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Measuring the 3-30-300 Rule to Help Cities Meet Nature Access Thresholds

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Abstract

The 3-30-300 rule offers benchmarks for cities to promote equitable nature access. It dictates that individuals should see three trees from their dwelling, have 30% tree canopy in their neighborhood, and live within 300 meters of a high-quality green space. Implementing this demands thorough measurement, monitoring, and evaluation methods, yet little guidance is currently available to pursue these actions. To overcome this gap, we employed an expert-based consensus approach to review the available ways to measure 3-30-300 as well as each measure's strengths and weaknesses. We described seven relevant data and processes: vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and green space maps. Based on the reviewed strengths and weaknesses of each measure, we presented a suitability matrix to link recommended measures with each component of the rule. These recommendations included surveys and window-view analyses for the '3 component', high-resolution land cover maps for the '30 component', and green space maps with network analyses for the '300 component'. These methods, responsive to local situations and resources, not only implement the 3-30-300 rule but foster broader dialogue on local desires and requirements. Consequently, these techniques can guide strategic investments in urban greening for health, equity, biodiversity, and climate adaptation.

1. Introduction

The health and well-being benefits of high-quality green space are increasingly recognized (Zhang et al., 2020). These benefits are prominent in the UN Sustainable Development Goal 11 Target 7, which states, "by 2030, providing universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities." Specifically, scholars and practitioners have increasingly focused on urban greening, which involves planting, conserving, and maintaining outdoor vegetation in cities and other urban areas (Eisenman et al., 2019), where increasing numbers of the world's population live. Relatedly, in 2021, Cecil Konijnendijk introduced a new standard for creating healthy, green, equitable cities: the 3-30-300 rule (Konijnendijk, 2021). 3-30-300 is a set of objective benchmarks for cities seeking to provide their residents with adequate access to nature and the benefits of exposure to natural settings. This approach leverages a vast and growing literature demonstrating the importance of trees and public green spaces, especially close to where people live, work, and play, for mental health, physical health, and climate adaptation (Nieuwenhuijsen, 2020; United Nations, n.d.; Yang et al., 2021).

3-30-300 incorporates three components of nature or “green”: visual green, residential green, and access to green for outdoor recreation. The goal states that everyone should be able to *see* at least 3 well-established trees from their home, workplace, or place of learning; *have* at least 30% tree canopy cover in their neighborhood; and *live* within 300-meters of a high-quality public green space (at least 0.5 ha in size) (Konijnendijk, 2022) (Figure 1). This new heuristic for urban nature and green space provision combines different metrics for proximity, quantity, and access.

The evidence and policy guidelines underpinning the rule are now being fully characterized (Konijnendijk, 2023). In brief, the 30 and 300 components are supported by a significant body of past research findings (Bosch et al., 2023; Nieuwenhuijsen, 2020; United Nations, n.d.). Studies of Australian adults have found that living in areas with ≥30% canopy cover is associated with reduced risk of Dementia (Astell-Burt et al., 2020); diabetes, hypertension, and cardiovascular disease (Astell-Burt and Feng, 2020); poor general health (Astell-Burt and Feng, 2019a); and short sleep duration (Astell-Burt and Feng, 2019b). Quantitative health impact assessments have estimated that increasing canopy cover to 30% could have prevented 2,644 premature deaths across 93 European cities in summer 2015 (Iungman et al., 2023) and 403 annually in Philadelphia, PA U.S. (Kondo et al., 2020). Meanwhile, living within 300-m of urban green space has been associated with fewer childhood mental and behavioral disorders in Spain (Pérez-del-Pulgar et al., 2021), hyperactivity/inattention problems in Munich, Germany (Markevych et al., 2014), poor mental health among women in Sweden (Annerstedt and Östergren, 2012), physical inactivity in the Netherlands (Klompmaker et al., 2018), breast cancer risk in Spain (O’Callaghan-Gordo et al., 2018), and cardiovascular disease in Kaunas, Lithuania (Tamosiunas et al., 2014). The 300 component also aligns with existing recommendations by the European Office of the World Health Organization (World Health Organization Regional Office for Europe, 2017). There is less evidence yet to support the 3 component, a practical aspiration that “alliterates” with 30 and 300, but numerous studies have identified tangible benefits of visual access to greenery for mental health, psychological restoration, and wellbeing (Benfield et al., 2015; Browning et al., 2020; Labib et al., 2022; Patwary et al., 2022; Ulrich, 1984). For instance, three visible trees from home have been associated with fewer medications and psychiatrist/psychologist visits in Spain (Nieuwenhuijsen et al., 2022), and larger numbers of mature street trees in a virtual reality simulation have improved recovery after acute stressors in the U.S. (Jiang et al., 2016). More broadly, access to greenery is associated with reduced risk of all-cause mortality, heart disease, obesity, mental disorders, low birth weight, physical inactivity, and sleep disorders, among dozens of other diseases, illnesses, and conditions (Bratman et al., 2019; Hartig et al., 2014; Markevych et al., 2017; Twohig-Bennett and Jones, 2018; Yang et al., 2021).

Since its launch, 3-30-300 has attracted considerable attention from urban foresters and allied environmental professionals–but also from urban planners and architects, politicians, and journalists. Many cities worldwide, including Malmo, Sweden; Zurich, Switzerland; St. Petersburg, Florida; Haarlem, The Netherlands; Saanich, British Columbia; and Viladecans, Spain have already adopted 3-30-300, either formally or informally, as part of their urban forestry or greening programs. International organizations such as the United Nations Economic Commission for Europe (United Nations Economic Commission for Europe, 2021) and the Nordic Council of Ministers (Nordic Council of Ministers, 2022) have recommended implementing 3-30-300. The region of Scania in Southern Sweden has asked consultants to develop an initial assessment method (Development Scania, n.d.). The NGO Future Woodlands Scotland started an urban forestry program with 3-30-300 as the key target (Future Woodlands Scotland, 2022). Another NGO, Nature Canada, recommends 3-30-300 as part of a strategy to reduce urban forest inequity (Nature Canada, 2022).

Epidemiologists have also embraced 3-30-300 as a set of “exposures” worth investigating for potential health and equity benefits. A recent city-wide 3-30-300 study in Barcelona, Spain, reported fewer per capita psychiatrist or psychologist visits in neighborhoods where all three rule components were met (Nieuwenhuijsen et al., 2022). Other outcomes were not associated with meeting all three components of 3-30-300, including self-reported mental health and the use of tranquilizers, sedatives, or antidepressants. A survey of 1,716 adults living in Florida, U.S., found 37.3% met all three components of 3-30-300 and that the most commonly reported benefits of trees by residents were shade, aesthetic value, nature access, and air filtration (Koeser et al., 2023).

Despite the excitement around the launch and early implementation of 3-30-300, much remains to be clarified about 3-30-300. Various public and private organizations have embarked on developing assessment and monitoring methods to implement the rule (Development Scania, n.d.; Future Woodlands Scotland, 2022; Nature Canada, 2022; Nordic Council of Ministers, 2022; United Nations Economic Commission for Europe, 2021). It could be difficult for city administrators and urban planners to know which options are available and recommended when measuring 3-30-300 across urban landscapes. Currently, there is no expert-based guidance on how to measure, monitor, or evaluate this rule, leaving its measurement up to the perspectives and knowledge base of the analysts available at each city or institution.

Therefore, this review aims to overcome the current gap in understanding how best to calculate the 3-30-300 rule by providing an expert-led and accessible overview of ways to measure each component of the rule. We summarize each metric relevant to 3-30-300, and describe each metric’s strengths and weaknesses, ultimately arriving at a suitability matrix for each component of the rule and the corresponding measures. We discuss considerations for measuring and adopting 3-30-300 according to geographical and contextual factors that may limit the relevance of the rule as a proxy for equitable nature access. Ultimately, we hope this review promotes robust monitoring and evaluation techniques for cities’ ongoing investments in improvements and expansions to urban canopy and green space.

2. Methods

2.1. Overview

Relevant research and methodological approaches to measuring urban greenspace/forestry span tens of thousands of studies from diverse disciplines (Zhang et al., 2020). We followed a former review's approach to retrieve relevant information from this large body of literature using expert-based consensus rather than the systematic collection of literature (Markevych et al., 2017). The former approach might be suitable for effectively collecting, classifying, and synthesizing this topic, as suggested by the scientific community's adoption of the former review: 1,400+ citations according to Google Scholar in the five years since its publication (October 2017). In the current review, we convened a series of asynchronous and synchronous virtual discussions from October 2022 to July 2023. Prior to the first discussion, an initial description of the relevant measures and their strengths and weaknesses were proposed by four authors (M.B., D.L., S.L., R.Y). These descriptions were critiqued, revised, and expanded by the remaining authors. The presented measures and their strengths and weaknesses were subject to multiple iterations. Ultimately, consensus was reached amongst all authors.

2.2. Definitions of terms

The multidisciplinary nature of this review's relevant fields of study warranted clear definitions of terms. These included "tree", "viewshed", "canopy cover", "neighborhood", and "urban green space." We define these terms in the following ways.

2.2.1. Tree—Although there is no standard botanical or taxonomic definition of 'tree', and varied ways of defining 'tree' in urban forestry (Doorn et al., 2020)in practical terms, trees are generally considered woody perennial plants whose trunks thicken over time, with some distinctions of tree vs. shrub and other woody herbaceous plants suggesting that trees are taller than 3 meters (Götmark et al., 2016; Richardson and Rejmánek, 2011). Decisions about what qualifies as a tree are often made locally or regionally, for instance, in tropical climates where palms function as trees but do not display the growth patterns of botanically-recognized trees (Doorn et al., 2020). In this review, we generally do not differentiate between tree types; however, 3-30-300 does recommend mature, well-established, larger trees (Konijnendijk, 2023). This recommendation has been supported by Belgian research finding wider crowns (the upper part of the tree) are associated with fewer mood disorders and cardiovascular medications, while higher densities of stems are associated with more of these medications (Chi et al., 2022). Further evidence is available from a study in Oregon, U.S., documenting older and presumably larger trees showed greater protective associations with lower non-accidental mortality rates than younger trees (Donovan et al., 2022). However, there are still numerous benefits associated with small-stature trees, including resident preferences for flowering and fruiting trees (Nguyen et al., 2017), and cultural affinity for palms (which are not always considered 'trees') in some regions (Blair et al., 2019).

2.2.2. Viewshed—Determining whether a person can view three trees from a window in a building requires an understanding of that person's viewshed. For this review, we define viewshed as the landscape visible from a vantage point without obstructions (i.e., buildings or sloped terrain) (Cimburova and Blumentrath, 2022). 3-30-300 focuses on viewsheds from any window in homes, offices, and schools. It does not limit viewsheds by location (i.e., bedroom or home office windows).

2.2.3. Canopy cover—We define urban tree canopy cover as the proportion of an area (e.g., neighborhood) covered by leaves, branches, and stems of trees when viewed from above. Canopy cover is usually expressed as a percentage, with 0% representing an area with no canopy, and 100% representing an area completely covered by canopy. 3-30-300 does not specify whether 30% canopy cover pertains to summer-time high estimates when deciduous trees are fully leafed. Much research on greenery and human health has utilized single-day estimates, such as maximum values during the summer (Markevych et al., 2017). City-wide tree canopy cover goals are common (Locke et al., 2017; Nguyen et al., 2017).

2.2.4. Neighborhood—We define neighborhoods within cities, towns and suburbs as geographically-bound areas of limited size, with relative homogeneity in housing and population, as well as some level of social interaction and symbolic significance to residents (Chaskin, 1997; Weiss et al., 2007). Two types of neighborhood definitions are commonly used in the reviewed research on greenery and human health: *allocentric* units based on administrative zones (e.g., census tracts) and *egocentric* units based on areas around an individual's location (e.g., their home) (Chaix et al., 2009; S M Labib et al., 2020). However, subjective boundaries can also represent individuals' perceptions of their neighborhood (Christensen et al., 2022; Yang et al., 2020).

