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Increasing Green Infrastructure in Compact Developments: Strategies for Providing Ecologically Beneficial Greenery in Modern, Urban-Built Environments

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ABSTRACT

Urban forest canopies are generally declining in areal extent across the United States. At the same time, urban areal extent per capita is increasing, and the human population is urbanizing. Eighty percent of North Americans are now living in urbanized areas. Municipalities are reacting to concerns about such trends by permitting an increasing number of compact developments that may conflict with beneficial green infrastructure. The urban forest canopy is a key component of reducing the urban heat island (UHI) and making urban environments more efficient and livable.

This paper presents innovative design details, specific zoning and code language, and best practices from multiple disciplines to frame a coherent set of strategies to increase canopy cover levels, decrease UHI effects, and lessen infrastructure conflicts in modern ordered compact developments.

Introduction

Urban forest canopies are generally decreasing in areal extent across the United States. At the same time, urban areal extent is increasing, with urban areas in the conterminous United States having doubled in size between 1969 and 1994 (Staley 2004), with increasing per capita land consumption being an important cause (Kahn 2006). Urbanized land area is projected to increase another 50% by the year 2050 (Nelson 2006).

As a result of these and other concerns, the patterns of urban-built environments are subject to increasing scrutiny across many disciplines (Alberti and Marzluff 2004; Glaeser and Kahn 2008). Urban planners, politicians, public health officials, and developers are recognizing that certain built-environment patterns (e.g., large-lot residential developments and single-use zoning) may have unintended and detrimental externalities on environmental health (Frumkin 2003); receiving waters (Greenberg et al. 1994); UHIs (Stone 2001; Stone and Rogers 2001); and municipal finance (Carruthers and Ulfarsson 2003; Soule 2006); among other effects.

This paper briefly reviews the issues challenging the coexistence of urban forests (green infrastructure) and built environments (gray infrastructure). This paper then integrates information and best practices from multiple disciplines to frame a coherent set of strategies to increase canopy cover and decrease infrastructure conflicts in modern ordered compact developments (OCD). This paper will assist cities and practitioners in remedying both UHI and urban sprawl to create supportive places in order to return to positive built-environment patterns.

Discussion

Land-Use Patterns

American land-use patterns changed after World War II. Land-use patterns became more dispersed, and housing more separated. This dispersed land-use pattern was fostered in large part by single-use zoning (Jacobs 1992), which seeks to separate urban uses. In the past decade, however, there has been an increase in market demand and stated preference for more mixed use, walkable, and more compact built-environments (Randolph 2004).

Compact development is one strategy to address urban sprawl and its associated environmental and social effects (Beatley 2004; Duany and Talen 2002; Speck 2007). Many cities, concerned about sprawl and development costs, are approving an increasing number of compact residential and commercial developments (Szold 2007). Compact developments often feature medium- to high-density building footprints, small-lot development, and shorter building setbacks. Modern expressions of OCD are variously named new urbanist, traditional neighborhood design, or smart growth developments (Farr 2008; Staley and Olson 2007). Such OCDs eschew single-use zoning and massing specifications in favor of mixed-use zoning and design specifications (Wickersham 2007).

Code language in OCDs often requires easements that may constrict both tree roots and tree canopies (Friedman 2007), providing insufficient room for healthy canopy and root growth and creating a greater likelihood of infrastructure conflicts. Potential social, economic, and environmental benefits of urban green infrastructure may be foregone. The presence of a high-quality, well-managed tree canopy is essential for a high quality of life and for the delivery of environmental services in higher density areas.

Urban Forests and the UHI

Analysis of temperature trends for the last 100 years in several large U.S. cities indicates that since approximately 1940, temperatures in urban areas have increased by about 0.5° to 3.0° C (Pokorný 2001). Perhaps 5% to 10% of the current urban electricity demand is spent to cool buildings just to compensate for the increased temperatures in urban areas (Akbari et al. 2001). Low-density land-use patterns and especially large-lot residential development may contribute to an increase in the thermal footprint of a region (Levitt et al. 1994; Stone 2001).

