wider choice of appropriate tree species is available than commonly thought for in streets and other hard landscaped areas. A wider choice of tree species is available than commonly thought.

As the possible combinations of the variables that influence tree choices are so numerous, conducting a site-specific robust assessment with support from expert tree knowledge is the best approach.

Aims

The aims of this section are to provide:

- A five-step process to guide the analysis required to achieve a long lasting and successful choice of trees.
- Basic knowledge of other selection, storage and handling parameters. that will affect the health and quality of newly planted trees.

Requirements

The project requirements covered in this section are:

- Tree selection criteria matrix for the site.
- Tree specification.

Wider Benefits

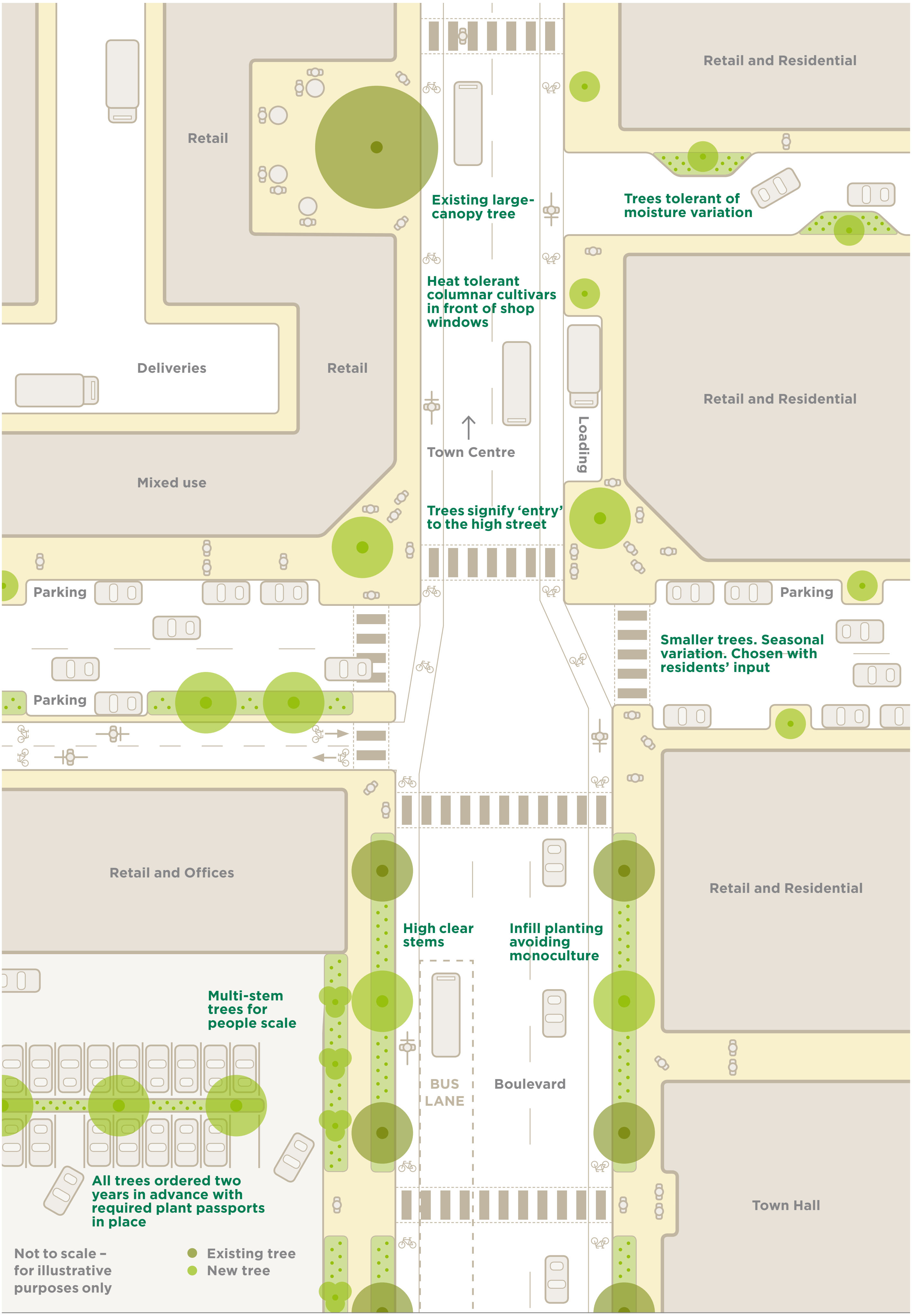
The wider benefits to be gained are:

- Achieving ‘right place, right tree’.
- Enhancing tree population resilience to pest, diseases and climate threats.