2.2.5. Urban green space—We rely on previous definitions to describe urban green space as city areas with greenery that support biodiversity, ecosystem services, or passive and/or active outdoor recreation (Grabowski et al., 2022; Jennings et al., 2019; Li et al., 2023; Matsler et al., 2021; Morpurgo et al., 2023; Taylor and Hochuli, 2017). These areas can take on many forms, such as parks, athletic fields, forests, cemeteries, private open spaces, gardens and agricultural areas, green stormwater infrastructure (i.e., rain gardens, bioswales, detention/infiltration basins), and green roofs/walls, among other forms (Grabowski et al., 2022; Jennings et al., 2019; Li et al., 2023; Matsler et al., 2021; Morpurgo et al., 2023; Taylor and Hochuli, 2017). 3-30-300 prioritizes definitions that include quality assessments as well as amenities and tangible abilities to affect residents' health and well-being positively. Identification of a high-quality urban green space may depend on place-specific features such as the total canopy and leaf area for heat reduction, recreational facilities such as sport fields and trails for physical activity, and infrastructure such as playgrounds and picnic shelters for social cohesion (Markevych et al., 2017).

3. Results

3.1. Measures and their strengths and weaknesses

The expert-based consensus found that most data related to measuring 3-30-300 can be organized into seven main categories: vegetation indices, street-level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space property maps (Figure 2). However, the methods of processing these data can overlap. For example, semantic segmentation - a computer vision technique used to classify and separate objects or regions of an image - can be applied to photographs from windows and street-view images to derive tree visibility. Additionally, some data sources can produce other datasets, such as airborne LiDAR and high-resolution imagery, which are used to derive high resolution (≤ 1m^2), high classification accuracy (≥ 95%) tree canopy maps. Therefore, we caution that these seven categories are discussion points rather than a complete and mutually exclusive set of data sources and processing techniques. The uneven material in these seven categories reflects, in part, the stage development and degree of applicability to 3-30-300.

3.1.1. Vegetation Indices—Numerous satellite-based products are available to measure vegetation cover. They do not measure tree canopy cover directly. For instance, vegetation continuous field (VCF) values indicate the percentage of vegetative cover ≥ 5-m in height (Hansen et al., 2003). Moderate Resolution Imaging Spectroradiometer (MODIS) derived VCF data are available annually (2000-present) and globally at a resolution of 250-m2. Annual and global VCF data are available from Landsat 5 and 7 imagery at 30-m2 resolution at 5-year intervals (2000, 2005, 2010, 2015) (Sexton et al., 2013). In the U.S., the Multi-Resolution Land Characteristics Consortium provides National Land Cover Database (NLCD) and tree canopy cover estimates at 30-m^2 resolution (Coulston et al., 2012; Nowak and Greenfield, 2010). Recently, Lang et al. used Sentinel 2 and Global Ecosystem Dynamics Investigation (GEDI) space-borne LiDAR data to generate 2017-present 10-m2 estimates of canopy height, which could be used to calculate canopy cover (2022, 2019). NDVI can also be calculated from other satellite, drone, or aerial imagery such as National Agriculture Inventory Program (NAIP) imagery can be used to generate NDVI. While providing an estimate of vegetation, these above-listed indices do not provide the percent cover metric for 3-30-300, or when they do, it is at coarse spatial scales.

3.1.2. Street level analyses—Georeferenced street view images (SVI) can be used to calculate several metrics related to 3-30-300 (Biljecki and Ito, 2021). Imagery is available from Google (2007-present), Baidu (2012-present), and Mapillary geotagged photos (2013-present), among other sources. For all three data sources, individual locations have 360-degree views from images in the four cardinal directions along streets. Images can be used to extract the percentage of greenery along streets. For instance, Harvard University researchers developed a 100-m street network grid for U.S. metropolitan statistical areas by utilizing Google API to find the nearest SVI at each point along a street each year. Computer vision was used to calculate visible greenery (e.g., trees, shrubs, grass, plants, and flowers) through a pyramid scene parsing network (PSPNet) (Zhou et al., 2017) deep learning model with the ADE20K pre-trained dataset (Zhou et al., 2017). Similarly, Helbich et al. (2021) used SVI in Amsterdam to create a high-resolution greenness visibility surface, and MIT’s Treepedia has performed a similar function for select cities globally (Cai et al., 2018). These datasets and image pixel analysis models often cannot count the number of visible trees but instead can create estimates (i.e., SVI with 10% tree cover may represent three visible trees). Other deep learning object detection models like You Only Look Once (YOLO) can also be used to detect and count individual trees in SVIs (Branson et al., 2018; Liu et al., 2023; Redmon and Farhadi, 2018). Pre-trained deep learning models, such as SegFormer and Mask2Former on CityScapes, are available through open APIs on the Hugging Face platform for tree visibility modeling using SVIs without requiring extensive programming skills. Other image segmentation approaches for SVIs include manual selection in Adobe Photoshop histograms (Adobe, San Jose, CA) and the Brown Dog Green Index (Suppakittpaisarn et al., 2022). Manual estimates of each tree location, species, and diameter at breast height (dbh) can be performed on SVI (Berland and Lange, 2017). By design, street-view images focus on streetscapes. So while they may capture street trees (with omission and commission errors), they miss trees in backyards and other spaces entirely (S.M. Labib et al., 2020).

Street-level analyses can also be performed with light detecting and ranging (LiDAR) products to conduct viewshed analyses that model tree visibility. LiDAR uses laser pulses to measure distances between a sensor and a surface (i.e., the Earth's surface), where the laser beam is sent toward the ground, and the time it takes for the light to bounce back is measured to determine the distance. Sensors are often located on low-flying aircraft but can be located on unmanned aerial vehicles (UAV) or handheld devices (Tang et al., 2023; Xia et al., 2023). The resulting high-resolution point cloud data can generate digital surface models (DSMs), three-dimensional representations of the Earth's surface, including natural and anthropogenic features such as trees, buildings, and terrain (S.M. Labib et al., 2020; Vosselman and Maas, 2010; Yu et al., 2016). LiDAR can, therefore, "see through" shadows in urban areas. Several viewshed analysis tools have been developed and applied to model eye-level vegetation visibility, for instance, the GVI-R/Python packages (Brinkmann and Labib, 2022; S.M. Labib et al., 2020). The open-source GRASS GIS AddOn *v.viewshed.impact* tool can also be applied to model individual tree visibility (Cimburova et al., 2023). By integrating these tools with building and window location information, precise representations of tree visibility can be estimated (Cimburova and Blumentrath, 2022).

3.1.3. Tree inventories—Tree inventories are systematic and comprehensive surveys of trees on public lands within a defined area, such as a city. Tree species, size, health, and geolocation are usually available in inventory datasets. Research teams and organizations like OpenTrees.org have compiled datasets across numerous municipalities, such as the Global Urban Tree Inventory (Ossola et al., 2020). Some countries have national-scale inventories as well, such as the UK National Tree Map™. In addition to surveys, photogrammetry can be applied to mobile phone images to create tree inventories (Arboreal AB, 2018; Marzulli et al., 2020; Roberts et al., 2019; Texas A&M Forest Service, n.d.; The Globe Program, n.d.; Vastaranta et al., 2015). Related to 3-30-300, tree inventories can generate maps that can be compared with residence locations for visibility assessments. Notably, tree inventories are often limited to publicly managed trees (e.g., street trees, public parks) and therefore do not capture private lands, representing a considerable portion of the urban forest in many neighborhoods. Municipal tree inventories may also be outdated, inconsistently updated, or contain imprecise location data for individual trees.

3.1.4. Questionnaires—Questionnaires can be administered to residents through the mail, internet, door-to-door interviews, phone calls, text messages, and other methods (Dillman et al., 2014) to collect data on several aspects of 3-30-300. For example, the Urban National Landowner Survey was developed by the U.S. Forest Service and asked respondents about the number of trees on their properties (United States Forest Service, 2021). Nieuwenhuijsen et al. assessed window views in Barcelona, Spain, by asking residents whether they could see green elements from their homes (Nieuwenhuijsen et al., 2022). These data were cross-referenced with geolocated tree census data. In addition, data on urban green space proximity has been collected by asking residents whether parks are within walking distance or not (Giles-Corti and Donovan, 2002), as well as the distance to the closest green space (Helbich et al., 2020).

3.1.5. Window-view analyses—Evaluating tree visibility for 3-30-300 requires self-reported, or researcher-assisted, data or geospatial and image analysis methods. In addition to questionnaires, image segmentation or object detection can be applied to residents' photographs (Lin et al., 2022) or trees can be manually counted in these images. Another approach is drawing buffers around building footprints and counting trees in a city census (Battisti et al., 2023). A more precise visibility approach using geospatial (e.g., viewshed) and image analysis methods requires three datasets: (1) window location including cardinal direction and exact geolocation, (2) window height including meters above ground level, and (3) terrain information from a digital elevation model or digital surface model, including buildings, trees, and other above-ground features. Zhang et al. (2023) proposed a green window-view index by extracting the green elements of photos taken by respondents from their most viewed windows with the best viewing angle in the daytime. The best viewing angle is relevant since wider fields of view may capture more trees than views farther away (Ko et al., 2023). This is an experimental method, not yet operational on a city-wide basis. Additionally, using the GVI model and *v.viewshed.impact* tool with window location and height information, window-view analyses can be performed using the viewshed approach.

3.1.6. Land cover maps—Land cover classification is the physical characteristics of the land into categories, such as tree canopy cover, soil, water, or rock. Summarizing a tree canopy class within neighborhood polygons directly can create the 30 component of 3-30-300. Recent developments in deep learning models and the availability of Sentinel satellite imagery have allowed the creation of global land cover datasets at 10-m2 spatial resolution (Table 1). The European Space Agency's WorldCover map, Esri's Sentinel-2 Land Cover Explorer, and Dynamic World (Brown et al., 2022) provide near real-time data (every 2–5 days) to classify areas with trees or assess green space locations. The Environmental Protection Agency (EPA) provides 1-m^2 resolution land cover data for select cities currently covering the places where about 70,000,000 people live.

Multiple land cover maps are available specifically for Europe. The Coordination of Information on the Environment (CORINE) Land Cover (CLC) covers all European Economic Area (EEA) countries (1990-present) (European Environment Agency, 2021). The resolution is limited to a Minimum Mapping Unit (MMU) of 25-ha for areal features and minimum width of 100-m for linear features, making it less suitable for intra-city studies. Another Europe-wide land cover map is the Urban Atlas, available for all EEA cities of more than 100,000 inhabitants (2006) or 50,000 inhabitants (2012, 2018) (European Commission, 2020), providing an MMU of 0.25-ha for urban classes and 1-ha for rural classes. The Urban Atlas in Europe since 2012 has included an extra layer for street trees with an MMU of 500-m2 and 10-m (European Commission, 2020) (Table 1). Additionally, some European countries have higher-resolution LULC datasets, including green space class, such as the Dutch land use model LGN 2020 and UK land use data LCM2015 (Table 1).

