THINKING LIKE A TREE: DEVELOPING A FRAMEWORK FOR TREE SENSITIVE URBAN DESIGN

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1.0 INTRODUCTION

The following paper summarizes research being undertaken at the University of Adelaide School of Architecture, Landscape Architecture and Urban Design, aimed at developing a framework for the more sustainable design off urban streets, to better integrate natural processes, including street trees, into the design of the street. The role of street trees and their biological needs are discussed, and a range of more sustainable design practices is presented, with examples from Australian cities.

2.0 STREET TREE BENEFITS

The benefits of urban trees

The benefits of urban trees and the urban forest are now well recognised. In environmental terms, trees help reduce the urban heat island effect, oxygenate and purify the air, and sequester carbon through photosynthesis. Trees and urban forests also play an important role in the urban, water cycle, intercepting rainfall and modifying runoff. Ecologically, urban trees can enhance biodiversity and create habitats and corridors for wildlife.

Urban trees are also of psychological value, and the therapeutic and restorative effects of urban nature have been well researched. Urban trees can be of significant cultural and symbolic value, with long lived trees providing continuity and a link between generations. Trees, because of their scale, are the major element in urban landscape design. Finally, the real economic value of urban trees is now being recognised, both individually and collectively in terms of the total economic value generated by the urban forest.

The role of street trees

Street trees, in addition to these more general benefits, also generate more specific benefits in terms of their role in the design and use of urban streets. Street trees are more than just “aesthetic decoration” and provide a range of tangible benefits. They are perhaps the single most important factor in the design of urban streetscapes.

According to Alan Jacobs in his book *Great Streets* (Jacobs 1993) p293

> Given a limited budget, the most effective expenditure of funds to improve a street would probably be on trees. Assuming that trees are appropriate in the first place, and that someone will take care of them, trees can transform a street more easily than any other physical improvement. Moreover, for many people trees are the most important single characteristic of a good street.

Street trees play an important visual role in the design of a street. They provide spatial definition and human scale in an environment dominated by large buildings. A row of trees planted alongside the kerb provides physical and psychological separation between pedestrians and passing traffic. An avenue of trees can provide a unifying element in a diverse streetscape. In a broader sense, street trees are “place-makers” that can create or reinforce a sense of local identity. The pattern of street tree planting can also be used to enhance legibility and way-finding in the city. Street trees are probably the single most important factor in creating pedestrian amenity. Properly selected trees provide much needed shade and shelter. They also provide visual interest in the streetscape due to their colour, shape and sense of movement.

The real economic benefits of street trees are now also well recognised, in terms of both residential property values and increasing visitation to business centres.

Street trees are now being recognised as important elements of “green infrastructure” existing alongside the “grey infrastructure” of roads, pipes and wires. Properly integrated into the design of a street, they can deliver tangible engineering benefits such as increased pavement life through shading, reducing demands on stormwater infrastructure through reduction of stormwater flows, and treatment of stormwater runoff. In a time of water restrictions and climate change, street trees will play an increasingly important “engineering” role. And unlike most “single purpose” infrastructure, a street tree can deliver multiple benefits from valuable urban space.

It is also evident that large trees deliver the greatest benefits, be it shading, streetscape presence, habitat creation or other considerations. It is therefore important that street trees be allowed to survive and grow to a mature size to maximize those benefits. Planting smaller trees is not necessarily the answer to street tree related problems.

3.0 THINKING LIKE A TREE

In the past we have left the needs of the tree last in the street design and construction process. Street trees are squeezed into whatever space is left after other functional and engineering needs have been met. The consequences have been declining tree health and longevity, tree mortality and infrastructure damage. Unsustainable management practices include ongoing tree maintenance and replacement, and infrastructure repair and replacement.

The biological needs of trees

In designing urban streets we should try to “think like a tree”.

The biological needs of urban trees are the same as those of the tree in the natural forest, even though the urban environment is a very different setting. The key natural processes are photosynthesis, respiration and transpiration. The following six requirements, either above or below ground, are needed to sustain tree life and growth (Trowbridge and Bassuk 2004).

- Oxygen
- Carbon dioxide
- Light
- Water
- Nutrients
- Appropriate temperatures

The hostile urban environment

Urban street trees, however, face life in a very hostile environment. In her 1984 book on urban ecological design, *The Granite Garden*, Anne Whiston Spirn identified the challenges facing urban trees (Spirn 1984). The list is long and includes competition for street space, both above and below ground, infrastructure conflicts, deliberate and accidental damage, polluted air, temperature extremes and either too little or too much water.