Species selection has been part of the iterative process

The diagram opposite shows how species selection is guided by site constraints, design intent and anticipated benefits.

Multiple species are used for resilience and supported by the procurement of quality stock.


Retail
Retail and Residential
Existing large-canopy tree
Trees tolerant of moisture variation
Heat tolerant columnar cultivars in front of shop windows
Deliveries
Retail
Retail and Residential
Town Centre
Loading
Mixed use
Trees signify 'entry' to the high street
Parking
Parking
Smaller trees. Seasonal variation. Chosen with residents' input
Parking
Retail and Offices
Retail and Residential
High clear stems
Infill planting avoiding monoculture
Multi-stem trees for people scale
BUS LANE
Boulevard
All trees ordered two years in advance with required plant passports in place
Town Hall
Not to scale – for illustrative purposes only
Existing tree
New tree

4.1
Key site constraints

In brief: what needs to be done	Who does it
Understand site constraints in respects to tree health, conflict and nuisance avoidance as well as maintenance needs and capacity.	– Design specialist(s) – Tree officer/specialist
In new developments, explore opportunities to influence site planning to provide suitable space and conditions for trees – don't take constraints for granted, be prepared to negotiate.	– Design specialist(s) – Tree officer/specialist

The selection of the appropriate species for any given planting site is dependent on many interlinked factors all of which influence the likelihood of final success or failure.

All trees have their own specific characteristics and tolerances which may make them more or less suitable for planting on a particular site. These characteristics and tolerances are linked to the geographic location and environmental conditions under which the tree grows in nature and can often be used to inform species choice for planting in the urban environment.

All trees are dependent on the environment in which they grow. The urban environment presents many challenges to tree health which need to be appraised and factored into the species choice. These include:

- *Soil characteristics*: texture and structure as determined by a soil scientist.
- *Soil compaction*: this inhibits and prevents root development, limiting gas exchange and inhibiting water flow.
- *Soil pH*: this inhibits or enhances the availability of nutrients available to the tree. In the urban environment pH is often found to be alkaline which can limit species choice. When using structural growing media, it is important to remember that the type of aggregate or stone used in the mix may affect the prevailing pH (see 3.2.1).
- *Water availability and movement*: this is influenced by soil structure and irrigation practice following planting. It should also be noted that many hard landscapes, particularly in inner-city environments in south east England, will require a degree of drought tolerance. Trees that can tolerate waterlogged soils are particularly useful for SuDS applications.
- *Temperature*: the urban heat island effect results in higher temperatures in the built environment. Reflected heat from buildings and other infrastructure often produce localised temperature gradients which also need to be considered. (See also 2.5.4)
- *Sunlight and shade*: exposure to sunlight and shade is influenced dramatically by the height of buildings, their aspect and position. Not all trees cope well with being in the shade most of the time.
- *Pollution*: trees growing near to high vehicular traffic are particularly exposed to atmospheric pollution, which not all species are able to cope with well. Trees in hard landscapes might also be exposed to the seasonal application of road salt, which can require species tolerant of salt spray and/or saline soils. (See 2.6.3)
- *Wind*: The canyon effect created by tall buildings influences and wind direction and speed often creating areas of localised turbulence. Wind increases water lost from the tree to the atmosphere so more drought tolerant species should be selected for windy locations.