DSMs from LiDAR, in conjunction with high-resolution imagery such as airborne NAIP or very high resolution satellite images (Sicard et al., 2023), can then be used to create high-resolution (≤1-m^2), high-accuracy (≥95%) land cover maps for measuring the green space locations and canopy cover estimates (Cardinali et al., 2023; Kimball et al., 2014). For example, the University of Vermont Spatial Analysis Lab has completed approximately 90 land cover and tree canopy change mapping projects (MacFaden et al., 2012; O'Neil-Dunne et al., 2014a, 2014b, 2012; University of Vermont Spatial Analysis Lab, n.d.). The combination of LiDAR and high-resolution imagery may be considered the gold standard for urban land cover mapping and in service of the 30% canopy cover measure. Other countries have national LiDAR data coverage, such as the AHN in the Netherlands (Actueel Hoogtebestand Nederland, n.d.) and Digimap (Digimap, n.d.) in the UK. Mobile apps can also leverage some smartphones' LiDAR sensors to create 3D scans of objects and landscapes. Notable examples are KIRI (KIRI Innovations, 2023) and ForestScanner (Tatsumi et al., 2022). When scaled, these apps may allow communities to create high-resolution 3D maps of trees and vegetation at a lower cost than traditional approaches (i.e., flyovers from low-flying aircraft) (Pace et al., 2022).

3.1.7. Urban green space property boundaries—Several national and regional urban green space GIS data are available to identify the locations of urban green spaces such as parks and other open spaces. These GIS datasets are usually stored in a vector data format (e.g., polygons) that are different from generally available grid-based land cover data discussed in the previous section, which does not pertain to land use. Browning et al. recently curated the Parks and Protected Areas Database United States (PAD-US) (U.S. Geological Survey, 2020) to create a PAD-US-AR (PAD-US-[A]ccessible[R]ecreational), specifying parks for public access and outdoor recreation for the U.S. (Browning et al., 2022). Esri's USA Parks contains parks across the U.S. (Environmental Systems Research Institute, 2022), and the Trust for Public Land's ParkServe contains park locations for nearly 14,000 U.S. cities, towns, and communities (Trust for Public Land, 2022). The Urban Atlas in Europe includes a class for urban green space with an MMU of 500-m2 and 10-m (European Commission, 2020). The OS MasterMap Greenspace layer in the United Kingdom provides very high resolution green space data, including multiple green space types (e.g., parks, gardens, amenity space) (Table 1). Outside of Europe and the U.S., Ju et al. created a map of urban green space in major Latin American cities (Ju et al., 2022). We are unaware of similar data beyond Ju et al. for other low to middle-income countries (LMICs) and nations. However, some cities in different LMICs countries have their public park data set locally through city authorities, often created as part of the urban master or strategic plans. For example, the city management authorities have detailed green space data in Dhaka (Labib and Harris, 2018) and Johannesburg (Khanyile and Fatti, 2022). Similar data might be available for other cities in different LMICs, but such data might only be accessible through local city authorities.

Globally, urban green space polygons are available from open street map (OSM), which requires a series of user-entered keys (topic/category) and values (features) to map parks and similar areas (i.e., dog parks, playgrounds). The accuracy and consistency of tags vary geographically and are often imprecise, making identifying green spaces difficult (Ludwig et al., 2021). Small, informal open spaces like vacant lots turned gardens are likely missed. Nonetheless, Boeing et al. demonstrated that OSM-based urban green space data could be used in green space accessibility assessments at diverse geographic locations with acceptable accuracy (Boeing et al., 2022).

Spatial proximity analysis can be used with urban green space data to determine the distances to the urban green space maps for 3-30-300. Distances are operationalized based on "as the crow flies" (i.e., Euclidean) or with more sophisticated analyses taking into account transportation networks (e.g., such as streets) and access points (e.g., centroids or entry points for the urban green space) (Cardinali et al., 2023; S M Labib et al., 2020; Wang et al., 2021) (Figure 3). Calculating Euclidean distances is simple and fast but can be inappropriate when physical barriers exist, such as roads without pedestrian crossings. Euclidean distances often evaluate whether a green space boundary or access point intersects with the 300-m circular buffer around the home. Necessary data for spatial proximity analysis include home location, green space boundary or access point locations, and road networks (Labib, 2021; Wang et al., 2021). Urban green space maps often represent polygonal areas (Wang et al., 2021), but for network analysis, the destination must be a point, ideally related to an access location to a green space (e.g., gate). While the polygon's center (centroid, Figure 3) can be used as this destination, this approach might lead to overestimated or otherwise inaccurate distances for larger or irregularly-shaped green spaces (Labib, 2021). Some locations have geolocated access points (Figure 3), such as the UK Ordnance Survey, and other locations might rely on pseudo-access points created by intersecting the polygon boundary with the road network (S M Labib et al., 2020; Wang et al., 2021). Network distances sum the lengths of the street links connecting the origin (home) to the green space. Numerous geospatial software tools such as ArcGIS Pro Network Analyst (esri, n.d.) and QGIS QNEAT3 (Raffler, 2018) as well as programming packages - igraph in C (igraph core team, 2023); NetworkX (NetworkX Developers, 2023) and OSMnx (Boeing, 2017) in Python; and sfnetwork (Meer et al., n.d.) and r5R (Pereira et al., 2021) in R - can run shortest path algorithms such as Dijkstra's or A* (Doran and Michie, 1966). These tools can connect with road network data and routing engines (e.g., MapBox (Walker, 2020) and OSRM (Luxen and Vetter, 2011)) through APIs, and can adopt different cost functions (e.g., distance, time, and composite cost) to find the shortest distances between origins and the nearest green space. The function of the road network (e.g., for driving, walking, biking, or all three) is relevant in these analyses (Boeing, 2017). If walking and biking are the preferred travel modes to green space, highways and other high-traffic roads should be excluded. See Talen (Talen, 2001) and Cardinali et al. (Cardinali et al., 2023) for additional guidance on measuring walking access to urban green space.

3.2. Suitability of each measure

Evaluating 3-30-300 can require substantial financial and technical resources. From LiDAR-derived canopy cover to professional assessments of urban green spaces, the necessary resources for highly accurate assessments may be out of reach for some municipalities (Hummel et al., 2011). Secondary datasets might be behind paywalls or difficult to process without advanced computing. Such issues are particularly relevant for cities in low and middle-income countries and medium-sized and small municipalities elsewhere. Larger

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cities in more developed countries, with more staff in planning and park management, might have the capacity and know-how to measure the 3-30-300 rule with the "best" metrics (Lowe et al., 2016; Rigolon and Christensen, 2023). The relative imbalance of the subsections describing the state of the technologies and measures used to operationalize 3-30-300 is itself a finding. Some measures are harder to describe than others. Not all aspects of 3-30-300 are well-developed, while others, like high-resolution tree canopy mapping, are well-established industry standards (Kimball et al., 2014).

Table 2 provides an overview of such metrics as well as the experts-based consensus on the suitability of each metric (i.e., best, fair, or poor). We present the heterogeneity in the quality and availability of data to measure and evaluate 3-30-300. Researchers and practitioners may still be well-served by selecting less-ideal metrics when assessing and monitoring their progress toward meeting the thresholds specified in 3-30-300 then none at all. If data and computational resources are available, questionnaires and window-view analyses are best for assessing the visibility of 3 trees, high-resolution land cover maps are best for measuring tree canopy cover, and urban green space property maps with network analyses are best for the 300 component.

4. Discussion

4.1. Overview on measuring 3-30-300

Implementing the 3-30-300 rule requires thorough measurement, monitoring, and evaluation methods, yet little guidance is currently available to pursue these actions. To overcome this gap, we employed an expert-based consensus approach to identify ways to measure the 3-30-300 rule of equitable green space access and availability. We also evaluated each measure's strengths and weaknesses and created a suitability matrix for which measure could be used for which component of the rule. Through virtual discussions from October 2022 to July 2023, we presented seven relevant data and processes for this goal: vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space maps. Furthermore, based on the available data and techniques available through July 2023, we identified the following suitable measures for each component of the rule: questionnaires and window-view analyses for the 3 component of the rule, high resolution land cover maps for the 30 component, and urban green space property maps with network analyses for the 300 component.

4.2. Considerations on measuring and adopting 3-30-300

Regardless of how the 3-30-300 rule is measured, each component might have varying degrees of applicability in specific geographic, economic, social, political, and cultural contexts. For example, old European cities, sprawling North American metropoles, new cities in China, and megacities in Latin America and Africa with informal settlements differ in building density, planning, transportation, zoning, other forms of infrastructure, and governance systems. Select components of the rule may not always be reasonable or warranted, given the opportunity costs of increasing nature access (Rigolon et al., 2018; Souza and Torres, 2021; Torres et al., 2022). McDonald et al. provided evidence that urbanization and greenery have competing trade-offs, both with benefits for sustainability and human health (McDonald et al., 2022). Still, numerous greening interventions have been successful at allowing neighborhoods to be both dense and green in diverse settings. For instance, new urban models during the COVID-19 pandemic enabled city streets to serve some of the same functions as urban green spaces, such as superblocks (Barcelona, Spain) and car-free neighborhoods (Freiburg, Germany) (Nieuwenhuijsen, 2021). Therefore, seeking to meet the components of 3-30-300 may need to be approached with care and creativity. In the section below, we discuss the difficulties and opportunities across geographic contexts for applying and measuring 3-30-300.

4.2.1. 3 and 30 components—Regarding the 3 and 30 components, many high-density neighborhoods may lack sufficient plantable space. Examples of such places, common to many European cities, eastern US and Canadian cities, and Asian megacities, often have dense apartment buildings, no yard space, and little room for trees outside of public streets or small parks (Schwab, 2009). In such neighborhoods, achieving a smaller threshold of canopy cover (e.g., 15%) could constitute a significant achievement in nature access (Pataki et al., 2021).

Climate and climate change might also limit the degree to which the 30 component could be achieved. This threshold might be an unrealistic and unattainable goal in climates with water restrictions (Begert, 2022; Pincetl et al., 2013; Schwab, 2009), such as dry cities in the Middle East, North Africa, the U.S. Southwest, northeastern China, and Australia. For example, the city of Las Vegas (Nevada, U.S.) aims to achieve a 20% canopy cover by 2025, an ambitious goal that would double its most recent estimate of 10% cover (City of Las Vegas, n.d.). In cities facing water scarcity outside of forested biomes, concentrating on 30% vegetation cover (rather than tree canopy) may be more appropriate, as well as focusing on native or drought-tolerant plants. Alternative measures to those suggested for 3-30-300 may be appropriate in these regions, including a modified soil-adjusted vegetation index (MSAVI) (Qi et al., 1994) and fractional vegetation cover (FVC; percent vertical projection of branch, stem and leaves in area) (Gitelson et al., 2002; Purevdorj et al., 1998).

Acceptance of new trees might also vary across populations, further hindering a city’s capacity to achieve the 3 and 30 components. Some racial/ethnic minority populations in the U.S. have rejected tree planting programs because there was not enough community engagement before planting, and due to legacies of municipal disinvestment, insufficient mature tree maintenance, and associated burdens (Carmichael and McDonough, 2019, 2018; Riedman et al., 2022). Similar barriers have been seen in European cities (Henley, 2023). Also, in the U.S., tree planting is often performed by cities or counties, but watering and upkeeping are delegated to residents, with some exceptions (Carmichael and McDonough, 2019, 2018; Riedman et al., 2022), creating additional barriers to tree planting and maintenance. In these cases, municipalities may maintain newly planted trees on private lands, facilitate programs for individuals, organizations, or companies to maintain trees along a road segment, or compensate residents for planting and maintaining new trees. In the recently released urban forest plan for Philadelphia (Pennsylvania, U.S.), investing in the maintenance of existing trees (including proactive inspection cycles and removal as appropriate) was framed as crucial to building trust and interest in new plantings (Philadelphia Parks & Recreation, 2023).

