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Urban forestry for cooler cities faces three critical hurdles

Thami Croeser, Mohammad A. Rahman & Arnab K. Ghosh

Urban trees can protect city residents from extreme heat, but tree planting programs seldom provide sufficient shade where it is most needed. We synthesize evidence highlighting three rarely fulfilled prerequisites for the effective use of trees in heat adaptation.

Heatwaves are becoming increasingly frequent and deadly, especially in cities, where the effects of hot weather are amplified by the extensive use of asphalt and concrete (i.e., the urban heat island [UHI] effect)[1]. Consequently, it is vital that cities rapidly expand tree canopy cover to protect urban residents against the threat of extreme heat. Urban forestry has grown quickly as a discipline in recent decades, often with a focus on planting a specific number of trees annually in a bid to reach an ambitious strategic target for canopy cover. However, planting large numbers of trees is not sufficient to reliably deliver urban cooling. While some of the concepts discussed may be well known among specialists in urban greening, the field of urban sustainability engages a broad and interdisciplinary readership. Thus, our intention is to synthesize and clarify these ideas for the wider community. Specifically, we outline three critical prerequisites for success, which need much closer attention in heat adaptation policy, funding and program implementation.

Effective cooling needs dense canopy, close to homes

Tree canopy needs to be close to homes, workplaces and public spaces to be effective as a countermeasure to extreme heat; homes surrounded by unshaded concrete and asphalt are vulnerable, even if they happen to be in suburbs or municipalities with high average levels of canopy. A Wisconsin-based study by Ziter et al. (2019) found that canopy cover exceeding 40%, within 60 m of housing, was needed to provide significant cooling effects[2]. Studies in Germany have shown similar results. When canopy exceeds 30–40%, shading and evapotranspiration effects begin to significantly lower both surface and air temperature in the immediate surroundings at levels that ensure adequate physiological cooling of humans[3].

While cities vary in their overall canopy cover, with some achieving totals around 30–40%, recent studies in Europe, South-East Asia, Australia and the USA have highlighted that much of this canopy is not close enough to homes to offer effective cooling. A large majority of urban residents live and work in buildings that fall far short of even 30%[4–8]. This shortfall of canopy coverage often occurs in low-income neighbourhoods subject to chronic disinvestment, an environmental injustice which further compounds the risks posed by heatwaves[9]. This is a striking finding when considering the sharp heat fluxes of unshaded surfaces in urban settings; while these vary across climates (e.g. air and soil dryness)[10], the basic thermal gain associated with such large areas of unshaded asphalt and concrete, aggravated by the lack of cooling from transpiration when leaf cover is low, amounts to a significant heat risk to human health. Urgent as it is, rollout of canopy must occur thoughtfully, avoiding potential pitfalls such as night-time 'heat trapping' in narrow, poorly ventilated street canyons[11].

An important challenge is that the gaps between street trees in urban areas are often too large to overcome these heat fluxes. In a study of five global cities (Ottawa, Stockholm, Paris, Buenos Aires, and Washington DC), Smart et al. (2020) found planting density to be in the range of 1.0 to 10.6 trees per 100 m of street segment length[12]—a very low planting density in design terms. Ten trees per 100 m of street (noting that this figure includes both sides of the street) represents a spacing of 20 m between trees on each side of the street. Figure 1 shows a 100 m street segment; in the top example (Fig. 1a), we see roughly 10 trees per 100 m, which is the high end of commonly observed densities. Below, in Fig. 1b, we show how using simple, common approaches (such as median planting, tree placement between parking areas, and footpath planting at 6 m spacing) can achieve 48 trees per 100 m all while retaining gaps of at least 6 m between trees on footpaths, and without loss of parking or lane viability.

The differences between these built outcomes are considerable in terms of heat adaptation. Compared to shaded asphalt, temperatures of unshaded asphalt can exceed 40 degrees (Celsius). Dense canopy is especially effective as a heat response, offering much stronger thermal comfort outcomes than sparser canopy. A study in Germany found that dense canopy in urban environments can reduce temperatures experienced by humans by 11 °C, compared to only 4 °C with sparse canopy coverage[13].