Probably the main concerns are those below ground, due to the highly modified nature of urban “soils”. The most critical and universal issue is soil compaction and it’s impacts on root growth. This leads to a range of consequences including: lack of adequate rooting volumes beyond the tree pit; decreased soil aeration; water-logging due to poor drainage; inadequate available water due to decreased soil moisture holding capacity; and exacerbated infrastructure conflicts.

Understanding tree needs

Timothy and Phillip Craul identify the following soil related factors to consider in the design of the “pedosphere” or below-ground space (Craul and Craul 2006).

- Available soil volume for adequate root growth over the life of the tree and/or other plants, and for mechanical support.
- Infiltration and available volume of soil moisture.
- Water drainage of the soil itself and the drainage of the element.
- Aeration of the soil.
- Amount and availability of plant nutrients.
- Relative heat loading of the plant palette.
- Exposure to toxic or other harmful factors.

Urban suggests that, to encourage the growth of large and healthy trees, five major parts of the tree structure, both above and below ground, must be accommodated in the design process (Urban 2007).

- **Tree crown**. Crown growth, including crown spread and it's interaction with other tree crowns and buildings
- **Tree trunk**. Trunk growth, including mature diameter, growth rate and potential for damage due to wind sway.
- **Trunk flare**. As a tree matures, a pronounced swelling or flare develops at the point where the tree trunk reaches the ground. This contributes to the tree's structural stability. The tree base can expand at more than twice the rate of the main trunk diameter. Any hard surfaces installed in this zone creates potential for conflicts damaging to both the infrastructure and the tree.
- **Zone of rapid root taper**. In a zone approximately two metres around the trunk base, tree roots emerge and divide into thick structural roots, rapidly tapering to finer roots. Most damage to paving will occur in this zone, which should be kept free of infrastructure to reduce damage and encourage long term tree health
- **Root zone**. Tree roots are mostly found in the top 300-600 mm of soil, where conditions are most favourable for growth. In all but the most well-drained soils, trees will not develop deep "tap roots". In open settings, trees will develop a circular root-plate, rather than root-ball, spreading 2-3 times the canopy diameter. An important relationship exists between the size of the tree canopy and the volume of rootable soil required to support growth. This relationship is the most critical factor in determining long-term tree health. Rootable soil should have low compaction, good drainage, sufficient water-holding capacity and sufficient nutrients to support growth. The root zone should be protected from compaction, and ideally the root zones of individual trees should be interconnected for healthier growth.

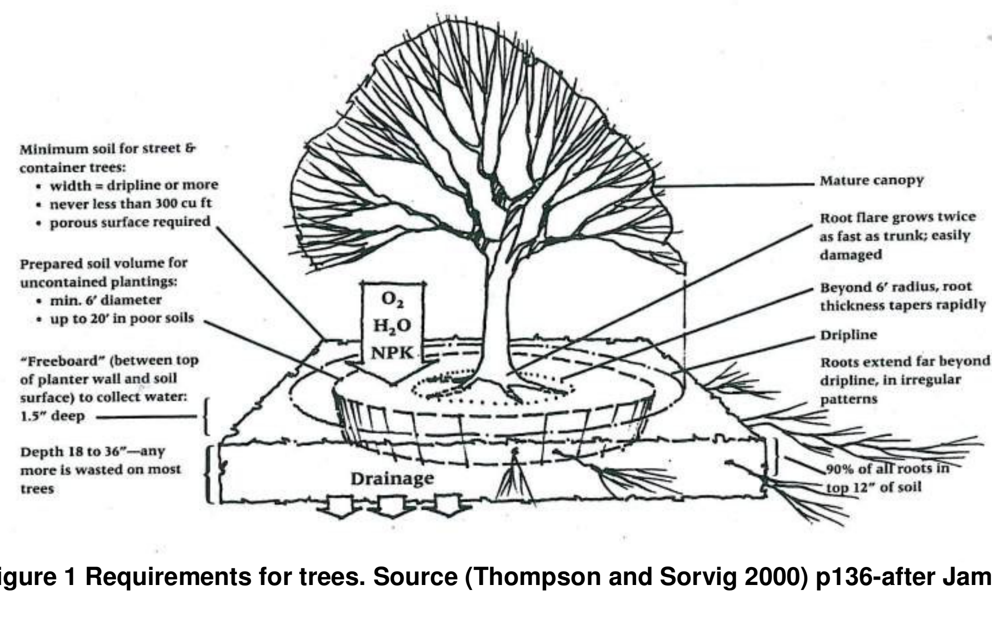

Figure 1 Requirements for trees. Source (Thompson and Sorvig 2000) p136-after James Urban.