Finally, the 3 and 30 components do not mention quality assessments of the trees (i.e., biodiversity, tree health), nor do they assess management and long-term likelihood of survival of trees that are being planted (Hilbert et al., 2019). Cities implementing 3-30-300 may also improve genus and species diversity who focusing on native species that are climate-change tolerant for particular areas (Which Plant Where, 2023). For instance, cities could combine 3-30-300 greening efforts with other heuristics such as the 10/20/30 benchmark (Santamour, 1990) suggesting municipal forests diversify with no more than 10% of any one particular species, 20% of any one genus or 30% of any single family; measures like the Shannon Diversity Index (a species diversity calculation) (Kendal et al., 2014) and Pest Vulnerability Matrix (an urban forest vulnerability calculation); aesthetic evaluations of canopy distributions and shapes (Hu et al., 2022).

4.2.2. 300 component—The feasibility of the 300 component may be dependent on population densities, financing systems for green spaces, and political will to fund urban green space. Low-density cities where the primary transportation mode is the automobile might be unlikely to achieve this threshold. Despite the U.S. goal of everyone living within 10-min walk (800-m) of a park (Trust for Public Land, 2023), very few cities (San Francisco, CA being the notable exception) have met this goal (Land, 2019). Estimates of how many U.S. residents live within a 10-min walk of a park vary between 33% and 75% (National Recreation and Park Association, 2022; Trust for Public Land, 2023). Because of relatively low population density and low tax bases in U.S. cities, it might be unattainable to have a park within 300-m of every resident. The same limitation in achieving the 300 component might apply to car-dominated, low-density cities in Canada, Oceania, Europe, and Asia.

The 300 component also does not specify visitation, green space use, or quality. Residents might choose to travel farther from their homes to reach a larger green space or that has the amenities they are looking for (e.g., a sports field) rather than visiting a green space that is within 300-m of their homes. Some studies have shown that park amenities, not proximity, are associated with park visitation (Kaczynski et al., 2014). Many people in North America choose to drive to parks instead of walking (Loukaitou-Sideris and Sideris, 2009; National Recreation and Park Association, 2018). Green space visits are associated with better mental and physical health; they may be a better indicator of health benefits than accessibility indicators (Triguero-Mas et al., 2017b). To this extent, the increasing use of self-report and GPS tracking green space visitation data may need to be cross-referenced with green space accessibility for meaningful measures of the 300 component (Triguero-Mas et al., 2017a). Additionally, cities can use participatory processes to define future green space to increase the likelihood of acceptance and use by residents (Loukaitou-Sideris and Mukhija, 2023; Mattijssen et al., 2018b, 2018a; Mell, 2020; Rigolon, 2018). Since green space visitation may be influenced by pressure and crowding (Westover and Collins, 1987), green space cover per capita can be considered a factor in use and subsequent benefits (Larson et al., 2022). Relatedly, green space quality may factor into visitation and observed benefits, so professional on-site assessments and delineations through instruments like the 90-item RECITAL survey can refine the extent to delineate the “high-quality” green spaces qualifying for meeting the 300 component (Knobel et al., 2020, 2019).

4.3. Limitations of review

Due to the expert-based consensus approach, the reported measures, their strengths and weaknesses, and the suitability matrix may not provide a comprehensive listing of the recommended options for measuring 3-30-300. Many of the reviewed measures have also not been tested against each other. Future research should incorporate multiple measures within the proposed “good,” “best,” and “unknown” cells of the suitability matrix (Table 2) to determine their reliability and validity across different geographic and sociopolitical contexts. Data and processes for measuring environmental exposures are also developing rapidly. Readers should continue to follow relevant bodies of literature for emerging ways to measure 3-30-300. At the same time, newer approaches should be vetted as we’ve done here (expert-based consensus) or through validation studies with established approaches, such as the “good” and “best” measures in our suitability matrix, to refine the recommendations presented.

5. Conclusion

The UN Sustainable Development Goal 11 Target 7 recommends universal access to safe, inclusive and accessible green and public spaces. The 3-30-300 rule provides a set of objective, universal benchmarks for cities to determine how they fare on urban green space proximity, tree canopy coverage, and access, as well as where to target investments for the future. Seven well-defined categories of data and processes to measure 3-30-300 are available, including vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space maps. Based on available data and current techniques, our expert-based consensus suggests questionnaires and window-view analyses for the 3 component, high resolution land cover maps for the 30 component, and urban green space property maps with network analyses for the 300 component. These data and processes can inform targeted investments in urban greening for health, equity, biodiversity, climate adaptation, and aesthetics. Ultimately, such decisions should be responsive to local conditions and available resources, with 3-30-300 representing a starting point for broader discussions about local needs and wants. 3-30-300 can serve as a powerful catalyst for action to address disparities in nature access and improve the health, equity, and well-being of our communities and cities.

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References

Actueel Hoogtebestand Nederland, n.d. Actueel Hoogtebestand Nederland [WWW Document]. URL https://www.ahn.nl/ (accessed 4.22.23).

Annerstedt M, Östergren PO, 2012. Green qualities in the neighbourhood and mental health–results from a longitudinal cohort study in Southern Sweden. BMC Public Health 12, 90. 10.1186/1471-2458-12-337 [PubMed: 22289260]

Arboreal AB, 2018. Apple App Store: Arboreal-Tree [WWW Document]. URL https://apps.apple.com/us/app/arboreal-tree/id1444138299 (accessed 2.27.23).

Astell-Burt T, Feng X, 2020. Urban green space, tree canopy and prevention of cardiometabolic diseases: a multilevel longitudinal study of 46 786 Australians. International Journal of Epidemiology 49, 926–933. 10.1093/ije/dyz239 [PubMed: 31722373]

Astell-Burt T, Feng X, 2019a. Association of Urban Green Space With Mental Health and General Health Among Adults in Australia. JAMA Network Open 2, e198209–e198209. 10.1001/jamanetworkopen.2019.8209 [PubMed: 31348510]

Astell-Burt T, Feng X, 2019b. Does sleep grow on trees? A longitudinal study to investigate potential prevention of insufficient sleep with different types of urban green space. SSM - Population Health 100497. [PubMed: 32025565]

Astell-Burt T, Navakatikyan MA, Feng X, 2020. Urban green space, tree canopy and 11-year risk of dementia in a cohort of 109,688 Australians. Environment International 145, 106102. 10.1016/j.envint.2020.106102 [PubMed: 32979811]

Battisti L, Aimar F, Giacco G, Devecchi M, 2023. Urban Green Development and Resilient Cities: A First Insight into Urban Forest Planning in Italy. Sustainability 15, 12085. 10.3390/su151512085

Begert B, 2022. Cities want more trees. Drought is complicating their efforts. [WWW Document]. Grist. URL https://grist.org/drought/cities-want-more-trees-drought-is-complicating-their-efforts/ (accessed 3.1.23).

Benfield JA, Rainbolt GN, Bell PA, Donovan GH, 2015. Classrooms with nature views: Evidence of differing student perceptions and behaviors. Environment and Behavior 47, 140–157. 10.1177/0013916513499583

Berland A, Lange DA, 2017. Google Street View shows promise for virtual street tree surveys. Urban For Urban Gree 21, 11–15. 10.1016/j.ufug.2016.11.006

Biljecki F, Ito K, 2021. Street view imagery in urban analytics and GIS: A review. Landscape Urban Plan 215, 104217. 10.1016/j.landurbplan.2021.104217

Blair SA, Koeser AK, Knox GW, Roman LA, Thetford M, 2019. Visual health assessments for palms. Urban For Urban Gree 41, 195–200. 10.1016/j.ufug.2019.03.017

Boeing G, 2017. OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. Comput Environ Urban Syst 65, 126–139. 10.1016/j.compenvurbsys.2017.05.004

Boeing G, Higgs C, Liu S, Giles-Corti B, Sallis JF, Cerin E, Lowe M, Adlakha D, Hinckson E, Moudon AV, Salvo D, Adams MA, Barrozo LV, Bozovic T, Delclòs-Alió X, Dygrýn J, Ferguson S, Gebel K, Ho TP, Lai P-C, Martori JC, Nitvimol K, Queralt A, Roberts JD, Sambo GH, Schipperijn J, Vale D, de Weghe NV, Vich G, Arundel J, 2022. Using open data and open-source software to develop spatial indicators of urban design and transport features for achieving healthy and sustainable cities. Lancet Global Heal 10, e907–e918. 10.1016/s2214-109x(22)00072-9

van den Bosch M, Dadvand P, Feng X, Morand S, Remans R, Tyrvainen L, de Vries S, Gibbs E, Sankam J, Bauer N, Dayamba D, Payyappalli U, Rasolofoson R, Shackleton C, Shanley P, van den Berg A, Bratman G, Browning MHEM, Donovan G, Fuertes E, O'Callaghan-Gordo C, Rojas-Rueda D, Sanesi G, Spano G, Tiguero-Mas M, Yang B-Y, Payyappallimana U, Bugni V, Laird S, Shukor SFA, Grima N, 2023. Forests and trees for human health: Pathways, impacts, challenges, and response options, IUFRO World Series Vol. 41. IUFRO.

Branson S, Wegner JD, Hall D, Lang N, Schindler K, Perona P, 2018. From Google Maps to a fine-grained catalog of street trees. ISPRS J. Photogramm. Remote Sens 135, 13–30. 10.1016/j.isprsjprs.2017.11.008

Bratman GN, Anderson CB, Berman MG, Cochran B, de Vries S, Flanders J, Folke C, Frumkin H, Gross JJ, Hartig T, Kahn PH Jr., Kuo M, Lawler JJ, Levin PS, Lindahl T, Meyer-Lindenberg A, Mitchell R, Ouyang Z, Roe J, Scarlett L, Smith JR, van den Bosch M, Wheeler BW, White MP, Zheng H, Daily GC, 2019. Nature and mental health: An ecosystem service perspective. Sci Adv 5, eaax0903. 10.1126/sciadv.aax0903

Brinkmann S, Labib SM, 2022. GVI: Greenness Visibility Index R Package [WWW Document]. URL https://zenodo.org/record/7057132#.Y_3c8OzMLmE (accessed 2.28.23).

Brown CF, Brumby SP, Guzder-Williams B, Birch T, Hyde SB, Mazzariello J, Czerwinski W, Pasquarella VJ, Haertel R, Ilyushchenko S, Schwehr K, Weisse M, Stolle F, Hanson C, Guinan O, Moore R, Tait AM, 2022. Dynamic World, Near real-time global 10 m land use land cover mapping. Sci Data 9, 251. 10.1038/s41597-022-01307-4

Browning MHEM, Rigolon A, Ogletree S, Wang R, Klompmaker JO, Bailey C, Gagnon R, James P, 2022. The PAD-US-AR dataset: Measuring accessible and recreational parks in the contiguous United States. Sci. Data 9, 773. 10.1038/s41597-022-01857-7 [PubMed: 36526628]

Browning MHEM, Saeidi-Rizi F, McAnirlin O, Yoon H, Pei Y, 2020. The role of methodological choices in the effects of experimental exposure to simulated natural landscapes on human health and cognitive performance: A systematic review. Environ. Behav 53, 687–731. 10.1177/0013916520906481

Cai BY, Li X, Seiferling I, Ratti C, 2018. Treepedia 2.0: Applying Deep Learning for Large-scale Quantification of Urban Tree Cover. 2018 Ieee Int Congr Big Data Bigdata Congr 49–56. 10.1109/bigdatacongress.2018.00014

Cardinali M, Beenackers MA, van Timmeren A, Pottgiesser U, 2023. Preferred reporting items in green space health research. Guiding principles for an interdisciplinary field. Environ Res 115893. 10.1016/j.envres.2023.115893 [PubMed: 37054830]

Carmichael CE, McDonough MH, 2019. Community Stories: Explaining Resistance to Street Tree-Planting Programs in Detroit, Michigan, USA. Soc Natur Resour 32, 588–605. 10.1080/08941920.2018.1550229