Canopy sparseness partly reflects the modest budgets assigned to municipal forestry departments, which effectively preclude more ambitious streetscape works (e.g. those requiring more excavation or changes to drainage). However, the large gaps between trees are also the hallmark of a more subtle, bureaucratic barrier to tree canopy expansion. Trees continue to be afforded low priority in streetscape design decisions. It is common that buried utilities, driveways, sightlines and signage are all treated as reasons to exclude trees, often through the application of very large 'no plant zones' around these common urban features[14]. This is driven by a culture of *risk exclusion* (often by actors with siloed interests and accountabilities) rather than one of comprehensive risk management in the public interest. Addressing conflicts between tree planting and utilities requires greater use of physical solutions such as root barriers and utility conduits, as well as changes in regulatory standards that minimise

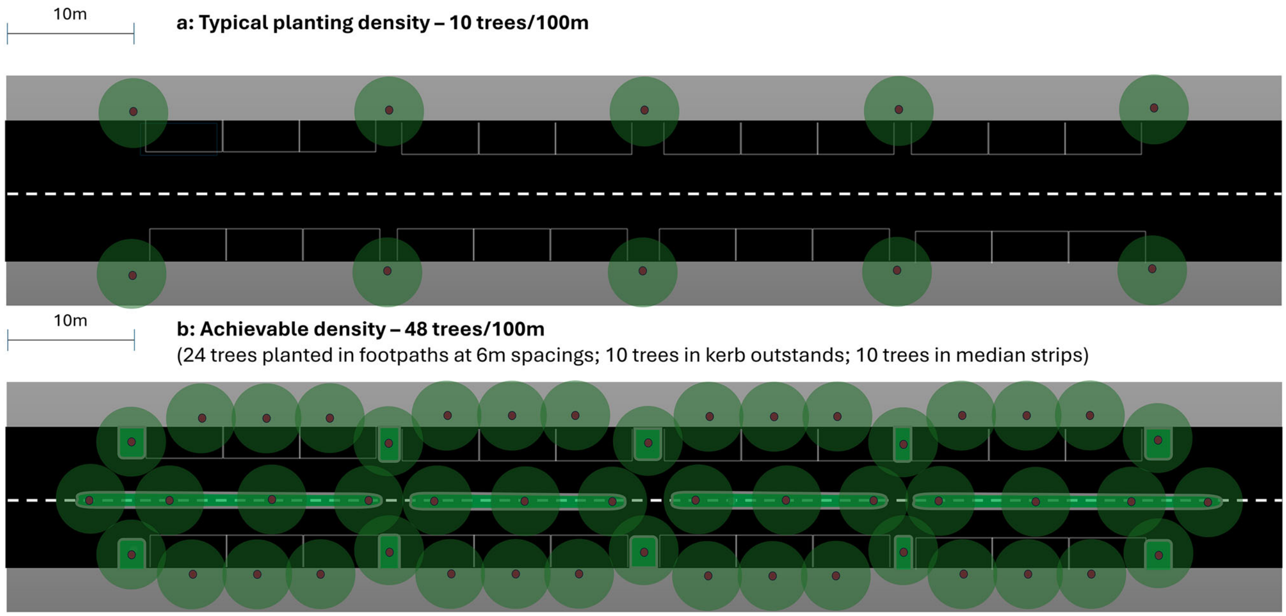

Fig. 1 | Demonstration of Typical vs. Achievable planting density. The streetscape designs below the plot demonstrate a 100 m street segment showing the high end of commonly-observed planting density (**a**), and achievable planting density (**b**). A density of 48 trees/100 m is achieved using common approaches such as median planting, tree planting between parking areas (outstands), and footpath planting with relatively close (6 m) spacing.

conflict and prioritize win-win design solutions. More broadly, a re-framing of these utility-related risks is necessary, to recognise tree exclusion as an inherently unacceptable 'solution' given the growing evidence that underscores the role of urban trees in the welfare of urban residents[9,15,16].