Other site constraints to take into consideration in order to minimise risks of conflicts and nuisances include:

- *Available space above and below ground* (see 2.1.1 and 2.3).
- *Intensity of use of the areas immediately around and beneath the tree*. Species that are known to have a propensity for premature whole-tree or limb failure, or for rapid deterioration of condition when damaged or infected should be avoided in high-use settings (see 2.5.1).
- *Presence of shrinkable clay or silts subsoils*. Where soil subsidence is a concern, the water uptake from the tree is an important factor to consider (see 3.3.4).

- *Proximity to sewer and surface water pipes* (see 3.4.3).
- *Impact of litter* (see 2.6.1).
- *Impact of pollens*. Most allergies are specific to one type of tree or to the male cultivar of certain trees (see 2.5.2).

The selection of the right tree species for any given planting site is an intellectual process in which all of the above factors are considered and matched with the natural tolerances and characteristics exhibited by the tree itself. The tendency is to look towards a limited palette of species which have a proven track record in the urban environment. This can be avoided by involving the tree specialist at an early stage in the design/planting process.

Given the longevity of correctly selected and planted trees it is important to note that the climate model projections for mid-century indicate an increasing risk of hotter drier summers and warmer wetter winters, coupled with increased frequency of extreme weather occurrences such as heat waves, dry spells, heavy rain and flooding. The selection of species more suited to extended dry periods and high heat will be beneficial. Other stresses caused by warming will include more pests and pathogens. The Right Tree for a Changing Climate online database[108] 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.

108
Found at: www.righttrees4cc.org.uk

Trees incorporating surface water runoff enhance this residential street in Vancouver, Canada. See Case study 27, p130.
Image: DeepRoot Green Infrastructure LLC

4.2
Tree population resilience requirements

In brief: what needs to be done	Who does it
Create or contribute to a diverse tree population, following the 5 or 10% rule at the population scale.	– Design specialist(s) – Tree officer/specialist
Consider using species with different growth rates and life expectancy.	– Design specialist(s) – Tree officer/specialist
Double check that the species considered are not on the invasive species list identified by the Great Britain Non-Native Secretariat or the EU list 'species of high concern' (from 2015).	– Design specialist(s) – Tree officer/specialist

> *"We need a diversity of trees in our urban forests, not only to guard against disasters like Dutch elm disease, but also to 'put the right tree in the right place' as the evolution of our cities and suburbs creates new settings for tree planting."*
>
> Frank S Santamour

The use of a limited palette has wider implications for the tree population as a whole. It has long been recognised that over reliance on one or a few species in the urban environment decreases the resilience of the tree population as a whole to the impact of pest and/or disease. Tree population resilience relates to the contribution the scheme makes to enhancing or sustaining the diversity of the local and wider tree population. Failure to take into consideration population 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 to contribute to population resilience when making species choices include:

- *The 5-10% species diversity rule*. Research[109] indicates that no single species should account for more than between 5-10% of any single population. This is reflected the recommendations made in *BS 8545:2014*. As demonstrated in Case study 31, p149, putting this principle into practice must consider scale: the 10% or 5% diversity rules are best considered at a citywide scale. There is however a responsibility at individual scheme, neighbourhood and borough level to understand the contribution of a particular proposal to overall species diversity.
- *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.
- *Compliance with invasive non-native species planting restrictions*. While non-native species might be appropriate for planting in hard landscapes, those that are invasive may cause harm to the environment, the economy and/or people's health and should therefore be avoided. Information on species banned in the UK is maintained by the GB Non-Native Secretariat[110] and from 2015, the EU is also expected to release a list of 'species of high concerns'. Both should be consulted prior to any final species choice is made. The local Biodiversity Partnership might also be maintaining a 'list of species of concern' for the area[111]. Checking against these existing lists helps ensure the longevity of tree planting programmes and limits the chance of unintentionally spreading invasive non-native species.

