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Opportunities and constraints of implementing the 3–30–300 rule for urban greening

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ABSTRACT

Urbanisation and climate change have increased the need for equitable access and visibility of urban green and blue spaces (GBS), to promote the sustainability and resilience of cities and to improve the well-being of their inhabitants. In this paper, we test an implementation of the newly proposed guideline to achieve equitable greening, the 3–30–300 rule, in three European cities: Paris Region (France), Aarhus Municipality (Denmark), and Grad Velika Gorica (Croatia). In this analysis, every residential building should have at least three viewable trees, 30 % neighbourhood GBS cover, and a GBS of at least 1 hectare within 300 m. Our results show that none of the cities currently meet any of these three components, and the three cities differed in which rules were most closely met. In our implementation, substantial changes were needed in all cities to meet the guidelines: 12.6 % of Paris, 10 % of Aarhus, and 18.4 % of Velika Gorica's urban footprint were converted to grass or tree cover, with implications for >100,000 buildings and >900,000 inhabitants. Our study discusses how existing conditions in each city impacted the viability of meeting the rule and proposes key considerations for future implementations of such guidelines, drawing on examples of innovative GBS already implemented globally.

1. Introduction

Cities and their inhabitants continually face new challenges as urbanization and climate change cause increases in temperature, noise, pollution, and stress (Huang et al. 2020). Urbanization has resulted in predominantly constructed landscapes in cities, fragmenting urban green and blue spaces (GBS) and placing enormous pressures on local and global ecosystems (Young, 2011; Haaland and Bosch, 2015; Kumar et al. 2019; Lin et al. 2020; Konijnendijk, 2023). Urban GBS are places with vegetation or water and can be highly heterogeneous in shape, size, and composition, including spaces such as parks, shrubland, urban forests, roof gardens as well as water bodies like ponds, rivers, reservoirs, and the sea (Breuste et al. 2013; Weber et al. 2014; Li et al. 2015; Artmann et al. 2019; Jones et al. 2022a). The role of GBS is increasingly recognised as essential, helping cities adapt to and mitigate climate change and provide extensive ecosystem services that benefit social, economic, and environmental well-being (Breuste et al. 2013; Kabisch et al. 2016; O'Brien et al. 2017; Artmann et al. 2019; Zuniga-Teran et al. 2020; Fletcher et al. 2022; Jones et al. 2024). However, differences in the visibility, proximity, or accessibility of GBS can underpin inequities in the received benefits, with disadvantaged population groups often losing out (Cruz-Sandoval et al. 2020).

In response to these challenges, the United Nations 2030 Agenda for Sustainable Development aims for cities to become more safe, accessible, inclusive, sustainable, and resilient (United Nations. 2015; Kabisch et al. 2016; Sikorska et al. 2020; Battisti et al. 2023; Konijnendijk, 2023; Ordóñez et al. 2023). Numerous cities have addressed this goal by introducing green initiatives and guidelines such as the ambition to achieve a 30 % canopy in cities including Barcelona, Bristol, Canberra, Seattle, and Vancouver (Konijnendijk, 2021; Conway et al. 2023).

Due to the demand for and the cost of land, introducing new grassy and forested areas in cities is difficult, expensive, and sometimes seemingly impossible (Karteris et al. 2016). Cities have addressed these

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challenges through innovative green infrastructure, with examples such as retrofitting buildings and creating vertical green spaces. For example, in cities such as Paris, Rotterdam, and Hamburg, existing buildings and infrastructure such as railway stations and yards as well as main roads have been covered by large-scale GBS (Maldonado, Melissa, 2000; Tillie and van der Heijden, 2016; Hansestadt Hamburg, 2023). Similarly, in high density cities such as Singapore, to overcome the lack of ground-level space, they are aiming to integrate 200 ha of vertical green spaces into high-rise buildings by 2030 (Kosorić et al. 2019). However, according to Young (2011), most GBS initiatives are small, individual-led projects, rather than community or metropolitan-wide scale. Therefore, in response, a new, comprehensive, city-wide and evidence-based guideline for urban forestry and greening was proposed in 2021; coined the *'3–30–300 rule'* (Konijnendijk, 2021, 2023).