Tree health is vital to effective cooling

Planting large numbers of trees is frequently portrayed as a sign of a project's success. While planting represents important progress, these claims may be premature and conceal substantial under-investment in the long-term care and survival of these trees. Unhealthy trees don't grow fast, live long, or cool effectively.

Poor tree health is often an issue of inadequate water and soil health, but alternatively also results from waterlogging or poor species selection. To ensure optimal survival and thriving of planted trees, government agencies must not only plant trees, but also ensure the conditions that enable tree health, long-term growth and good cooling performance. Empirical studies conducted in the German cities of Munich and Würzburg demonstrate how tree growth and transpiration are significantly impacted by dry conditions and urban land-use constraints. For instance, *Platanus* x *hispanica* showed a 61% reduction in growth during soil drought, while *Robinia pseudoacacia* exhibited a 58% decline in transpiration under extreme drought stress (Fig. 2a, b). Trees planted in paved or compacted sites—common in high-impervious urban areas - experienced up to 60% reductions in both structural growth and cooling performance (Fig. 2b, c). These findings underscore the importance of ensuring adequate soil volume, infiltration, and moisture availability. Selecting species suited to site conditions and integrating root-friendly, water-sensitive design practices, are essential steps in securing the long-term cooling benefits of urban trees as living infrastructure.

Trees take decades to reach their cooling potential

Once trees are planted at suitable densities in suitable conditions, protecting the growth of the tree to maturity is a key factor in maximising cooling potential[17,18]. Trees in their first decade of life generally offer very limited shade and leaf area relative to decades-old specimens. As is visible in Fig. 3, a tree that is kept alive for 50 or 75 years provides canopy that is multiple times the area that is more common in urban forests, where longevity can be considerably shorter[17,19].

To date, analyses of tree retention show tree losses remain significant in many cities with rates of mortality likely considerably higher than what is necessary to support strong canopy progress[20–22]. Removal of urban trees is often so frequent as to be problematic to canopy growth; this is both due to high rate of avoidable tree removals (e.g. due to development, poor growth conditions, removal requests from residents) and shorter tree lifespans due to poor growing conditions such as constrained soil volume and low rainfall infiltration due to impermeable surfaces[21,23].

This is why active tree protection—the full suite of governance actions that limit premature tree removal—is a third crucial frontier in the use of urban forestry to address heat risks. A range of established tools, from 'exceptional tree' protections to sliding-scale fees for tree removal based on tree size, can be useful in reducing premature tree removal rates[22].