Tree sensitive urban design

It is suggested that we could adopt a concept of "Tree Sensitive Urban Design" similar to that of Water Sensitive Urban Design.

Water Sensitive Urban Design (WSUD) is a new and accepted paradigm for the more sustainable management of the urban water cycle. It has developed in response to the negative environmental consequences of traditional engineering practices which viewed stormwater as having no real value. WSUD is based on a new attitude, that stormwater is a valuable resource, and on a new set of practices aimed at better replicating the natural water cycle into the planning and design of urban areas (Argue 2004).

Similarly, the traditional engineering-driven approach to streetscape design has had undesirable environmental and other consequences. A new Tree Sensitive Urban Design paradigm would recognize street trees as a valuable resource, and better integrating the biological needs of trees into the design of urban streets.

WSUD is now a widely accepted concept, and is being implemented in a number of areas through WSUD frameworks, which incorporate objectives, principles, and "best management practices" (Wong 2006). A similar framework could be developed for
A tree sensitive or tree literate urban design framework could have the following objectives.

- Fully recognize the value of street trees
- Give street trees equal priority to other forms of infrastructure.
- Design streets around the biological needs of trees
- Select the "right tree for the right place"
- Maximize available space for trees in streetscape design
- Provide the necessary resources for growth
- Minimize tree/infrastructure conflicts
- Integrate street trees with related Water Sensitive Urban Design initiatives
- Adopt an interdisciplinary**,** collaborative approach

4.0 OVERVIEW OF PRACTICES

An important component of a Water Sensitive Urban Design strategy is a set of Best Management Practices aimed at achieving WSUD objectives. The following is a summary of some of the current and emerging "best practices" in sustainable streetscape design and street tree planting, which are directed towards

- Increasing available space for street trees , both above and below ground
- Providing the necessary resources for growth
- Reducing street tree/infrastructure conflicts

Sustainable street tree planting practices include

- Streetscape design and geometry
- Design of the below-ground space
- Street tree water management
- Infrastructure design
- Tree species selection

4.1 STREETSCAPE DESIGN

Streets can be designed or reconstructed to provide greater opportunities for tree planting, and more space for individual trees.

Enlarged cut-outs. Trees are still planted in undersized cut-outs in footpaths, resulting in damage to kerbs and pavements as the tree matures. Existing cut-outs can be enlarged, and new cut-outs designed to increase separation between the tree trunk and infrastructure, reducing hardscape damage. The enlarged cut-out also provide an increased permeable surface area with improved environment for root growth.

Footpath widening. Removing traffic lanes or narrowing over-engineered traffic lanes can create additional footpath space for street tree planting. There are often, however, competing demands for such space for bicycle lanes, bus lanes and bus parking bays, and traffic medians.

Planting in the parking lane. Street trees can be repositioned from narrow footpaths to the adjacent parking lane, where more space is available, at least 2.1-2.4 m for parallel parking. Trees can be installed at road pavement level, protected from cars with bollards or wheel-stops. Planting at grade also creates opportunities for passive watering. However planting in the parking lane often generates opposition due to some loss of on-street parking spaces.

Planting in kerb extensions. Street trees can also be planted in the parking lane in raised kerb extensions (known as protruberances in South Australia). Trees can be incorporated into traffic calming devices or WSUD applications, creating the benefits of multiple versus single use installations.

Median planting. Trees can be planted in traffic medians in arterial roads and boulevards, provided the median is of sufficient width, appropriately shaped tree species are selected, and crowns lifted by pruning if required. Median trees often contribute more to the creation of significant boulevard streetscapes than to actual pedestrian amenity.

Alternative tree locations. Street trees are traditionally planted in the verge adjacent to the kerb. An alternative is to plant trees adjacent to the property boundary where they have access to adjacent soil resources, and are less likely to cause damage to footpaths and kerbs. Disadvantages include loss of spatial streetscape definition created with planting adjacent to the kerb, and declining water and soil resources with more intensive urban consolidation.

Informal avenue planting. The formal avenue or alley, with a single tree species, planted symmetrically and at uniform spacings in a line adjacent to the kerb, is the historical street planting prototype, creating visually cohesive streetscapes. Alternative arrangements may include a mix of tree species, irregular tree spacings, planting in groups or clusters, and planting at locations other than next to the kerb.