Carmichael CE, McDonough MH, 2018. The trouble with trees? Social and political dynamics of street tree-planting efforts in Detroit, Michigan, USA. Urban For Urban Gree 31, 221–229. 10.1016/j.ufug.2018.03.009

Chaix B, Merlo J, Evans D, Leal C, Havard S, 2009. Neighbourhoods in eco-epidemiologic research: Delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. Soc Sci Med 69, 1306–1310. 10.1016/j.socscimed.2009.07.018 [PubMed: 19692161]

Chaskin RJ, 1997. Perspectives on Neighborhood and Community: A Review of the Literature. Soc Serv Rev 71, 521–547. 10.1086/604277

Chi D, Aerts R, Nieuwenhuyse AV, Bauwelinck M, Demoury C, Plusquin M, Nawrot TS, Casas L, Somers B, 2022. Residential Exposure to Urban Trees and Medication Sales for Mood Disorders and Cardiovascular Disease in Brussels, Belgium: An Ecological Study. Environ Health Persp 130, 057003. 10.1289/ehp9924

Christensen A, Griffiths C, Hobbs M, Gorse C, Radley D, 2022. Investigating where adolescents engage in moderate to vigorous physical activity and sedentary behaviour: An exploratory study. PLOS ONE 17, e0276934. 10.1371/journal.pone.0276934 [PubMed: 36472978]

Cimburova Z, Blumentrath S, 2022. Viewshed-based modelling of visual exposure to urban greenery – An efficient GIS tool for practical planning applications. Landscape Urban Plan 222, 104395. 10.1016/j.landurbplan.2022.104395

Cimburova Z, Blumentrath S, Barton DN, 2023. Making trees visible: A GIS method and tool for modelling visibility in the valuation of urban trees. Urban For Urban Gree 81, 127839. 10.1016/j.ufug.2023.127839

City of Las Vegas, n.d. City of Las Vegas Sustainability Policies and Codes [WWW Document]. URL https://files.lasvegasnevada.gov/planning/CLV-Sustainability-Policies-and-Codes.pdf (accessed 3.1.23).

Coulston JW, Moisen GG, Wilson BT, Finco MV, Cohen WB, Brewer CK, 2012. Modeling Percent Tree Canopy Cover: A Pilot Study. Photogrammetric Eng Remote Sens 78, 715–727. 10.14358/pers.78.7.715

Development Scania, n.d. 3-30-300 in Skåne [WWW Document]. URL https://utveckling.skane.se/publikationer/regional-utveckling/3-30-300-i-skane-analysmodell-for-gronare-och-halsosammare-stader/ (accessed 4.22.23).

Digimap, n.d. LiDAR [WWW Document]. URL https://digimap.edina.ac.uk/lidar (accessed 4.22.23).

Dillman DA, Smyth JD, Christian LM, 2014. Internet, phone, mail, and mixed-mode surveys, John Wiley & Sons. John Wiley & Sons.

Donovan GH, Prestemon JP, Gatziolis D, Michael YL, Kaminskie AR, Dadvand P, 2022. The association between tree planting and mortality: a natural experiment and cost-benefit analysis. Environ Int 107609. 10.1016/j.envint.2022.107609 [PubMed: 36332494]

van Doorn NS, Roman LA, McPherson EG, Scharenbroch BC, Henning JG, Östberg JPA, Mueller LS, Koeser AK, Mills JR, Hallett RA, Sanders JE, Battles JJ, Boyer DJ, Fristensky JP, Mincey SK, Peper PJ, Vogt J, 2020. Urban tree monitoring: A field guide. 10.2737/nrs-gtr-194

Doran JE, Michie D, 1966. Experiments with the Graph Traverser program. Proc Royal Soc Lond Ser Math Phys Sci 294, 235–259. 10.1098/rspa.1966.0205

Eisenman TS, Churkina G, Jariwala SP, Kumar P, Lovasi GS, Pataki DE, Weinberger KR, Whitlow TH, 2019. Urban trees, air quality, and asthma: An interdisciplinary review. Landscape and Urban Planning 187, 47–59. 10.1016/j.landurbplan.2019.02.010

Environmental Systems Research Institute, 2022. USA Parks [WWW Document]. URL https://www.arcgis.com/home/item.html?id=578968f975774d3fab79fe56c8c90941 (accessed 9.1.22).

esri, n.d. Network Analyst tutorials [WWW Document]. URL https://pro.arcgis.com/en/pro-app/latest/help/analysis/networks/network-analyst-tutorials.htm (accessed 3.1.23).

European Commission, 2020. Mapping Guide v6.3 for a Urban Atlas

European Environment Agency, 2021. Copernicus Land Monitoring Service.

Future Woodlands Scotland, 2022. Invitation to Tender: The Development of a £10m Urban Forestry Fund for Scotland. Introduction: Overview of Future Woodlands Scotland The Urban Forestry Fund.

Giles-Corti B, Donovan RJ, 2002. Socioeconomic Status Differences in Recreational Physical Activity Levels and Real and Perceived Access to a Supportive Physical Environment. Prev Med 35, 601–611. 10.1006/pmed.2002.1115 [PubMed: 12460528]

Gitelson AA, Kaufman YJ, Stark R, Rundquist D, 2002. Novel algorithms for remote estimation of vegetation fraction. Remote Sens Environ 80, 76–87. 10.1016/s0034-4257(01)00289-9

Götmark F, Götmark E, Jensen AM, 2016. Why Be a Shrub? A Basic Model and Hypotheses for the Adaptive Values of a Common Growth Form. Front Plant Sci 7, 1095. 10.3389/fpls.2016.01095 [PubMed: 27507981]

Grabowski ZJ, McPhearson T, Matsler AM, Groffman P, Pickett ST, 2022. What is green infrastructure? A study of definitions in US city planning. Front Ecol Environ 20, 152–160. 10.1002/fee.2445

Hansen MC, DeFries RS, Townshend JRG, Carroll M, Dimiceli C, Sohlberg RA, 2003. Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm. Earth Interact 7, 1–15. 10.1175/1087-3562(2003)007<0001:gptcaa>2.0.co;2

Hartig T, Mitchell RJ, de Vries S, Frumkin H, 2014. Nature and health. Annual Reviews in Public Health 35, 207–228. 10.1146/annurev-publhealth-032013-182443

Helbich M, Hagenauer J, Roberts H, 2020. Relative importance of perceived physical and social neighborhood characteristics for depression: a machine learning approach. Soc Psych Psych Epid 55, 599–610. 10.1007/s00127-019-01808-5

Helbich M, Poppe R, Oberski D, van Emmichoven MZ, Schram R, 2021. Can't see the wood for the trees? An assessment of street view- and satellite-derived greenness measures in relation to mental health. Landsc. Urban Plan 214, 104181. 10.1016/j.landurbplan.2021.104181

Henley J, 2023. "We need trees": Green vision struggles to take root in Europe's cities [WWW Document]. URL https://www.theguardian.com/cities/2023/jan/16/trees-green-vision-europe-cities (accessed 3.1.23).

Hilbert DR, Roman LA, Koeser AK, Vogt J, van Doorn NS, 2019. Urban tree mortality: A literature review. Arboriculture & Urban Forestry 5, 167–200. 10.13140/rg.2.2.25953.15204

Hu T, Wei D, Su Y, Wang X, Zhang J, Sun X, Liu Y, Guo Q, 2022. Quantifying the shape of urban street trees and evaluating its influence on their aesthetic functions based mobile lidar data. Isprs J Photogramm 184, 203–214. 10.1016/j.isprsjprs.2022.01.002

Hummel S, Hudak AT, Uebler EH, Falkowski MJ, Megown KA, 2011. A Comparison of Accuracy and Cost of LiDAR versus Stand Exam Data for Landscape Management on the Malheur National Forest. Journal of Forestry.

igraph core team, 2023. igraph - The network analysis package [WWW Document]. URL https://igraph.org/ (accessed 3.1.23).

Iungman T, Cirach M, Marando F, Barboza EP, Khomenko S, Masselot P, Quijal-Zamorano M, Mueller N, Gasparrini A, Urquiza J, Heris M, Thondoo M, Nieuwenhuijsen M, 2023. Cooling cities through urban green infrastructure: a health impact assessment of European cities. Lancet 401, 577–589. 10.1016/s0140-6736(22)02585-5 [PubMed: 36736334]

Jennings V, Browning MHEM, Rigolon A, 2019. Urban Green Spaces, Public Health and Sustainability in the United States, SpringerBriefs in Geography. Springer. 10.1007/978-3-030-10469-6

Jiang B, Li D, Larsen L, Sullivan WC, 2016. A dose-response curve describing the relationship between urban tree cover density and self-reported stress recovery. Environment and Behavior 48, 607–629. 10.1177/0013916514552321

Ju Y, Dronova I, Delclòs-Alió X, 2022. A 10 m resolution urban green space map for major Latin American cities from Sentinel-2 remote sensing images and OpenStreetMap. Sci Data 9, 586. 10.1038/s41597-022-01701-y [PubMed: 36153342]

Kaczynski AT, Besenyi GM, Stanis SAW, Koohsari MJ, Oestman KB, Bergstrom R, Potwarka LR, Reis RS, 2014. Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. Int J Behav Nutr Phy 11, 146. 10.1186/s12966-014-0146-4

Kendal D, Dobbs C, Lohr VI, 2014. Global patterns of diversity in the urban forest: Is there evidence to support the 10/20/30 rule? Urban For Urban Gree 13, 411–417. 10.1016/j.ufug.2014.04.004

Khanyile S, Fatti CC, 2022. Interrogating park access and equity in Johannesburg, South Africa. Environ Urbanization 34, 10–31. 10.1177/09562478221083891

Kimball LL, Wiseman PE, Day SD, Munsell JF, 2014. Use of Urban Tree Canopy Assessments by Localities in the Chesapeake Bay Watershed. Cities and the Environment 7.

KIRI Innovations, 2023. Google Play Store: KIRI Engine - 3D Scanner [WWW Document]. URL https://play.google.com/store/apps/details?id=com.kiri.kiriengine&pli=1 (accessed 2.27.23).

Klompmaker JO, Hoek G, Bloemsma LD, Gehring U, Strak M, Wijga AH, van den Brink C, Brunekreef B, Lebret E, Janssen NAH, 2018. Green space definition affects associations of green space with overweight and physical activity. Environmental Research 160, 531–540. 10.1016/j.envres.2017.10.027 [PubMed: 29106952]

Knobel P, Dadvand P, Alonso L, Costa L, Español M, Maneja R, 2020. Development of the urban green space quality assessment tool (RECITAL). Urban Forestry & Urban Greening 126895. 10.1016/j.ufug.2020.126895

Knobel P, Dadvand P, Maneja-Zaragoza R, 2019. A systematic review of multi-dimensional quality assessment tools for urban green spaces. Health & Place 59, 102198. 10.1016/j.healthplace.2019.102198 [PubMed: 31525616]

Ko WH, Schiavon S, Santos L, Kent M, Kim H, Keshavarzi M, 2023. View access index: The effects of geometric variables of window views on occupants' satisfaction. Build Environ 110132. 10.1016/j.buildenv.2023.110132

Koeser A, Hauer R, Andreu M, Northrop R, Clarke M, Diaz J, Hilbert D, Konijnendijk C, Landry S, Thompson G, Zarger R, 2023. Using the 3-30-300 Rule to Assess Urban Forest Access and Preferences in Florida (United States). 10.20944/preprints202305.1760.v1

Kondo MC, Mueller N, Locke DH, Roman LA, Rojas-Rueda D, Schinasi LH, Gascon M, Nieuwenhuijsen MJ, 2020. Health impact assessment of Philadelphia's 2025 tree canopy cover goals. The Lancet Planetary Health 4, e149–e157. 10.1016/s2542-5196(20)30058-9 [PubMed: 32353295]

Konijnendijk C, 2022. The 3-30-300 Rule for Urban Forestry and Greener Cities. Biophilic Cities Journal 4.