The 3–30–300 rule is a simple, easy-to-remember and easy-to-understand guideline with three main components/targets: each workplace, school, or home should have a minimum of three viewable trees, 30 % neighbourhood tree canopy cover, and be within 300 m from their nearest green space of 1 hectare (ha) (Konijnendijk, 2021, 2023). The rule aims to provide transferable targets and offers a benchmark for cities to create and improve equitable access to trees and green spaces, resulting in improved city and resident health, well-being, and resilience (Konijnendijk, 2021, 2023; Browning et al. 2023). The benefits associated with each component are widely documented in the literature: visibility of green space from a home/window has been associated with better mental health and restoration (Ulrich, 1984; Ekkel and de Vries, 2017; Larkin and Hystad, 2019; Sikorska et al. 2020; Nieuwenhuijsen et al. 2022); 30 % canopy cover has been associated with reduced temperatures, less urban heat island-related mortality, better sleep, and reduced stress (Barboza et al. 2021; Daland, 2023; Koeser et al., 2023); and access to urban green spaces within 300 m has a statistically significant impact on residents' self-reported health (Wu and Kim, 2021), increasing rates of physical activity (Neuvonen et al. 2007), lowering blood pressure, and encouraging more social interactions (Grazuleviciene et al. 2014; Tillie and van der Heijden, 2016; Ekkel and de Vries, 2017).

Since the announcement of the 3–30–300 rule (Konijnendijk, 2021), a number of studies (Nieuwenhuijsen et al. 2022; Battisti et al. 2023, Browning et al. 2023; Koeser et al. 2023) have explored the rule and have looked at the extent to which some urban areas currently meet, or fail to meet, the rule. However, no study has yet quantified or tried to implement the changes that would be required to meet the rule.

The aim of this study was to i) create an automated, systematic, and reproducible rule-based approach, applicable in cities of different shapes, sizes, and population densities in order to ii) explore the feasibility and quantify the changes that would be required to meet the 3–30–300 rule. We explore this rule as it has great potential impact for planning as it can supplement existing greening initiatives. It achieves this by not only increasing the presence of GBS, but specifically increasing the equitable distribution of GBS in cities.

Our study creates a GIS rule-based approach using high resolution land cover and open-access data in three contrasting European cities: Paris Region (France), Aarhus Municipality (Denmark), and Grad Velika Gorica (Croatia). Using the rule-based approach, we quantify the changes in land cover that would be required to satisfy every component of the 3–30–300 rule. With minor adjustments, we follow the guidance outlined in Konijnendijk (2023), defined as follows: every residential building has visibility of three trees, every neighbourhood has a 30 % green or blue space cover, and every residential building is within 300 m of its nearest green space of one hectare. In the discussion we present the challenges as well as the opportunities that implementing the rule might bring, to provide insight on the feasibility to implement the 3–30–300 rule, and how the uniqueness of each city can prevent, or promote that intention.

2. Materials and methods

This section outlines the three study sites selected, the data used, the definitions of the three components, and a description of the spatial processes and optimisation/selection processes implemented in the rule-based approach to meet the rule in all three cities. To increase the transparency and reproducibility, a flow diagram of the rule-based approach is included (Fig. 2) and the land cover scenarios have been made openly available (Owen et al., 2024).

2.1. Study sites

The three cities in this study are: Paris Region (France), Aarhus Municipality (Denmark), and Grad Velika Gorica (Croatia). The three urban areas represent different sizes, population counts, and population densities (Table 1, Fig. 1). Paris is an example of a large European city, with over 6.5 million inhabitants within its four central départements and it's characterised by fragmented GBS towards the core city centre (Fig. 1a, Table 1). In contrast, the size and population of Aarhus and Velika Gorica are much smaller, with just under 335,000 and 30,000 residents respectively (Table 1). The population density in Paris is high, over three and a half times the population density of Velika Gorica and nearly four and a half times the population density of Aarhus (Table 1).