Block planting. In some streets it may be possible to find opportunities for planting trees in blocks or groves. Streets sometimes contain areas of underutilized space, for example road junction reconstructions. Trees planted in groups may better reflect their natural forest environment, and may provide opportunities for improved soil conditions and water management.

Alternative street templates. Alternative street "templates" can be adopted in the design of new or reconstructed streets, to create more space for trees planting. Two feasible alternatives are the "curved template" and the "offset template". The "curved template" involves a winding carriageway, and is usually most applicable in residential streets where traffic calming can be combined with "greening". With the "offset template" the carriageway is offset to one side of the road reserve, creating a wider planting zone on one side of the street. This can be applied in narrow streets where a viable planting verge on both sides is not feasible.

Streetscape Design	
Practice	**Example**
Enlarged cut-outs	Paisley Street, Footscray, Melbourne
Footpath widening	Swanston Walk, Melbourne
Planting in parking lane	Acland Street, South Yarra, Melbourne
Planting in kerb extensions	William Street, Sydney
Median planting	Grey Street, Southbank, Brisbane
Informal avenue planting	Melbourne Street, Brisbane
Block planting	Docklands Esplanade, Melbourne
Alternative street templates	North Terrace boulevard, Adelaide

Table 1. Streetscape Design Practices

4.2 BELOW-GROUND DESIGN

The space below ground should be designed to provide increased soil volumes for trees, and to better provide the resources necessary for growth.

Enlarged tree pits. Current practices are moving towards specifying a larger tree pit than the traditional 1m x 1m x 1m pit squeezed between the footpath and kerb. The tree pit can be extended below the surrounding pavement to provide a better approximation of the required rootable soil volume for a particular tree species. The shape of the rooting volume should also reflect the known morphology of tree roots, forming an extended shallow root-plate rather than a deep root-ball. NSW Landcom's *Street Tree Design Guidelines* recommend a 1m deep unobstructed root area of 5-15 cubic metres for a small sized tree (4 m diameter canopy), 20-40 cubic metres for a medium sized tree (8 m diameter canopy) and 50-80 cubic metres for a large tree (16 m diameter canopy) (Landcom 2008).

Structural soils. The term "structural soils" applies to a family of engineered soils that attempt to solve the problem of providing engineered support for trafficable pavements (a compacted sub-base), while meeting biological needs of the tree (pore space, aeration and water). These include sand-based "Amsterdam Tree Soils" developed in Europe, and skeletal or gap-graded soils, composed of an interlocking stone matrix with the voids filled with loose, uncompacted soil (notably CU Structural Soil first developed by Jason Grabosky and others at Cornell University). Structural soils need to be designed to suit local conditions. Gap-graded stone soils, however, may not be the ultimate solution to creating appropriate growing conditions below pavements, as the mix may comprises 80% inert rocks, substantially reducing effective rootable volume.

David Lawry's investigation commencing in 1995 into the beneficial reuse of municipal water treatment residues, has resulted in a stable lightweight colloidal based structural soil called "SPACE",(Structural Permeable Aerated Compactable Earth). Unique to Adelaide there are now a number of successful trial sites around the city where "SPACE" has been used beneath pavements. These sites and further proposed research projects will assist in making SPACE become more readily available.

Suspended pavements. Another solution to extending rooting zones below footpaths is the use of "suspended pavements". These pavements are engineered to span an area of loosely compacted soil suitable for root growth, for instance with paving laid on a thickened or reinforced concrete slab. Unlike structural soils the rootable soil volume is not reduced by a stone lattice. Suspended pavements work best with long narrow rooting volumes with shorter lengths to span. A disadvantage is that the suspended concrete slab may reduce potential for air and moisture exchange with the soil below.

Continuous soil trench. In a street setting, an extended rooting zone may best be created with a linear root trench connecting individual tree pits. Trees have been shown to benefit from a shared rooting zone, as occurs in nature, in terms of rate and uniformity of growth. Such a channel, usually about two metres wide and a maximum of one metre deep, may be designed as an open verge, or covered with pavement supported by structural soils or a suspended slab. Tree root channels also need to be designed on arboricultural principles, including the provision of underdrainage.

Subsurface cells. Possibly the "next generation" of design to extend street tree rooting volumes comprises a system of underground reinforced plastic cells creating a "honeycomb" which provides structural support for pavements, as well as cells filled with loosely compacted soil for root growth. Such a system is being marketed as Deep Root Silva Cell. Cells can also be utilized for below ground water storage allowing integration of WSUD practices with street tree planting.