Konijnendijk CC, 2023. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3-30-300 rule. J. For. Res 34, 821–830. 10.1007/s11676-022-01523-z

Konijnendijk CC, 2021. Promoting health and wellbeing through urban forests – Introducing the 3-30-300 rule. IUCN. URL https://iucnurbanalliance.org/promoting-health-and-wellbeing-through-urban-forests-introducing-the-3-30-300-rule/

Labib SM, 2021. Estimating multiple greenspace exposure types and their associations with neighbourhood premature mortality: a socioecological study. Sci Total Environ 147919. 10.1016/j.scitotenv.2021.147919 [PubMed: 34062470]

Labib SM, Browning MHEM, Rigolon A, Helbich M, James P, 2022. Nature's contributions in coping with a pandemic in the 21st century: A narrative review of evidence during COVID-19. Sci. Total Environ 833, 155095. 10.1016/j.scitotenv.2022.155095 [PubMed: 35395304]

Labib SM, Harris A, 2018. The potentials of Sentinel-2 and LandSat-8 data in green infrastructure extraction, using object based image analysis (OBIA) method. Eur J Remote Sens 51, 231–240. 10.1080/22797254.2017.1419441

Labib SM, Huck JJ, Lindley S, 2020. Modelling and mapping eye-level greenness visibility exposure using multi-source data at high spatial resolutions. Sci Total Environ 755, 143050. 10.1016/j.scitotenv.2020.143050 [PubMed: 33129523]

Labib SM, Lindley S, Huck JJ, 2020. Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. Environmental Research 180, 108869. 10.1016/j.envres.2019.108869 [PubMed: 31722804]

Land, T.T. for P., 2019. ParkScore 2018 Ranking Analysis [WWW Document]. URL https://parkscore.tpl.org/rankings_advanced.php#sm.00013514enxjsda0yth1z1uwoadwo

Lang N, Kalischek N, Armston J, Schindler K, Dubayah R, Wegner JD, 2022. Global canopy height regression and uncertainty estimation from GEDI LIDAR waveforms with deep ensembles. Remote Sens Environ 268, 112760. 10.1016/j.rse.2021.112760

Lang N, Schindler K, Wegner JD, 2019. Country-wide high-resolution vegetation height mapping with Sentinel-2. Remote Sens Environ 233, 111347. 10.1016/j.rse.2019.111347

Larson LR, Mullenbach LE, Browning MHEM, Rigolon A, Thomsen J, Metcalf EC, Reigner NP, Sharaievska I, McAnirlin O, D'Antonio A, Cloutier S, Helbich M, Labib SM, 2022. Greenspace and park use associated with less emotional distress among college students in the United States during the COVID-19 pandemic. Environ. Res 204, 112367. 10.1016/j.envres.2021.112367 [PubMed: 34774510]

Li H, Browning MHEM, Rigolon A, Larson LR, Taff D, Labib SM, Benfield J, Yuan S, McAnirlin O, Hatami N, Kahn PH, 2023. Beyond "bluespace" and "greenspace": A narrative review of possible health benefits from exposure to other natural landscapes. Sci. Total Environ 856, 159292. 10.1016/j.scitotenv.2022.159292 [PubMed: 36208731]

Lin T-Y, Le A-V, Chan Y-C, 2022. Evaluation of window view preference using quantitative and qualitative factors of window view content. Build Environ 213, 108886. 10.1016/j.buildenv.2022.108886

Liu D, Jiang Y, Wang R, Lu Y, 2023. Establishing a citywide street tree inventory with street view images and computer vision techniques. Comput Environ Urban Syst 100, 101924. 10.1016/j.compenvurbsys.2022.101924

Locke DH, Romolini M, Galvin M, O'Neil-Dunne JPM, Strauss EG, 2017. Tree Canopy Change in Coastal Los Angeles 2009 – 2014. Cities and the Environment 10.

Loukaitou-Sideris A, Mukhija V, 2023. Promotores for Parks? The Potential of a Public Health Model to Improve Outreach and Community Engagement in Park Planning. Leisure Sci 45, 281–303. 10.1080/01490400.2020.1817202

Loukaitou-Sideris A, Sideris A, 2009. What Brings Children to the Park? Analysis and Measurement of the Variables Affecting Children's Use of Parks. J Am Plann Assoc 76, 89–107. 10.1080/01944360903418338

Lowe K, Reckhow S, Gainsborough JF, 2016. Capacity and Equity: Federal Funding Competition between and Within Metropolitan Regions. J Urban Aff 38, 25–41. 10.1111/juaf.12203

Ludwig C, Fendrich S, Zipf A, 2021. Regional variations of context-based association rules in OpenStreetMap. T Gis 25, 602–621. 10.1111/tgis.12694

Luxen D, Vetter C, 2011. Real-time routing with OpenStreetMap data. Proc 19th Acm Sigspatial Int Conf Adv Geogr Information Syst - Gis '11 513–516. 10.1145/2093973.2094062

MacFaden SW, O'Neil-Dunne JPM, Royar AR, Lu JWT, Rundle AG, 2012. High-resolution tree canopy mapping for New York City using LIDAR and object-based image analysis. Journal of Applied Remote Sensing 6, 063567–1-063567–23. 10.1117/1.jrs.6.063567

Markevych I, Schoierer J, Hartig T, Chudnovsky A, Hystad P, Dzhambov AM, de Vries S, Triguero-Mas M, Brauer M, Nieuwenhuijsen MJ, Lupp G, Richardson EA, Astell-Burt T, Dimitrova DD, Feng X, Sadeh M, Standl M, Heinrich J, Fuertes E, 2017. Exploring pathways linking greenspace to health: Theoretical and methodological guidance. Environmental Research 158, 301–317. 10.1016/j.envres.2017.06.028 [PubMed: 28672128]

Markevych I, Tiesler CMT, Fuertes E, Romanos M, Dadvand P, Nieuwenhuijsen MJ, Berdel D, Koletzko S, Heinrich J, 2014. Access to urban green spaces and behavioural problems in children: Results from the GINIplus and LISAplus studies. Environment International 71, 29–35. 10.1016/j.envint.2014.06.002 [PubMed: 24953038]

Marzulli MI, Raumonen P, Greco R, Persia M, Tartarino P, 2020. Estimating tree stem diameters and volume from smartphone photogrammetric point clouds. For Int J For Res 93, 411–429. 10.1093/forestry/cpz067

Matsler AM, Meerow S, Mell IC, Pavao-Zuckerman MA, 2021. A 'green' chameleon: Exploring the many disciplinary definitions, goals, and forms of "green infrastructure." Landscape Urban Plan 214, 104145. 10.1016/j.landurbplan.2021.104145

Mattijssen T, Buijs A, Elands B, 2018a. The benefits of self-governance for nature conservation: A study on active citizenship in the Netherlands. J Nat Conserv 43, 19–26. 10.1016/j.jnc.2018.01.006

Mattijssen T, Buijs A, Elands B, Arts B, 2018b. The 'green' and 'self' in green self-governance – a study of 264 green space initiatives by citizens. J Environ Pol Plan 20, 96–113. 10.1080/1523908x.2017.1322945

McDonald RI, Aronson MFJ, Beatley T, Beller E, Bazo M, Grossinger R, Jessup K, Mansur AV, de Oliveira JAP, Panlasigui S, Burg J, Pevzner N, Shanahan D, Stoneburner L, Rudd A, Spotswood E, 2022. Denser and greener cities: Green interventions to achieve both urban density and nature. People Nat. 10.1002/pan3.10423

van der Meer L, Abad L, Bilardi A, Lovelace R, n.d. Tidy Geospatial Networks in R [WWW Document]. URL https://luukvdmeer.github.io/sfnetworks/ (accessed 3.1.23).

Mell I, 2020. The impact of austerity on funding green infrastructure: A DPSIR evaluation of the Liverpool Green & Open Space Review (LG&OSR), UK. Land Use Policy 91, 104284. 10.1016/j.landusepol.2019.104284

Morpurgo J, Remme RP, Bodegom PMV, 2023. CUGIC: The Consolidated Urban Green Infrastructure Classification for assessing ecosystem services and biodiversity. Landscape Urban Plan 234, 104726. 10.1016/j.landurbplan.2023.104726

National Recreation and Park Association, 2022. 2022 Engagement with Parks Report.

National Recreation and Park Association, 2018. 2018 American's Engagement with Parks Report.

Nature Canada, 2022. Canada's Urban Forests: Bringing the Canopy to All September 2022.

NetworkX Developers, 2023. NetworkX: Network analysis in Python [WWW Document]. URL https://networkx.org/ (accessed 3.1.23).

Nguyen VD, Roman LA, Locke DH, Mincey SK, Sanders JR, Fichman ES, Duran-Mitchell M, Tobing SL, 2017. Branching out to residential lands: Missions and strategies of five tree distribution programs in the U.S. Urban For Urban Gree 22, 24–35. 10.1016/j.ufug.2017.01.007

Nieuwenhuijsen MJ, 2021. New urban models for more sustainable, liveable and healthier cities post covid19; reducing air pollution, noise and heat island effects and increasing green space and physical activity. Environ Int 106850. 10.1016/j.envint.2021.106850 [PubMed: 34531034]

Nieuwenhuijsen MJ, 2020. Green infrastructure and health. Annual Review of Public Health 42, annurev-publhealth-090419–102511-12. 10.1146/annurev-publhealth-090419-102511

Nieuwenhuijsen MJ, Dadvand P, Márquez S, Bartoll X, Barboza EP, Cirach M, Borrell C, Zijlema WL, 2022. The evaluation of the 3-30-300 green space rule and mental health. Environ Res 114387. 10.1016/j.envres.2022.114387 [PubMed: 36162472]

Nordic Council of Ministers, 2022. Policy Brief: Unpacking the Green Recovery Spending.

Nowak DJ, Greenfield EJ, 2010. Evaluating The National Land Cover Database Tree Canopy and Impervious Cover Estimates Across the Conterminous United States: A Comparison with Photo-Interpreted Estimates. Environmental Management 46, 378–390. 10.1007/s00267-010-9536-9 [PubMed: 20676888]

O'Callaghan-Gordo C, Kogevinas M, Cirach M, Castaño-Vinyals G, Aragonés N, Delfrade J, Fernández-Villa T, Amiano P, Dierssen-Sotos T, Tardón A, Capelo R, Peiró-Perez R, Moreno V, Roca-Barceló A, Perez-Gomez B, Vidan J, Molina AJ, Oribe M, Gràcia-Lavedan E, Espinosa A, Valentín A, Pollán M, Nieuwenhuijsen MJ, 2018. Residential proximity to green spaces and breast cancer risk: The multicase-control study in Spain (MCC-Spain). International Journal of Hygiene and Environmental Health 221, 1097–1106. 10.1016/j.ijheh.2018.07.014 [PubMed: 30076044]

O'Neil-Dunne J, MacFaden S, Royar A, 2014a. A Versatile, Production-Oriented Approach to High-Resolution Tree-Canopy Mapping in Urban and Suburban Landscapes Using GEOBIA and Data Fusion. Remote Sens-basel 6, 12837–12865. 10.3390/rs61212837

O'Neil-Dunne J, MacFaden S, Royar A, Reis M, Dubayah R, Swatantran A, 2014b. An object-based approach to statewide land cover mapping, in: ASPRS 2014 Annual Conference.