109
Santamour, FS (1990), *Trees for urban planting: diversity, uniformity, and common sense.* USDA, Proceedings of the 7th Conference of the Metropolitan Tree Improvement Alliance

110
www.nonnativespecies.org/home/index.cfm

111
See for example the list maintained by the London Biodiversity Partnership found at: www.lbp.org.uk/LISI.html

4.3
Functional and aesthetic attributes

In brief: what needs to be done	Who does it
Factor the "tree benefits" to be gained (eg reduction of PM10, enhancing wildlife habitat, etc).	– Design specialist(s) – Tree officer/specialist
Factor aesthetic considerations (tree crown shape, density, texture, colour of foliage, seasonal variations) and mature size and longevity.	– Design specialist(s) – Tree officer/specialist

Each tree species and cultivar offers functional and aesthetic characteristics such as flower colour, bark colour, leaf shape and autumn colour, shape and habit, shade provision. While such characteristics are obviously important, they are often used as the primary driver in species choice. The use of these characteristics irrespective of the suitability of the tree to survive in the environment in which it is being planted (see 4.1) is likely to lead to failure.

Trees also offer many additional benefits such as habitats for urban wildlife, interception and absorption of some air pollutants, the potential to intercept rainwater and contribute to stormwater attenuation etc. Different species have different potential to deliver the above benefits and few will deliver them all. Identifying the benefits required and matching them with the characteristics and tolerances found in different trees species is likely to create the conditions for success.

4.4
Shortlist of options and customer feedback

In brief: what needs to be done	Who does it
Seek expert advice to make an informed pre-selection.	– Design specialist(s)
Consult nurseries prior to finalise the shortlist.	– Design specialist(s)
Whenever possible, engage end-users and maintenance staff in the final decision.	– Design specialist(s) – Tree officer/specialist

Detailed design and species selection is an iterative process.

Substantial knowledge of tree species and their cultivars 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.

It is vital to engage with a tree nursery or nurseries at an early stage in a project as this will help to ensure that the desired species and specification is actually achieved and delivered on time to the final planting site.

It is important to consult local communities, end users and maintenance staff before making a final decision.

In brief: what needs to be done	Who does it
Understand the constraints and benefits of each of the three main tree production systems prior to issuing specifications.	– Design specialist(s) – Tree officer/specialist
Follow Chapter 8 of *BS 8545:2014* for writing the tree specification.	– Design specialist(s) – Tree officer/specialist
Visit the providing nursery to select and check the trees being purchased (this maybe several years in advance).	– Design specialist(s) – Tree officer/specialist

Once a suitable species or combination of species has been selected for any given site it is imperative that high quality tree stock is provided.

Specifying good practice in nursery production, handling and storage, planting and aftercare and maintenance is crucial for success. *BS 8545:2014* provides a comprehensive reference for the construction of detailed specifications to encompass all of the above elements.

Specifications should require that tree nurseries supply trees of the highest quality and fit for purpose. Beyond identifying the species and cultivar(s) required, specifications should cover morphological conditions, physiological condition, production method(s) and bio-security issues.

Specifications related to morphological conditions, should include details of:
- Stem girth.
- Tree height.
- Clear stem height.
- Central leader and branch structure.

Additional features such as stem taper and height to stem ratio can also be specified.

Beyond morphological conditions, it is also important to ask for evidence of good physiological health.

In describing the nursery production system required (bare root, root-balled or containerised tree), a specification should include the number of times the tree(s) has been transplanted.

For bio-security, full traceability (plant passport) should be required.

Finally, it is important to visit the supplying nursery or nurseries to check that good practice is adhered to and also to take part in selecting and tagging the trees.

Refer to Appendix D1 of *BS 8545:2014* for further background. Recommendations presented in Chapter 8 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 fruit. Image Anne Jaluzot

Deciduous and evergreen mix for ecological resilience and year round interest in Stoke Newington, Hackney, London. Image: Rupert Bentley-Walls, London Borough of Hackney

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

4.6
Reception, handling and temporary storage

In brief: what needs to be done	Who does it
Use the checklist in paragraph 10.4 of *BS 4585:2014* to inspect trees upon delivery; do not accept poor stock.	– Tree officer/specialist
Adhere to paragraph 9.5 of *BS 4585:2014* for on-site handling and storage of trees prior to planting.	– Tree officer/specialist – Tree contractor(s)
Plant trees as quickly as possible following delivery.	– Project manager – Tree officer/specialist – Tree contractor(s)

For maximum chance of success, it is important that new trees planted are healthy and fully meet the specification issued. This will be best ensured through:

- *Visiting the supplying nursery*. Choose the tree stock and/or check that the earmarked tree stock is of adequate quality. It will also provide an opportunity to ensure that the supplying nursery adheres to good practice.
- *Inspecting of the tree stock upon delivery*. The checklist provided in *BS 8545:2014*, paragraph 10.4, Table 1, should be used to inspect every tree prior to acceptance of delivery to site and planting. Trees showing defects, damage due to lifting and dispatching, or not meeting the specifications should not be accepted and the dispatching nursery immediately notified.
- *Good on-site handling and temporary storage*[112]. Care is required to unload the tree(s) from the delivery lorry. Under no circumstances should trees be dropped from the lorry platform onto the ground as this would cause serious damage to the tree roots. If bare root trees are used, adequate protective measures should immediately be taken after unloading to avoid drying of the roots. Whether bare root, root balled or containerised, trees should always be stored in an upright position, supported and irrigated. Temporary storage before planting ought to be kept as short as possible.

112
Refer to *BS 8545:2014*, paragraph 9.5

Oak trees at the heart of New Street Square, City of London. Image: Steve Parker

Case study 29
Choosing trees for South Street, St Andrews then and now

Location
Fife, Scotland

Project category
Highway

South Street is one of the two principal streets that form the basis of the medieval town plan, which was laid out on a rough grid. The street was designed to accommodate ceremonial processions to the cathedral precinct.

As shown in the two photographs below, the street has preserved the 19th-century tripartite design. Both sides of the carriageway feature a paved footway and cobblestone strip planted with large leaved lime trees (*Tilia platyphyllos*). 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 uses 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 preferred over its UK-native, large-leaved cousin as it is smaller in size with a similar form, and offers disease and pest resistance – including aphids.

Postcard of South Street in 1896 South Street in 2014. Image: Stephen Liscoe

Case study 30
Wise microclimate tree selection for Cheapside

Location
City of London, England

Project category
Highway

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. Unnecessary street furniture has 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 species. 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 team further observed that, while Cheapside is a historic street, it had lost its historic building frontage and 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. The design approach therefore prioritised a linear planting arrangement and adaptation to microclimate over the creation of a unified avenue effect. The shady side of the street is planted with alder trees (*Alnus x spaethii*) while the opposite, sunnier and hotter footway has American sweet gums (*Liquidambar orientalis*).

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%, bicycle traffic has risen by over 200%, while motorised traffic has remained stable.

Cheapside in the early autumn.
Image: City of London

Case study 31
Building local identities through tree diversification

Location
Lyon,
France

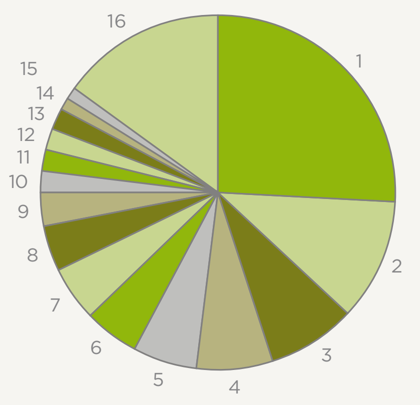
Project category
Public policy

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 p39, and Sathonay p51 for examples).

According to Frédéric Ségur, the GLA tree specialist, 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, conditions or space availability."*

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

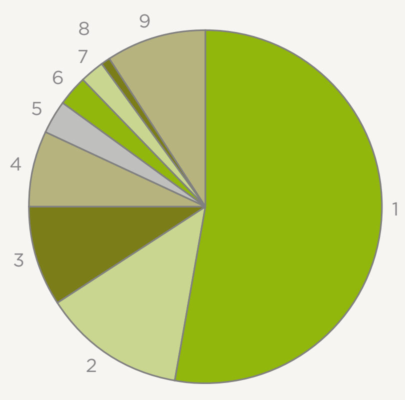
Species distribution in 2013 (%)



		%
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**

Case study 32
Westminster's plan for Church Street and Paddington Green

Location
London, England

Project category
Residential

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 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 to complement these targeted interventions with a wider range of environmental enhancements.