Healthy green infrastructure ameliorates the effects of UHIs by providing a significant flux of water and latent heat into the urban boundary layer (Peterson 2003). Tree canopy coverage is the main determinant of temperature reduction (Stone and Rogers 2001). These vegetation-reduced temperatures lessen energy demands in addition to lessening the heat stress on vegetation. A study of Sacramento, California found that the urban forest reduced the city's cooling requirement by 12% (Simpson 1998). Large-stature mature shade trees likely have a beneficial effect on residential pavement performance, as well (McPherson and Muchnick 2005).

Urban forest canopies and green infrastructure provide ecosystem services that benefit the goals of numerous professional disciplines as well as residents under their shade. This paper widens the purview of urban forest benefits to a multidisciplinary audience to ensure that the environmental, economic, and social benefits are not foregone as the number of compact developments continues to increase.

Conflicts between Green and Gray Infrastructure

Although urban forests and green infrastructure confer many unseen benefits, conflicts caused by urban trees are often seen and remembered when considering tree provision and placement in compact developments. Trees may conflict with gray infrastructure, such as sidewalks, sewers, and overhead power lines. The most likely reason for green-gray infrastructure conflicts is not adhering to the adage "right tree, right place."

The most common infrastructure conflicts come from tree roots. Trees need adequate soil volume for their roots to absorb nutrients and water to maintain metabolic functions (Harris et al. 1999). Urban soils are frequently of poor quality and often inadequate to allow woody plants to flourish (Miller 1997). Although large-statured trees provide the most benefits (McPherson et al. 2001), tree diameter at breast height (DBH) is directly related to infrastructure damage (Randrup et al. 2001). There is a linear relationship between tree DBH, distance from concrete, and probability of damage. A 30 cm DBH tree 2 m from concrete has an approximately 0% probability of damage (Coder 1998, Figure 2). In California, approximately US$71 million in year 2000 dollars is spent statewide annually on conflicts between street tree roots and gray infrastructure (McPherson 2000), the average repair cost at $480 (McPherson and Peper 2000).

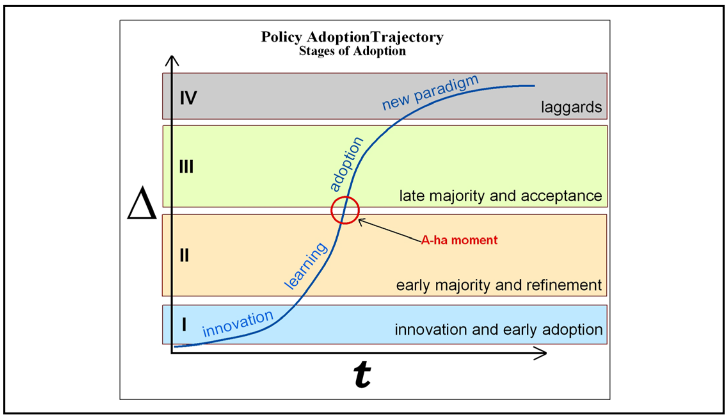
Avoiding the costs of green and gray infrastructure conflicts should be a goal and design strategy for every compact development project that is permitted and built. The remainder of this paper details specific goals, policies, and strategies to avoid such conflicts and provides effective sample land-development code to that end that should be relatively easy to enact.

Integrated Strategies for Green and Gray Infrastructure Coexistence: Plans, Policies, and Land Development Codes

Community Structure

All communities are not similar and do not adopt the same plans, polices, and development code as their neighbors (Hoch 1994). This fact prevents the creation of a standardized plan or policy for communities to adopt and enforce. This fact is a main theme of this paper and is the basis for the following sections. Nonetheless, the planning process is well, established and includes creation of short- and long-term goals, change management, balancing competing interests, and using a plan to guide and explain goals and policies (Hoch et al. 2000). This paper recommends polices according to where a community lies on the adoption curve presented in Figure 1. Communities are assumed to fall into one of four innovation categories, and therefore are more likely to adopt goals and policies according to where they are on the curve in Figure 1.

Category I communities are generally progressive and early adopters of technology and innovation. Most communities fall on a continuum somewhere in categories II and III, and are neither early adopters nor laggards. An isolated, conservative small rural town might be expected to fall into category IV. Representative category I jurisdictions are Davis, CA, USA and Boulder, CO, USA. With respect to tree canopy, Davis has progressive parking-lot shading standards and Boulder has innovative solar-access standards.