O'Neil-Dunne JPM, MacFaden SW, Royar AR, Pelletier KC, 2012. An object-based system for LiDAR data fusion and feature extraction. Geocarto International 28, 227–242. 10.1080/10106049.2012.689015

Ossola A, Hoeppner MJ, Burley HM, Gallagher RV, Beaumont LJ, Leishman MR, 2020. The Global Urban Tree Inventory: A database of the diverse tree flora that inhabits the world's cities. Global Ecology and Biogeography geb. 13169–8. 10.1111/geb.13169

Pace R, Masini E, Giuliarelli D, Biagiola L, Tomao A, Guidolotti G, Agrimi M, Portoghesi L, Angelis PD, Calfapietra C, 2022. Tree Measurements in the Urban Environment: Insights from Traditional and Digital Field Instruments to Smartphone Applications. Arboric Urban For 48, 113–123. 10.48044/jauf.2022.009

Pataki DE, Alberti M, Cadenasso ML, Felson AJ, McDonnell MJ, Pincetl S, Pouyat RV, Setälä H, Whitlow TH, 2021. The Benefits and Limits of Urban Tree Planting for Environmental and Human Health. Frontiers Ecol Evol 9, 603757. 10.3389/fevo.2021.603757

Patwary MM, Dzhambov A, Disha AS, Bardhan M, Haque MZ, Rahman MA, Tareq MF, Browning MHEM, Larson LR, Alam MA, Labib SM, Shuvo FK, Parkinson C, 2022. Exposure to nature during the COVID-19 pandemic and the associated effect on mental health: a systematic review with meta-analysis. Lancet Planet. Heal 6, S20. 10.1016/s2542-5196(22)00282-0

Pereira RHM, Saraiva M, Herszenhut D, Braga CKV, Conway MW, 2021. r5r: Rapid Realistic Routing on Multimodal Transport Networks with R 5 in R. Find. 10.32866/001c.21262

Pérez-del-Pulgar C, Anguelovski I, Cole HVS, de Bont J, Connolly J, Baró F, Díaz Y, Fontán-Vela M, Duarte-Salles T, Triguero-Mas M, 2021. The relationship between residential proximity to outdoor play spaces and children's mental and behavioral health: the importance of neighborhood socio-economic characteristics. Environ Res 111326. 10.1016/j.envres.2021.111326 [PubMed: 34029548]

Philadelphia Parks & Recreation, 2023. Philly Tree Plan.

Pincetl S, Gillespie T, Pataki DE, Saatchi S, Saphores J-D, 2013. Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. Geoj 78, 475–493. 10.1007/s10708-012-9446-x

Purevdorj TS, Tateishi R, Ishiyama T, Honda Y, 1998. Relationships between percent vegetation cover and vegetation indices. Int J Remote Sens 19, 3519–3535. 10.1080/014311698213795

Qi J, Chehbouni A, Huete AR, Kerr YH, Sorooshian S, 1994. A modified soil adjusted vegetation index. Remote Sens Environ 48, 119–126. 10.1016/0034-4257(94)90134-1

Raffler C, 2018. QGIS Network Analysis Toolbox 3 [WWW Document]. URL https://root676.github.io/index.html (accessed 3.1.23).

Redmon J, Farhadi A, 2018. YOLOv3: An Incremental Improvement. Arxiv. 10.48550/arxiv.1804.02767

Richardson DM, Rejmánek M, 2011. Trees and shrubs as invasive alien species – a global review. Divers Distrib 17, 788–809. 10.1111/j.1472-4642.2011.00782.x

Riedman E, Roman LA, Pearsall H, Maslin M, Ifill T, Dentice D, 2022. Why Don't People Plant Trees? Uncovering Barriers to Participation in Urban Tree Planting Initiatives. Urban For Urban Gree 73, 127597. 10.1016/j.ufug.2022.127597

Rigolon A, 2018. Nonprofits and park equity in Los Angeles: a promising way forward for environmental justice. Urban Geography 00, 1–26. 10.1080/02723638.2018.1511192

Rigolon A, Browning MHEM, Lee K, Shin S, 2018. Access to urban green space in cities of the global south: A systematic literature review. Urban Sci 2, 67. 10.3390/urbansci2030067

Rigolon A, Christensen J, 2023. Examining facilitators and challenges to implementing equitable green space policies: Lessons from Los Angeles County. Journal of Urban Affairs. 10.1080/07352166.2023.2184695

Roberts J, Koeser A, Abd-Elrahman A, Wilkinson B, Hansen G, Landry S, Perez A, 2019. Mobile Terrestrial Photogrammetry for Street Tree Mapping and Measurements. Forests 10, 701. 10.3390/f10080701

Santamour FS, 1990. Trees for urban planting: diversity, uniformity, and common sense, in: Proceedings of the Seventh Conference of the Metropolitan Tree Improvement Alliance (METRIA).

Schwab JC, 2009. Planning the Urban Forest: Ecology, Economy, and Community Development. American Planning Association.

Sexton JO, Song X-P, Feng M, Noojipady P, Anand A, Huang C, Kim D-H, Collins KM, Channan S, DiMiceli C, Townshend JR, 2013. Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. International Journal of Digital Earth 6, 427–448. 10.1080/17538947.2013.786146

Sicard P, Coulibaly F, Lameiro M, Araminiene V, Marco AD, Sorrentino B, Anav A, Manzini J, Hoshika Y, Moura BB, Paoletti E, 2023. Object-based classification of urban plant species from very high-resolution satellite imagery. Urban For. Urban Green 81, 127866. 10.1016/j.ufug.2023.127866

de Souza DT, Torres PHC, 2021. Greening and Just Cities: Elements for Fostering a South–North Dialogue Based on a Systematic Literature Review. Frontiers Sustain Cities 3, 669944. 10.3389/frsc.2021.669944

Suppakittpaisarn P, Lu Y, Jiang B, Slavenas M, 2022. How do computers see landscapes? comparisons of eye-level greenery assessments between computer and human perceptions. Landscape Urban Plan 227, 104547. 10.1016/j.landurbplan.2022.104547

Talen E, 2001. Neighborhoods as Service Providers: A Methodology for Evaluating Pedestrian Access. Environ Plan B Plan Des 30, 181–200. 10.1068/b12977

Tamosiunas A, Grazuleviciene R, Luksiene D, Dedele A, Reklaitiene R, Baceviciene M, Vencloviene J, Bernotiene G, Radisauskas R, Malinauskiene V, Milinaviciene E, Bobak M, Peasey A, Nieuwenhuijsen MJ, 2014. Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. Environmental Health 13, 20. 10.1186/1476-069x-13-20 [PubMed: 24645935]

Tang L, He J, Peng W, Huang H, Chen C, Yu C, 2023. Assessing the visibility of urban greenery using MLS LiDAR data. Landscape Urban Plan 232, 104662. 10.1016/j.landurbplan.2022.104662

Tatsumi S, Yamaguchi K, Furuya N, 2022. ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad. Methods Ecol Evol. 10.1111/2041-210x.13900

Taylor L, Hochuli DF, 2017. Defining greenspace: Multiple uses across multiple disciplines. Landscape and Urban Planning 158, 25–28. 10.1016/j.landurbplan.2016.09.024

Texas A&M Forest Service, n.d. Trees Count Mobile App [WWW Document]. URL https://texasforestinfo.tamu.edu/MobileApps/TreesCount/ (accessed 2.27.23).

The Globe Program, n.d. Using Globe Data in your Research [WWW Document]. URL https://observer.globe.gov/get-data (accessed 2.27.23).

Torres PHC, Irazábal C, Jacobi PR, 2022. Editorial: Urban Greening in the Global South: Green Gentrification and Beyond. Frontiers Sustain Cities 4, 865940. 10.3389/frsc.2022.865940

Triguero-Mas M, Donaire-Gonzalez D, Seto E, Valentín A, Martínez D, Smith G, Hurst G, Carrasco-Turigas G, Masterson D, van den Berg MM, Ambrós A, Martínez-Íñiguez T, Dedele A, Ellis

N, Grazulevicius T, Voorsmit M, Cirach M, Cirac-Claveras J, Swart W, Clasquin E, Ruijsbroek A, Maas J, Jerret M, Grazuleviciene R, Kruize H, Gidlow CJ, Nieuwenhuijsen MJ, 2017a. Natural outdoor environments and mental health: Stress as a possible mechanism. Environmental Research 159, 629–638. 10.1016/j.envres.2017.08.048 [PubMed: 28938204]

Triguero-Mas M, Donaire-Gonzalez D, Seto E, Valentín A, Smith G, Martínez D, Carrasco-Turigas G, Masterson D, van den Berg M, Ambròs A, Martínez-Íñiguez T, Dedele A, Hurst G, Ellis N, Grazulevicius T, Voorsmit M, Cirach M, Cirac-Claveras J, Swart W, Clasquin E, Maas J, Wendel-Vos W, Jerrett M, Gražulevičienė R, Kruize H, Gidlow CJ, Nieuwenhuijsen MJ, 2017b. Living Close to Natural Outdoor Environments in Four European Cities: Adults' Contact with the Environments and Physical Activity. Int J Environ Res Pu 14, 1162. 10.3390/ijerph14101162

Trust for Public Land, 2023. 10-Minute Walk [WWW Document]. URL https://10minutewalk.org/ (accessed 3.1.23).

Trust for Public Land, 2022. ParkServe® Data Downloads [WWW Document]. URL https://www.tpl.org/parkserve/downloads (accessed 8.1.22).

Twohig-Bennett C, Jones A, 2018. The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. Environmental Research 166, 628–637. 10.1016/j.envres.2018.06.030 [PubMed: 29982151]

Ulrich RS, 1984. View through a window may influence recovery. Science 224, 420–421. [PubMed: 6143402]

United Nations, n.d. SDG Indicators [WWW Document]. URL https://unstats.un.org/sdgs/metadata/?Text=&Goal=11&Target= (accessed 2.27.23).

United Nations Economic Commission for Europe, 2021. Sustainable Urban and Peri-urban Forestry.

United States Forest Service, 2021. Family Forest Ownerships of the United States, 2018: Results from the USDA Forest Service, National Woodland Owner Survey.

University of Vermont Spatial Analysis Lab, n.d. Land Cover Inventory (within the U.S.) [WWW Document]. URL https://uvm.maps.arcgis.com/apps/webappviewer/index.html?id=fe15424caceb4dd294be816581ec2d77 (accessed 2.28.23).

U.S. Geological Survey, 2020. Protected Areas Database of the United States (PAD-US) 2.1 [WWW Document]. URL 10.5066/P955KPLE (accessed 10.20.21).

Vastaranta M, Latorre EG, Luoma V, Saarinen N, Holopainen M, Hyyppä J, 2015. Evaluation of a Smartphone App for Forest Sample Plot Measurements. Forests 6, 1179–1194. 10.3390/f6041179

Vosselman G, Maas H-G, 2010. Airborne and Terrestrial Laser Scanning. Whittles Publishing.

Walker K, 2020. Penn MUSA Masterclass 2020 [WWW Document]. URL http://walker-data.com/MUSAmasterclass/tutorial/ (accessed 3.19.23).

Wang S, Wang M, Liu Y, 2021. Access to urban parks: Comparing spatial accessibility measures using three GIS-based approaches. Comput Environ Urban Syst 90, 101713. 10.1016/j.compenvurbsys.2021.101713

Weiss L, Ompad D, Galea S, Vlahov D, 2007. Defining Neighborhood Boundaries for Urban Health Research. Am J Prev Med 32, S154–S159. 10.1016/j.amepre.2007.02.034 [PubMed: 17543706]

Westover TN, Collins JR, 1987. Perceived crowding in recreation settings: An urban case study. Leisure Sci 9, 87–99. 10.1080/01490408709512149

Which Plant Where, 2023. Future proof urban landscape projects with climate-ready species [WWW Document]. URL https://www.whichplantwhere.com.au/ (accessed 4.29.23).

World Health Organization Regional Office for Europe, 2017. Urban green spaces: a brief for action.