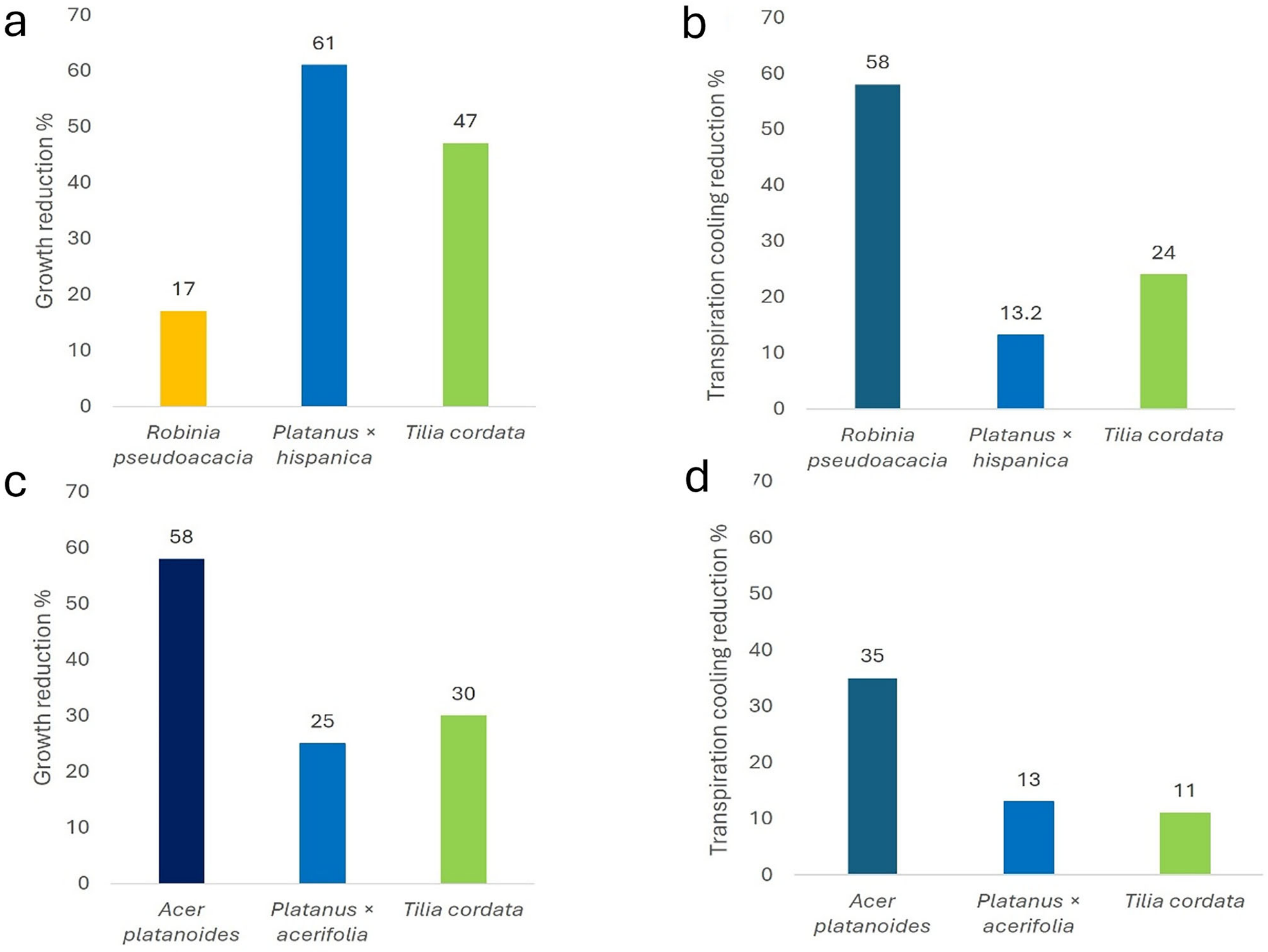

Fig. 2 | Species-specific growth and transpirational responses to drought and urban imperviousness. Panel **a** shows biomass increment per kg dry matter in 2018/2019 vs. normal years for Tilia cordata and Robinia pseudoacacia[24] and DBH increment for Platanus × hispanica under soil drought[25]; **b** shows transpiration sums during drought relative to long-term means (1965–2015), with leaf-level energy loss for Platanus × hispanica; **c** basal area of 60-year-old trees in high vs. low impervious zones; and **d** leaf transpirational cooling in urban areas with contrasting imperviousness[19].

Synthesis

While canopy cover close to buildings is a vital tool for urban heat adaptation, it remains inadequate in commonly used urban designs. This is the case even in cities with relatively high overall canopy cover. Upscaling urban tree planting programs will be important in responding to this problem. However, to do so meaningfully today and into the future, cities must plant large numbers of trees in a way that: (1) Achieve sufficient density to provide meaningful shade in streets; (2) Ensure adequate soil volume, water infiltration, and appropriate species selection for healthy growth; and (3) Ensure these trees grow to maturity over their decades-long life course. We currently possess the means to achieve these outcomes; an array of governance tools (e.g. building and civil design codes, zoning provisions, tree protection ordinances and urban forestry implementation plans) is available or can be modified to achieve what is required.