Each of the three cities in this study has already adopted or is planning to implement nature-based solutions to address the increasing challenges that they face. In Velika Gorica, to address the threat of urban expansion, the city has set a goal of 40 m^2 per capita of public green space by increasing the green area coverage in the city from 1 km^2 to 1.6 km^2 (REGREEN, 2020). In Aarhus, to address pressures such as urban densification and pluvial flooding, the city aims to double GBS area and increase forested land by 60 % by 2030 (REGREEN. n.d.). Lastly, in Paris, multiple green initiatives have been adopted to address the limited amount of green space per capita and pressing challenges such as the urban heat island effect. By 2020, as a part of the C40 network, Paris aimed to build an additional 100 ha of green roofs largely through requiring vegetation to be planted on all new buildings (C40. 2015). Since then, Paris has adopted a new scheme and now aims to plant 170,000 new trees by 2026 (World Economic Forum. 2022).

2.2. Data

2.2.1. Physical environment: land cover, accessible green space, urban footprint, and roads

2.2.1.1. Land cover. In this study, land cover maps as raster data in GIS software are used to represent the existing GBS in each city. The land cover files used in this study are high-resolution, 5 m land cover data, created using a combination of remote sensing datasets, described below. Land cover classes are documented in Table 2, and differ slightly for each city, depending on available data for the classification. For the Paris Region, land cover was computed using the MOS+ 2017 dataset (Institut Paris Region. 2020a), along with additional information retrieved from a vegetation height dataset (Atelier Parisien d'Urbanisme, 2015) and the green cadastre (Département des Hauts-de-Seine, 2012). In Aarhus Municipality, the dataset described in Knopp et al. (2023) was used. For Velika Gorica, land cover was computed from

Table 1
Descriptive statistics of the three study cities.

	Paris*	Aarhus	Velika Gorica
Total population	6,656,128	334,084	28,879
Total Residential Buildings	583,236	83,476	4,519
Urban footprint (km^2)	731.9	163.1	11.6
Population density (population/km^2)	9,094	2,048	2,490