Xia T, Zhao B, Xian Z, Zhang J, 2023. How to Systematically Evaluate the Greenspace Exposure of Residential Communities? A 3-D Novel Perspective Using UAV Photogrammetry. Remote Sens-basel 15, 1543. 10.3390/rs15061543

Yang B-Y, Zhao T, Hu L-X, Browning MHEM, Heinrich J, Dharmage SC, Jalaludin B, Knibbs LD, Liu X-X, Luo Y-N, James P, Li S, Huang W-Z, Chen G, Zeng X-W, Hu L-W, Yu Y, Dong G-H, 2021. Greenspace and human health: An umbrella review. Innov. 2, 100164. 10.1016/j.xinn.2021.100164

Yang M, Dijst M, Faber J, Helbich M, 2020. Using structural equation modeling to examine pathways between perceived residential green space and mental health among internal migrants in China. Environmental Research 109121. 10.1016/j.envres.2020.109121 [PubMed: 32006771]

Yu S, Yu B, Song W, Wu B, Zhou J, Huang Y, Wu J, Zhao F, Mao W, 2016. View-based greenery: A three-dimensional assessment of city buildings' green visibility using Floor Green View Index. Landscape Urban Plan 152, 13–26. 10.1016/j.landurbplan.2016.04.004

Zhang J, Browning MHEM, Liu J, Cheng Y, Zhao B, Dadvand P, 2023. Is indoor and outdoor greenery associated with fewer depressive symptoms during COVID-19 lockdowns? A mechanistic study in Shanghai, China. Build. Environ 227, 109799. 10.1016/j.buildenv.2022.109799 [PubMed: 36407014]

Zhang J, Yu Z, Zhao B, Sun R, Vejre H, 2020. Links between green space and public health: A bibliometric review of global research trends and future prospects from 1901 to 2019. Environmental Research Letters 15, 063001–37. 10.1088/1748-9326/ab7f64

Zhou B, Zhao H, Puig X, Fidler S, Barriuso A, Torralba A, 2017. Scene Parsing Through ADE20K Dataset. 2017 Ieee Conf Comput Vis Pattern Recognit Cvpr 5122–5130. 10.1109/cvpr.2017.544

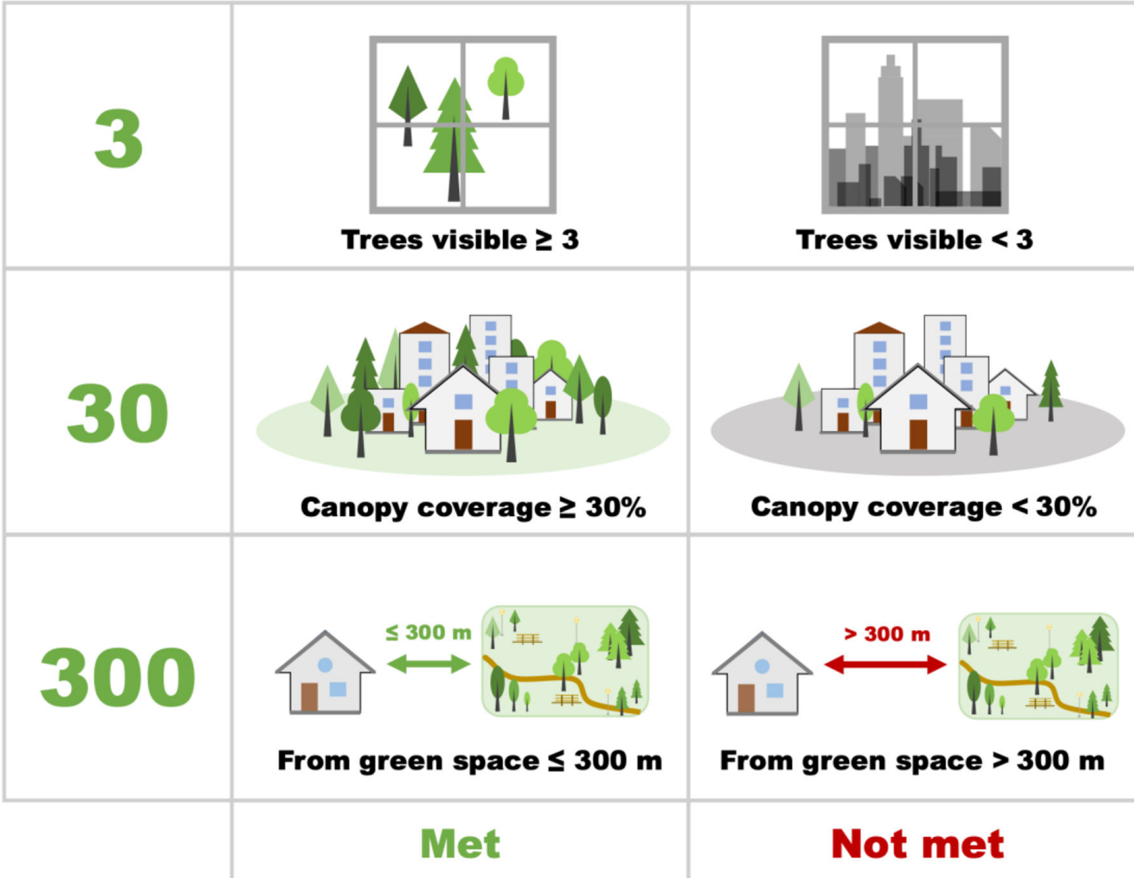

Figure 1.

3-30-300 recommends that everyone should be able to *see* at least 3 trees from their residence, workplace, or place of learning; *have* at least 30% tree canopy cover in their neighborhood; and *live* within 300-meters of a high-quality public green space (at least 0.5 ha in size) (Konijnendijk, 2021).

Figure 2.
Categories of data and processing techniques for 3-30-300

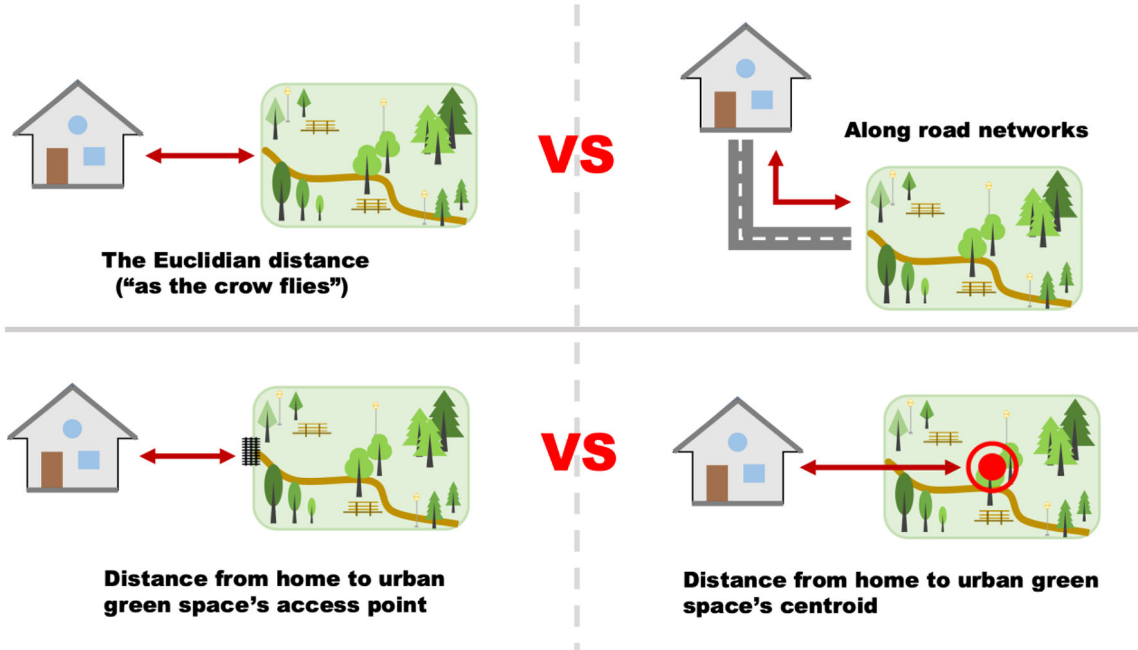

Fig 3.

Calculating distance to urban green space is based on transportation mode (Euclidean vs. network) and access point (formal entry vs. centroid distance)

Table 1.

Selected datasets to measure 3-30-300

Measure	Name	Coverage	Further information
Tree locations	OpenTree.org's database of municipal street and park trees	Street trees in selected Cities	https://opentrees.org/
	Global Urban Tree Inventory	Street trees in selected Cities	https://figshare.com/articles/dataset/Global_Urban_Tree_Inventory_GUTI_vers_1_0_/12062634/1
	MIT Senseable City Lab's Treepedia	Street trees in selected Cities	https://senseable.mit.edu/treepedia
	Bluesky International's National Tree Map	United Kingdom	https://bluesky-world.com/ntm/
Canopy cover	ETH Zurich-Barry Callebau's global canopy height from GEDI LIDAR	Global	https://prs.igp.ethz.ch/research/current_projects/automated_large-scale_high_carbon_stock.html
	Google's Environmental Insights Explorer	Selected Cities	https://insights.sustainability.google/?hl=en-US
	Multi-Resolution Land Characteristics Consortium's NLCD tree canopy cover	United States	https://www.mrlc.gov/data/type/tree-canopy
	Local sources	Varies	For example, Chesapeake Conservancy, United States (https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/)
Urban green space	Multi-Resolution Land Characteristics Consortium's National Land Cover Database	United States	https://www.mrlc.gov/
	GlobaLand30	China	http://globallandcover.com/
	Commission for Environmental Cooperation's North American Environmental Atlas	North America	http://www.cec.org/north-american-environmental-atlas/
	European Environment Agency's coordination of information on the environment (CORINE) Land Cover (CLC) inventory	Europe	https://land.copernicus.eu/pan-european/corine-land-cover
	Ordnance Survey (OS) MasterMap Greenspace Layer	United Kingdom	https://beta.ordnancesurvey.co.uk/products/os-mastermap-greenspace-layer
	Land Use Database of the Netherlands (LGN)	The Netherlands	https://www.wur.nl/en/research-results/research-institutes/environmental-research/facilities-tools/kaarten-en-gis-bestanden/land-use-database-of-the-netherlands/different-versions-of-databases/lgn2018-lgn2019-and-lgn2020.htm
	Land Cover Map 2015 (LCM 2015)	UK	https://catalogue.ceh.ac.uk/documents/0255c014-1630-4c2f-bc05-48a6400dd045
	U.S. Environmental Protection Agency (EPA)	United States	https://www.epa.gov/enviroatlas/
	European Environment Agency's Urban Atlas	Selected European Cities	https://land.copernicus.eu/local/urban-atlas
	Esri's Land Cover	Global	https://livingatlas.arcgis.com/landcover/
	PAD-US-AR	United States	https://www.nature.com/articles/s41597-022-01857-7
	Google and The World Resources Institute's Dynamic World	Global	https://dynamicworld.app/
	Latin American cities urban green space map	Selected Latin American cities	https://www.nature.com/articles/s41597-022-01701-y

Table 2.

Assessment of approaches and datasets (rows) and their suitability for each component of 3-30-300

	Suitability		
	3 trees	***30% canopy***	***300-m distance***
Vegetation indices	**Poor**	**Fair**	**Poor**
Street-level analyses	**Fair**	**Poor**	**Poor**
Tree inventories	**Fair**	**Fair**	**Poor**
Questionnaires	**Best**	**Unknown**	**Fair**
Window-view analyses	**Best**	**Poor**	**Poor**
Land cover maps	**Fair**	**Best**	**Poor**
Urban green space property maps	**Poor**	**Poor**	**Best**