Source: modified from Bass 1969

Figure 1. Societal learning and adoption curve

Policy Legitimacy: Comprehensive Plans

Most plans in urban areas become policy through adoption by local government (Hoch et al. 2000). Urban infrastructure (e.g., roads and sewers) is the most powerful determinant of the location and scale of urban-built environments. Therefore, many communities create comprehensive plans to guide, clarify, and enforce development of the built environment.

Accepted planning principles state that all sections of comprehensive plans should enforce each other (American Planning Association 2009), which is called "concurrence." For example, when a city's economic development section states that affordable housing is a goal, the land-use section should not state as a goal that only luxury homes are desired.

Urban forests and green infrastructure support many goals in comprehensive plans (American Planning Association 2009). From national goals and requirements (e.g., ameliorating storm-water runoff) to local goals (e.g., affordable housing, efficient infrastructure, and economic development), the goals of urban forestry are easily integrated into comprehensive plans. Urban forestry and green infrastructure goals should be explicitly included in several elements of comprehensive plans to take advantage of these multiple benefits. Land use, infrastructure, and economic development are the logical places for inclusion of green infrastructure goals. A few communities are just beginning to include separate green infrastructure sections in their comprehensive plans (Prince George's County 2005; City of Baltimore 2009). Category I and II jurisdictions likely have precedents and should seek to explicitly include green infrastructure in goals, priorities, policies, and land-development codes. Such wording should include the word 'shall,' which legally is more enforceable than words such as 'should' and 'may.' 'Shall' is a directive, whereas 'should' is a suggestion.

Design Standards

Design standards regulate the form of commercial, residential, and industrial buildings. Design standards may also regulate road, sidewalk, and pathway form and dimension. Such standards also regulate the spacing in between buildings and roads. These standards are commonly attached to land -development codes and are often called zoning, development, or subdivision regulations. Almost all communities per Figure 1 have design standards.

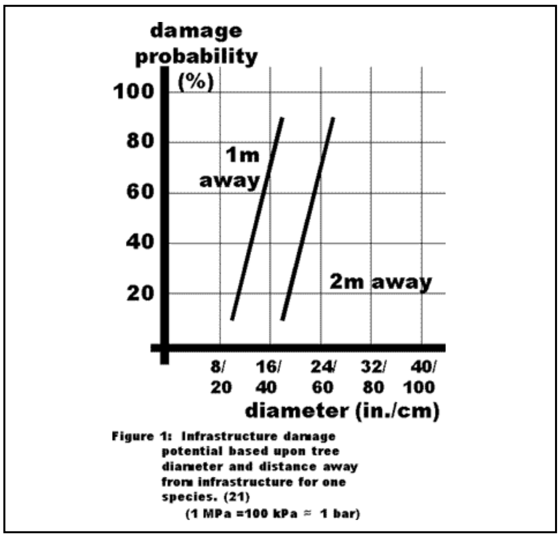
Design Standards: Purpose Statement

A purpose statement is a common statement in planning and code text. Purpose statements signal the intent of plans, policies, and code. With respect to green infrastructure and urban forests, the purpose statement should explicitly state that *green infrastructure is valued for the protection of community values and improving the quality of life* and *the built environment shall be harmonious with green infrastructure* and *plans shall include accommodations for medium and large urban trees.*

Design Standards: Achieving Maximum Tree Size Next to Buildings and Rights of Way

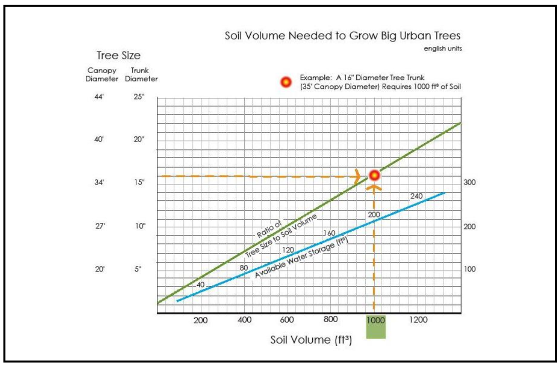
Woody plants have maximum or expected sizes (Miller 1997) and therefore have optimum placement away from buildings and each other. Existing design standards may not acknowledge the ultimate size of plants. It is important that minimum plant spacing from infrastructure is explicitly stated, especially minimum distance from utility easements. Figure 2 is an example of a diagram depicting tree size and distance from infrastructure that should be included in a design standard. Distances from sidewalks, curbs, and utility cores are appropriate applications for such a standard. Sample code language where such a diagram is appropriate: *All tree lawns in residential public rights of way shall be a minimum of 6 (six) feet (2 m) in width.*