* The four central départements of the Paris Region

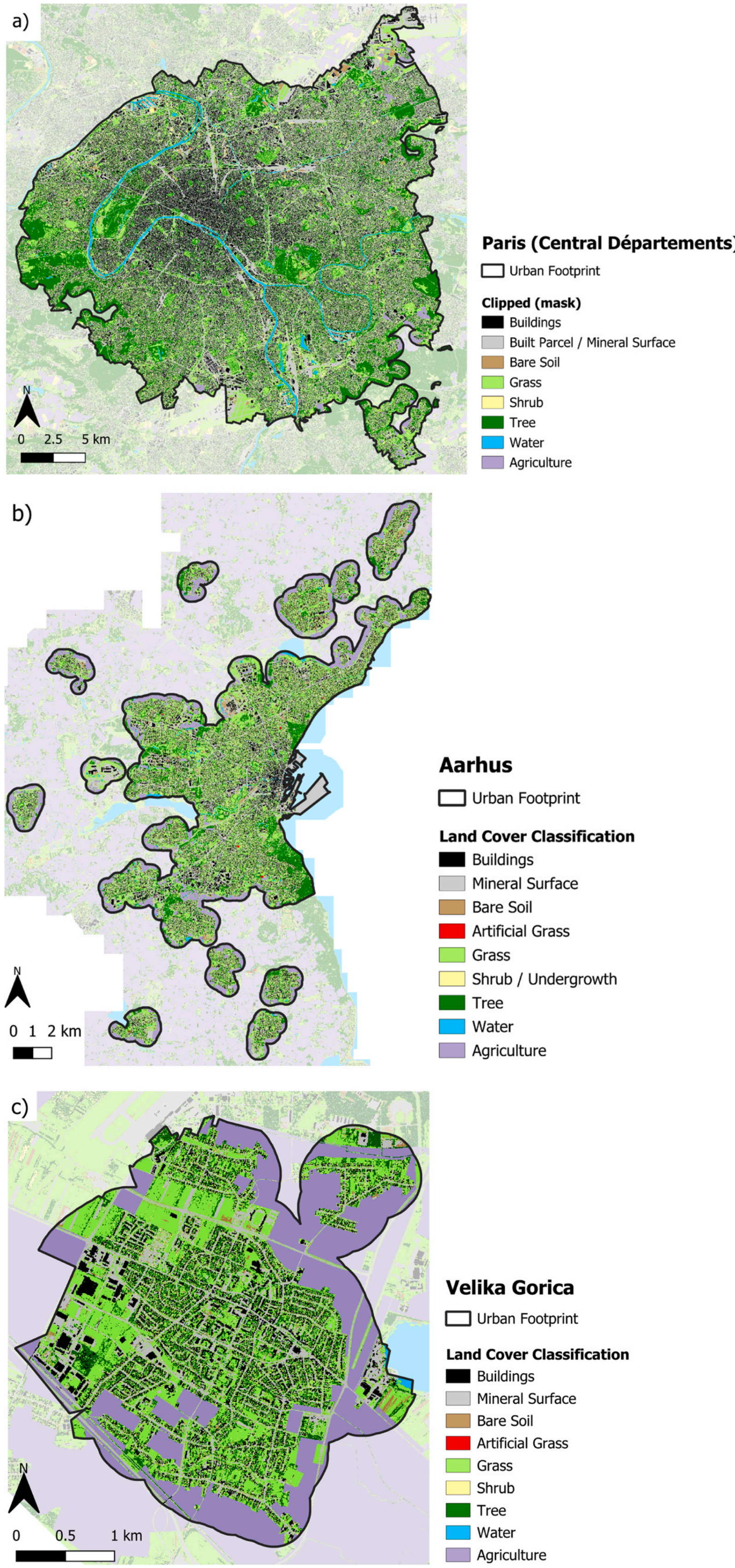

Fig. 1. Land cover in the urban footprint of a) Paris' four central départements, b) Aarhus, and c) Velika Gorica.

Table 2
Distribution of land cover classes in Paris Region, Aarhus Municipality, and Grad Velika Gorica.

Land cover class	Land cover in urban footprint (%)		
	Aarhus	Paris	Velika Gorica
Building*	13.4	12.2	12.1
Mineral surface	20.4	13.1	16.3
Built parcel	n.r.	13.2	n.r.
Bare soil	3.7	0.7	2.1
Artificial grass	0.03	n.r.	<0.01
Grass	28.6	18.6	30.0
Shrub*	5.0	8.1	2.5
Trees*	13.8	23.5	10.5
Water*	0.8	1.9	0.2
Agriculture*	14.2	8.7	26.4

n.r. - not represented in that classification;
* These classifications are aggregated values. For example, trees consist of deciduous and evergreen, water consists of lakes, river, and the sea.

bi-temporal World-View 3 imagery and a normalized Digital Surface Model (nDSM) which is used to model the height of features such as structures and vegetation, above the ground (Knopp, 2022).

2.2.1.2. Accessible green space. Whilst the land cover data identifies the presence of GBS, additional data sources are required to identify publicly accessible GBS. In Paris, an accessible green spaces data layer is readily available and made openly available by L'Institut Paris Region. 2020b. In Aarhus, we delineated accessible green spaces using cadastral data, removing the building footprints from publicly accessible land such as public institutions, cemeteries, and sports and leisure. These spaces were then dissolved (except for public schools and cemeteries) if the distance between adjacent spaces was less than or equal to 25 m, unless intersected by a primary road or motorway. In Velika Gorica, we also defined accessible green spaces using cadastral parcels. The land use type and accessibility (private or public) were derived using datasets from Grad Velika Gorica's webgis (Grad Velika Gorica, n.d.), and publicly accessible green spaces were defined as land use types such as public park and playgrounds, cemeteries, and sports and recreation. In each city, only publicly accessible green spaces of greater than or equal to 1 ha were used for this analysis.

2.2.1.3. Urban footprint. In each city, the 3–30–300 rule was applied to residential buildings within the urban footprint. The urban footprint incorporates both the built-up area and any enclosed GBS that would be considered part of the urban fabric by a resident – i.e., it includes existing areas of GBS. For Aarhus and Velika Gorica, we apply the 3–30–300 rule to the entire urban footprint. However, in Paris, the rule was only applied to the urban footprint of the four central Départements, the second-tier administrative subdivisions of France.