The final selection of the multi-disciplinary design team appointed to lead on this work 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 pollutants removal 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 Infrastructure and Public Realm Plan provides clear principles and recommendations for tree selection, below-ground tree-rooting environment design and integration with utilities. Given local constraints and project objectives, the recommended tree planting list is designed as a matrix highlighting maturity size, rooting habits and management requirements as well as the air pollutants removal benefits, ability to withstand varying soil moisture (to suit the rain garden locations) and the wildlife value of each species included. 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 plan 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 layout was informed by a radar service survey and existing underground utility maps.

For delivery, the Infrastructure and Public Realm Plan is broken down in sections, each associated with one of the development plots. 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. All principles established in the plan are reproduced in the brief issued to developers tendering.

Rendering for Orchardson Street.
Image: Grant Associates

Well-managed leaning trees can be compatible with high-sided vehicles. Image: Steve Parker

Celebrating the grandeur of trees in winter. The Turl, Oxford. Image: Michael Murray

Quick Check

Are tree selection and procurement on the right track?

Project manager

Have you...

- ○ Ensured that tree selection and ordering processes meet the project programme?

Design specialist(s)

Have you...

- ○ In a new development, explored opportunities to influence site planning to provide suitable space and conditions for trees?
- ○ Identified key site constraints for trees (soil texture and structure, water access, temperature, sunlight, wind exposure, pest and pathogens present in the area, presence of shrinkable soils, proximity to sewer or surface water pipes, available space, intensity of use, tolerance for tree litter, capacity for maintenance)?
- ○ Identified aesthetic and functional requirement for trees (shape, scale, texture, seasonal variations, particulate matter filtering capacity, wildlife benefits, etc)?
- ○ Sought input from the tree officer/specialist on the characteristics of the local tree population?
- ○ Sought specialist input to analyse the tree selection criteria identified (site constraints, expected benefits, tree population resilience) and shortlist some potential options?
- ○ Liaised with tree nurseries to understand availability and lead time before making any final choices?
- ○ Recommended to client the possibility of advanced procurement?
- ○ Sought customer / community engagement in final decisions?
- ○ Worked with a tree specialist to write a competent tree specification, following the recommendations in chapter 8 of *BS 4585:2014* and featuring adequate definition of morphological conditions (including expected stem girth, tree height, clear stem height, branch structure, stem taper, height/stem ratio) as well as physiological health and traceability?
- ○ Visited the tree nursery to tag tree stock and, if advanced procurement, to ensure necessary agreements are in place?

Tree specialist

Have you...

- ○ Ensured nurseries are consulted early on stock availability and lead-time for special orders?
- ○ Followed chapter 7 of *BS 8545:2014* when guiding or advising on tree selection?
- ○ Followed chapter 8 of *BS 8545* when issuing or guiding the writing of the tree specification – ensuring morphological, physiological, and traceability issues are all adequately covered?
- ○ Visited the tree nursery with the design specialist to pick the tree stock to be used and checked evidence of abidance with specification?
- ○ Ensured adequate storage of the tree stock once delivered onsite?

References

Non-technical publications and resources	Professional publications and resources	Academic publications

P

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

A

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

A

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

P

Trowbridge, PJ and Bassuk, NL (2004), *Trees in the Urban Landscape: Site Assessment, Design, and Installation*. Hoboken, NJ: Wiley & Sons, Inc.