Tree health and vigor are strongly associated with the amount of available soil rooting volume (Urban 1992). Design standards should require adequate rooting volume for the ultimate size of the plant. An example of a design standard for determining rooting volume is in Figure 3. Such a standard is appropriate for trees in a commercial retail area, in low-impact



Source: Coder 1998

Figure 2. Sample graphic for minimum required distance from infrastructure



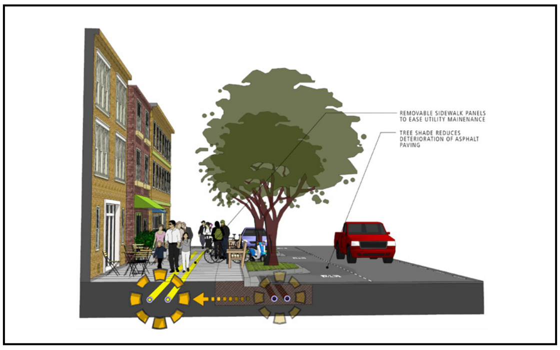
Source: Urban 1992

Figure 3. Sample soil volume graphic for required minimum design standards

development areas alongside roadways, and in parking-lot standards. Such requirements are much more attainable in new construction when incorporated into the design and planning process. Sample appropriate code language is: *Tree species' mature canopy size shall be accommodated by an appropriate volume of soil. The developer shall provide the appropriate volume of soil based on tree species and the figure below*:

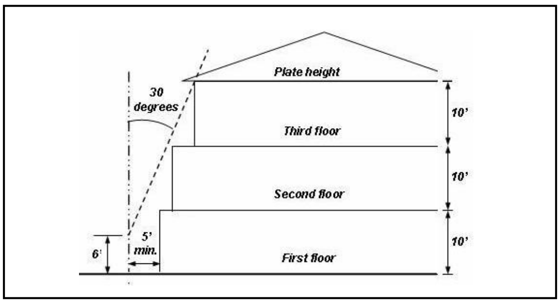
Tree roots in commercial and residential zones can be constricted by poor underground utility easement placement. Poor placement can result in root or trunk damage during maintenance, endangering the health of the plant. In OCDs, a dedicated utility core easement should be required and sited to avoid conflicts with tree roots and minimizing disruptions to public traffic flow in roadways. Examples of appropriate easement placement are under dedicated bicycle lanes in the street traveled way or underneath sidewalk hardscape adjacent to structures. Utility easements under hardscape should have panelized concrete or dedicated sections above the utility corridor for ease of access. Figure 4 provides an example of utility core placement adjacent to a commercial area under hardscape. Such placement should be easily justified in category I, II and III jurisdictions.

Tree canopy may be severely restricted in OCDs by setbacks. An example of a setback is the minimum distance of a structure to a property line. Commercial development may allow a setback of zero feet to the property line, limiting the canopy spread of large trees. Canopy spread limitation can be overcome by restricting the upper floors of certain buildings, as in Figure 5, appropriate for new or infill construction only. The upper floors are limited in their forward extent by imposing an angled line projecting up from a point in the front of a building, across which the building cannot project. This is typically called an encroachment plane. Which buildings are desired to have the upper floors restricted is determined by the planning process. This restriction likely will not be acceptable to some category III and IV jurisdictions. Example code wording for such restriction: *The second and higher floors of buildings in the commercial district shall not extend beyond an encroachment plane defined as a 30-degree angle measured from the vertical, at a point beginning six feet above the existing grade along the front property line.*



Source: Tree Trust and Bonestroo 2007.