Above ground containers. Trees planted in containers or raised planters were an unsuccessful feature of many early civic design projects. In some situations, for example when planting above services or over underground structures, they may be a reasonable alternative, provided they are designed on scientific principles with adequate volume, designed soils, adequate water and nutrients and a long term management plan.

Below ground containers. Street trees can also be planted in containerised situations below ground, in large “tree bunkers”. Once again these require design based on scientific principles including appropriate soil volumes, water and nutrient supply and drainage.

Below Ground Design	
Practice	**Example**
Enlarged tree pits	Melbourne CBD
Structural soils	Adelaide bus station
Suspended pavements	Brisbane CBD
Tree root channels	Albert Street, Brisbane
Subsurface cells	Port Arthur, Tasmania
Containerised-above ground	Barkly Street, Footscray, Melbourne
Containerised-below ground	Collins Street, Docklands, Melbourne

Table 2. Below Ground Design Practices

4.3 WATER MANAGEMENT

In times of drought and water shortages there is a need to find better ways to deliver water to street trees. This may include integration with WSUD practices which have recently been adapted to the urban streetscape scale.

Porous surfaces. Urban areas are characterized by dramatically increased runoff and decreased infiltration, due to the predominance of hard surfaces, combined with highly efficient engineered stormwater drainage systems. More porous “soft surfaces” are required in urban areas, to increase infiltration rates and groundwater recharge, and to reduce pressures on stormwater drainage systems. Seattle landscape Richard Haag advocates a “Haag’s Theory of Softness” which states that “no ground surface should be harder than absolutely necessary for it’s function”, as an alternative to the more common desire to compact and pave every piece of ground in sight. The same principle can be applied to permeability, that “no ground surface should be more impervious than necessary”(Thompson and Sorvig 2000)

There are a number of “families” of porous surfaces, including: soft landscaped surfaces; porous (gap graded) asphalt, concrete or resin bonded gravel mixes; and pervious paving systems using unit pavers on a permeable subgrade.

Pervious pavers. Pervious pavements, when properly designed, can provide a surface of segmental pavers which supports heavy loads while infiltrating and filtering runoff, either to the subsoil or to underground storage and re-use. Unit pavers are laid on an engineered aggregate sub-base, which enhances infiltration rates, and can provide an underground water storage reservoir. Pervious pavements can be installed in street situations such as footpaths and parking bays with the benefits of multiple use versus single use of valuable street space. Costs of construction can be offset by reducing the need for conventional drainage infrastructure. While the feasibility of pervious paving has been established in structural and hydrological engineering terms, interactions between tree roots and pervious paving and it’s sub-base are still uncertain. Traditionally trees have been discouraged in proximity to pervious paving, due to concerns about tree root damage and clogging of infiltration openings in the pavement.

Raingardens. Bioretention systems, also known as “raingardens”, are WSUD applications that collect and filter stormwater runoff through the combined biofiltration properties of a designed filter media and plant root-zones. Treated runoff is then returned to the conventional stormwater system or stored for re-use. Bioretention systems are most feasible where there is a need to protect the water quality of the receiving waters. Bioretention systems can be designed at range of scales and are well suited to streetscape scale applications. They can be installed in street verges or traffic calming devices providing multiple use benefits including water treatment combined with street greening. Raingardens meet WSUD best practices, including: collection and treatment of stormwater at source; protection of receiving waterways; local re-use of water in self-watering landscape features, with a subsequent reduction in mains water irrigation; and, providing visual connectivity with the urban water cycle. They also contribute to the greening of streets, and provide for multiple, rather than single purpose use of valuable urban space.

Bioretention tree pits. A special case of a bioretention system, utilizing the tree's root zone as part of the biofiltration process. They allow stormwater management at the most confined streetscape level, with a tree pit often being the only soil/plant opportunity in an urban area. Bioretention tree pits can be designed to manage small impervious catchments. Benefits for the tree include high rates of watering, even from very small rainfall events. They require precise engineering and design for integration into a confined urban space, including with services below ground and with street users above ground. They can be installed at grade in a parking lane, or in the footpath with a kerb inlet. One issue to be addressed is the need for a lowered soil surface in the tree pit, to provide for temporary ponding, requiring a tree pit cover to address pedestrian safety issues.

Bioretention swales. One variation on the bioretention basin is the bioretention swale, which may provide for stormwater conveyance as well as treatment. Bioretention swales are well suited to linear streetscape situations such as continuous verges or medians. Street cross-sections can be redesigned to fall towards drainage swales, with conventional kerbs replaced with "permeable kerbs" to allow entry of stormwater runoff.