Case study finder

	Case study reference	Location	Page	Context: Arterial street	Context: High street	Context: Residential street	Context: Public square	Context: Car park
1	Melbourne's urban forestry programme	Melbourne, Australia	30	●	●	●	●	
2	Supporting retail on Ocean Road	South Tyneside, England	31		●			
3	New trees at Chobham Manor Phase 1	Stratford, England	32			●		
4	Stockholm system in the USA	Minneapolis, MN, USA	33			●		
5	Specimen trees in Dortmund Square	Leeds, England	34				●	
6	The Angel Building – unlocking planning	Islington, London, England	35	●				
7	Wirral Green Streets Programme	Birkenhead, England	36	●		●		
8	Bath Road integrating trees and highway	Bristol, England	37	●				
9	Trees in public car park, Henley-on-Thames	Henley-on-Thames, England	38					●
10	Green-grey-blue infrastructure in Lyon	Lyon, France	39	●				
11	Reclaiming road space for trees	Lyon, France, London, England	71	●	●	●	●	●
12	Enhancing road safety and bus journeys	Bristol, England	72	●	●			
13	Improving safety in Glen Innes	Auckland, New Zealand	73			●		
14	Linear orchards for cycling route	Hackney, London, England	74			●		
15	Shared space and trees in Leonard Circus	Hackney, London, England	75				●	
16	Revitalising retail	Bristol, England	76	●	●			
17	Rainwater harvesting for irrigation	Lyon, France	77	●				
18	Tree-lined boulevard in Swansea	Swansea, Wales	122	●				
19	Trees and resilient footways, Slaney Road	Walsall, England	123			●		
20	Existing and new trees in skeleton soil	Stockholm, Sweden	124	●	●			
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Case study reference	Design objectives								Use of load-bearing or load-spreading tree planting solutions				
	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 (Stockholm system)	Crate system	Raft system
1	●						●	●					
2	●		●									●	●
3	●												
4	●										●		
5						●						●	
6	●												
7	●		●	●									
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9							●					●	
10			●	●			●	●			●		
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28		●	●				●						
29			●					●					
30	●	●						●					
31													
32	●		●				●						

Glossary

Arboriculturist: cultivates and manages trees, hedgerows including felling, preserving, planting and protecting trees and providing information and advice on specific tree-related issues.

Arborist: works at a practical level doing hands-on tree and shrub maintenance.

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.

Dormant season: a phase in the lifecycle of trees when growth and many associated metabolic processes are temporarily stopped, helping to conserve energy until warmer and lighter conditions return. Trees typically go dormant during the winter months.

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.

Invasive non-native species: a non-native animal or plant that has the ability to spread causing damage to the environment, the economy, our health and the way we live.

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.

Post-planting care: minimum five year maintenance programme of watering, formative pruning, adjusting of support systems.

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.

Root protection area: the minimum area around a tree deemed to contain sufficient roots and rooting volume for the tree to remain alive, and where the protection of the roots and soil structure is treated as a priority (formerly called tree protection zone in *BS 5837* before the 2012 revision).

Safe useful life expectancy (SULE): method of assessing the relative importance of individual trees, categorized as 'good', 'medium' or 'bad' within an identified group or area (usually a development site). Subjective and so cannot be absolute judgement.

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 footways, car parks, carriageways) while permitting root growth.

Structural soil: see structural growing medium

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.

Surface opening: the opening created for and left after the tree has been planted.

Stockholm system: tree-rooting environments with large stones (large-stone skeleton soil) for stormwater infiltration and effective gas exchange.

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

Tree opening: see surface opening.

Tree planting hole: excavated hole of adequate dimensions to accommodate the root ball of a newly planted tree.

Tree protection zone: see root protection area.

Tree-growing environment: see tree-rooting environment below.

Tree-rooting environment: the wider area of growing medium that roots can expand into to support the growth of the tree.

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

Urban forest: the overall tree population in a defined urban area.

Urban forestry: is the planning, design, establishment and management of trees for their contribution to the physiological, sociological and economic well-being of urban society.

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* Member of the project steering group

***Trees in Hard Landscapes: A Guide for Delivery* was produced by the following core team:**

- Project management and fundraising: Sue James, TDAG
- Lead advisors: Martin Gammie, arboriculture consultant and Mike Morris, consultant highway engineer
- Project steering group: see names marked with [*] below
- Research and writing: Anne Jaluzot, green infrastructure planning consultant
- Design: Reduction
- Editing: Michelle Pauli

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Afterword

A wide range of experts has 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. Periodic updates will therefore 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.

Photographs are mostly from site visits by project team members rather than professional photographs and reflect the conditions found at that time. TDAG will endeavour to post some updated images on its website to show how some of the schemes are maturing.

Martin Kelly
Chair Trees and Design Action Group
and Director of Land Planning,
Capita Property and Infrastructure

Trees & Design Action Group

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

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