Figure 4. Sample utility core placement diagram for commercial areas



Source: Dan Staley

Figure 5. Sample encroachment plane diagram for tree canopy coverage

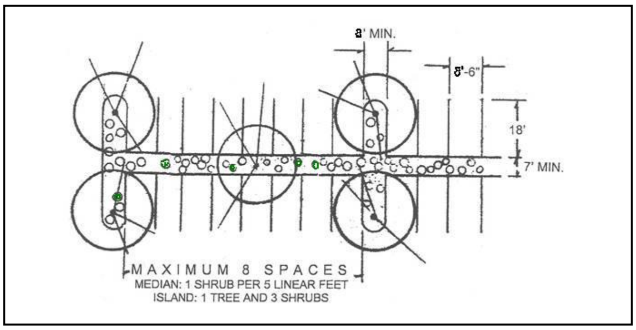
Design Standards: Parking Lots

Parking lots afford an excellent opportunity to achieve UHI reduction and canopy cover goals. A commitment must be made to allow for fewer parking stalls because parking surface area must be reduced and dedicated to tree roots. Category I and II jurisdictions may be able to easily make these commitments because there is a growing indication that many areas in the United States may provide too much parking for various reasons (Mukhija and Shoup 2006).

Perhaps the easiest way to allow developers and cities to provide adequate rooting volume for trees is to allow them easy calculations to determine the requirements for the minimum size of planting areas in parking-lot interiors of approximately equal width to parking stalls. One parking stall of 8.5 x 18 ft. dimension (2.5 x 5.4 m) provides approximately 460 ft^3 (138 m^3) of volume, adequate for a canopy diameter of approximately 25 ft (7.5 m).

Code language that should be easily adopted in category I and II jurisdictions include: *Required parking-lot interior islands* (Figure 6). *Interior islands and peninsulas shall be a minimum of 8 (eight) feet in width and 18 (eighteen) feet in length. Islands and peninsulas shall be excavated post-paving and prior to planting in accordance with the provisions in* [appropriate Public Works Regulations] *to provide a minimum of 750* ft^3 *(cubic feet) per large-statured tree and 500* ft^3 *(cubic feet) per medium-statured tree. There shall be no more than 8 parking stalls between islands and/or peninsulas* (Figure 6). *Tree:stall ratio. There shall be a minimum of one tree for every 8 parking stalls. No more than 25 (twenty-five) percent of total trees shall be on the landscaped perimeter.* Category III jurisdictions may wish to have a tree:stall ratio of 1:10 or 1:12.

The spatial arrangement and geometry of surface parking



Source: Dan Staley adopted from Wolf 2004

Figure 6. Sample parking-lot design standard requirement

Table 1. Sample changes in surface parking-lot geometry

	Parking Angle		
	0º	**45º**	**90º**
1-Way Aisle Width	13 feet	13 feet	16 feet
2-Way Aisle Width	19 feet	21 feet	24 feet
Maximum Stall Width	8.5 feet	8.5 feet	8.5 feet
Maximum Stall Length	20 feet	19 feet	17 feet

Source: adapted from Wolf 2004, English units only given

can be differently configured in category I and perhaps category II jurisdictions as well, to make driving aisles narrower. This reduces the impervious area needed for canopy coverage and allows developers to more easily meet off-street parking requirements. Sample configurations are detailed in Table 1.

Conclusion

Green infrastructure in an urbanizing world provides ecosystem services that reduce UHI effects, benefit residents in its shade, and help to attain the goals of numerous professional disciplines. Avoiding the costs of green and gray infrastructure conflicts should be a goal and design strategy for every compact development project that is permitted and built. This paper has presented basic architectural and infrastructure design elements to create more space for tree canopy and roots, providing opportunities for planting larger, woodier plants in compact developments. This paper presented specific code language and best practices to assist in the changing of building and parking-lot forms to create more room for green infrastructure. Multiple professional disciplines, including urban and transportation planning, architecture, and landscape architecture, have disparate but mutual goals that can be synthesized and implemented under the canopy of green infrastructure. This synthesis under green infrastructure can help practitioners return to creating supportive built-environment patterns to ameliorate the unintended effects of urban land-use patterns.

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