Passive watering. In most streets, stormwater runoff flows past street trees along engineered kerbs and water-tables, and out to sea. Provision can be made for some of this runoff to be diverted to the adjacent tee pits, providing passive irrigation during rainfall events. Stormwater can be directed to individual tree pits by some form of kerb inlet, or to larger capacity, gravel filled, infiltration trenches connecting tree pits. Alternatively trees can be planted in the parking lane, with a lowered soil surface, allowing surface flows to directly enter the pit.

Active watering. A more complex variation of passive irrigation is to harvest and store stormwater below ground, for subsequent reuse by pumping. Such systems may be complex and expensive to install and maintain

Water Management	
Practice	**Examples**
Pervious paving	Smith Street, Manly
Raingardens	Marwal Avenue, Melbourne
Bioretention tree pit	Bourke Street, Docklands, Melbourne
Bioretention swale	Victoria Park, Sydney
Passive watering	Redfern Street, Redfern, NSW
Active watering	Melbourne Street, Brisbane

Table 3. Water Management Practices

4.4 INFRASTRUCTURE DESIGN

In situations where conflicts occur between trees and infrastructure, the tree is usually blamed, resulting in severe pruning, tree removal and possible restrictions on further tree planting. Service authorities often proscribe tree planting setbacks and lists of prohibited tree species. Engineering standards limit tree planting near buildings. If all of these restrictions were followed we would have cities with few trees.

Tree/infrastructure conflicts, however, can also be resolved through improved infrastructure design, given that street trees are a valued component of the urban environment. Such measures can include strengthened pavements, flexible pavements, and pavement underlays. Below ground measures can include service relocations, service pipe design to prevent root entry and improved building footing designs. Above ground measures include undergrounding of power lines and aerial cable bundling.

4.5 SPECIES SELECTION

A key aim is to better match trees and planting sites, selecting "the right tree for the right place". Some form of site analysis should be undertaken before tree species selection, site preparation and planting. In addition to the many other criteria for selecting a street tree, consideration should be given to factors related to the urban environment, such as drought tolerance, tolerance of inundation and de-oxygenation, and the impacts of basal trunk flare and rooting depth on surrounding infrastructure.

5.0 CONCLUSION-GREEN STREETS

The ultimate aim would be to fully integrate tree literate practices into the design of "green streets". Green streets are a growing practice in the United States, where streets are designed or reconfigured to accommodate stormwater runoff management and treatment with other sustainable design practices including traffic calming, pedestrian and cycle use and the creation of attractive streetscapes. Green streets have been described as "constructed ecological networks"(Thompson and Sorvig 2000).

Two cities leading the way in green street design are Portland, Oregon and Seattle (Vogel 2006).

Portland, Oregon

The City of Portland has a history of comprehensive planning including urban design, multi-modal public transport and green infrastructure systems. In Portland, a street that uses vegetated components to manage stormwater runoff at it's source is referred to as a Green Street. Portland offers several examples of well designed green streets. The SW 12th Ave Green Street project in 2005 involved retrofitting a series of stormwater planters into an inner urban street. The retrofit project demonstrates how existing or new streets in highly urbanized areas can be designed to achieve both environmental benefits and be aesthetically and functionally integrated into the urban streetscape (ASLA 2006)

Seattle

Seattle has probably developed the most innovative green street solutions. Seattle Public Utilities has adopted a Natural Drainage System (NDS) strategy. This is based on Street Edge Alternative (SEA) neighbourhood streets incorporating a variety of low impact development techniques to store, infiltrate and filter stormwater (City of Seattle 2008). These techniques were tested in SEA-Street No 1 where a conventional street was redesigned with a narrowed, curvilinear carriageway. A subsequent project, Pinehurst green grid, (covering twelve city blocks), involved redesigned the streets with an offset template, incorporating drainage swales in the widened side of the street.

The next step in Seattle is to adapt NDS to more densely developed areas. A current project, "Swale on Yale" applies NDS techniques to the redevelopment of high-density commercial area, incorporating four blocks of interconnected swales in a wide planting strip between street and footpath

New York City

New York City has developed a set of High Performance Infrastructure Guidelines, which provides a roadmap for incorporating sustainable practices into the City's right-of-way infrastructure capital program (New York City Department of Design and Construction 2005). In guidelines such as these, street trees are formally recognised as a form of "green infrastructure" delivering tangible benefits to the city

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