Practitioners directly responsible for canopy expansion are generally well-aware of these vital prerequisites to success. However, without governance reforms, they cannot act effectively on these frontiers[28]. Reforms to improve achievement in these areas will require careful engagement with communities, financing structures, institutions and legislation, led thoughtfully by executive and political leaders who understand the long-term potential of urban forestry. Improving achievement in the areas we have outlined is not just a matter of changing planting designs or tree protection rules. The value of the urban forest as a truly heat adaptive measure relies upon overcoming the barriers of inadequate capital and maintenance budgets, organisational silos, obstructive regulations, obsolete design practices, and disengaged local communities.

While the social benefits of urban trees are not limited only to heat mitigation (e.g., improved social capital, improved safety, and increased mental health benefits), as heat waves grow in intensity, frequency, and severity, we see enormous promise for cities in countries at varying levels of economic capacity to successfully tackle this nexus of barriers and deliver dense, shady plantings of healthy, long-lived trees for their communities and their climate resilience.

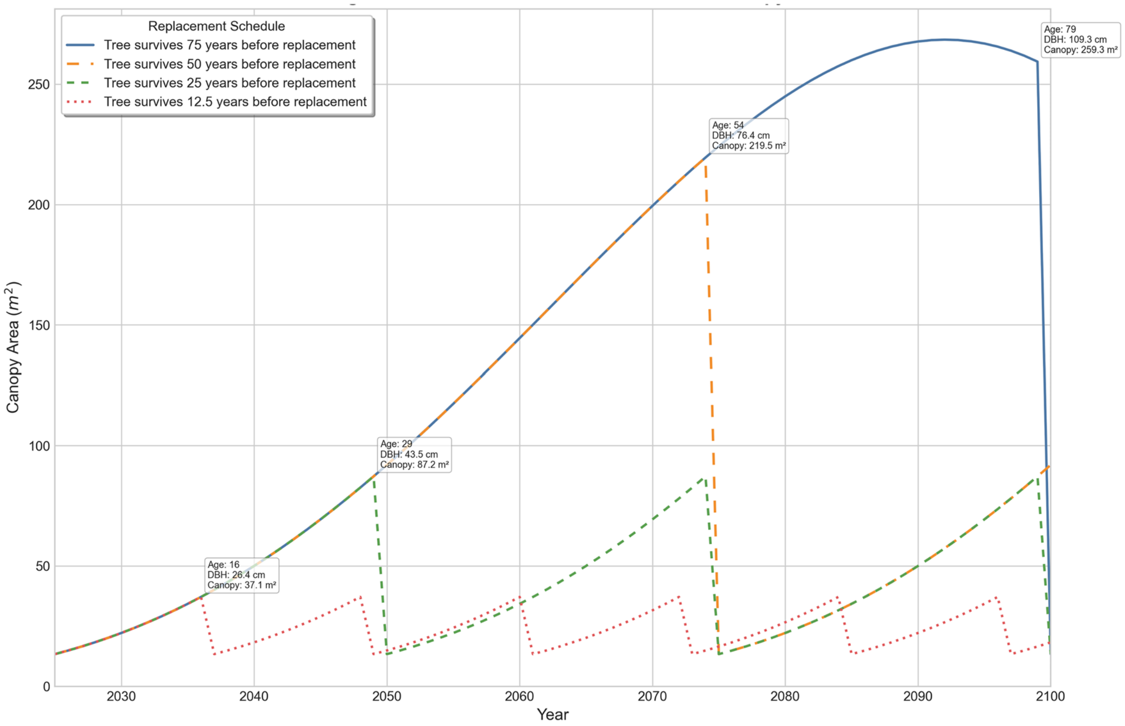

Fig. 3 | Canopy growth of the American Elm (Ulmus americana) over four modelled survival timeframes. Growth modelling is based on a US Forestry Service dataset, which provides city-specific growth equations for common urban tree species[26]. Strong tree protections that can support 50+ year lifespans in urban trees promise radically improved canopy outcomes, especially when applied across urban forests of thousands of trees.

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Author contributions

T.C. led the writing, conceptual development, and data visualisation, and acted as the corresponding author. M.R. contributed to writing, review and editing, conceptual development, and data visualisation. A.G. contributed to writing, editing, and conceptual development.

Competing interests

The authors declare no competing interests.

Additional information

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