For each study site, we used a consistent approach to delineate the urban footprint within each administrative boundary using the world settlement footprint (https://geoservice.dlr.de) as input data, adapting methods in Jones et al. (2019) and Fletcher et al. (2021). The urban footprints were created by first generating a Binary Settlement map which uses focal statistics with a circular moving window at a 250 m radius. Areas with the proportion of urban above a threshold value of 0.2 were selected and buffered by 300 m. In the delineation of each urban footprint, a 10 km^2 exclusion threshold was implemented and in each study site, some specific areas were added or removed as needed. For example, in Aarhus, the neighbourhood of Risskov, the lakes Brabrand and Årslev Engsø, and forests south of Aarhus down to Moesgaard were added to the urban footprint, while the coastal area of Ajstrup Strand was excluded. For Grad Velika Gorica, the airport and military areas in the north and northwest were excluded.

2.2.1.4. Roads. This study used OpenStreetMap (OSM) road layers (Geofabrik, 2023). The road layers were used to delineate city blocks. These blocks were then used in the 300-component to create new GBS areas, and in the 30-component to help define individual neighbourhoods (Fig. 2). OSM roads were converted to city blocks using the Polygonize tool in QGIS v3.4.

2.2.2. Buildings and residents

The residential population of each city in this study is represented as the number of inhabitants per building footprint. This information is readily available for Paris (Instutit d'Aménagement et d'Urbanisme d'Ile-de-France) and Aarhus. For Velika Gorica, we combined a digital elevation model with building footprints to approximate the number of storeys per building. Overlaying this dataset with gridded population data, we estimated population numbers for each residential building. For each city, only buildings with population were used (omitting industrial and institutional buildings) in all components and cities to ensure consistency.

2.3. Interpretation of how to meet the rule

In this section, we define each of our 3-, 30-, and 300-components and highlight any differences from the original guidelines outlined in Konijnendijk (2023). How these rules were implemented and optimised is described in *Section 2.4* .

2.3.1. Definition of three visible trees

Konijnendijk (2023) states that every resident should be able to see three trees from their home, school, and place of work. The selection of three trees specifically is not supported by scientific evidence, however, it is used as a proxy for visible greenspace, which is associated with increasing contact with nature and is better for citizens' mental health and restoration (Sahraoui et al. 2016; Larkin and Hystad, 2019; Konijnendijk, 2023).

Defining the visibility of three trees from a building is challenging. Some studies measure the visibility of trees from households by conducting surveys and window-view analyses (Browning et al. 2023; Koeser et al. 2023), others quantify street greenery using computer vision (Zhang and Dong, 2018), and others define visibility of trees as the presence of trees within a buffer with varying distance thresholds, ranging from 15 m to 100 m (Nieuwenhuijsen et al. 2022; Battisti et al. 2023; Daland, 2023).

Our study defines the visibility of three trees as the presence of at least two, 5 m resolution tree raster cells, within a 30 m buffer from every building. Firstly, we select 30 m as a distance threshold as this threshold is suggested in Konijnendijk (2023), the author of the 3–30–300 rule, and this threshold has been used in other studies on the 3–30–300 rule (Battisti et al. 2023) where trees within 30 m are deemed close/visible. Secondly, we assume that two 5 m raster cells are equivalent to three trees. We make this assumption as it may be necessary for a cell to contain more than one street tree to register as 'tree cover' in satellite data. This assumption is supported by ground truthing carried out by the authors on urban street trees, and from the findings in Pretzsch et al. (2015), where some of the smallest mean crown radius from 22 common urban tree species indicate that an individual tree may not fill a single, 25 m^2 raster cell (smallest mean crown radius for Silver Birch and European Ash = 1.6 m).

2.3.2. Definition of 30 % green and blue space cover

The 30-component, as defined in Konijnendijk (2023), suggests that every neighbourhood should aim for 30 % canopy cover. Konijnendijk (2023) recognises that achieving a 30 % canopy cover may be challenging or even unattainable, particularly in high-density cities or arid environments due to spatial and environmental constraints. In such cases, Konijnendijk (2023) suggests that the rule should allow some flexibility, and instead cities should strive for 30 % vegetation cover rather than specifically tree cover. Green spaces other than trees can also

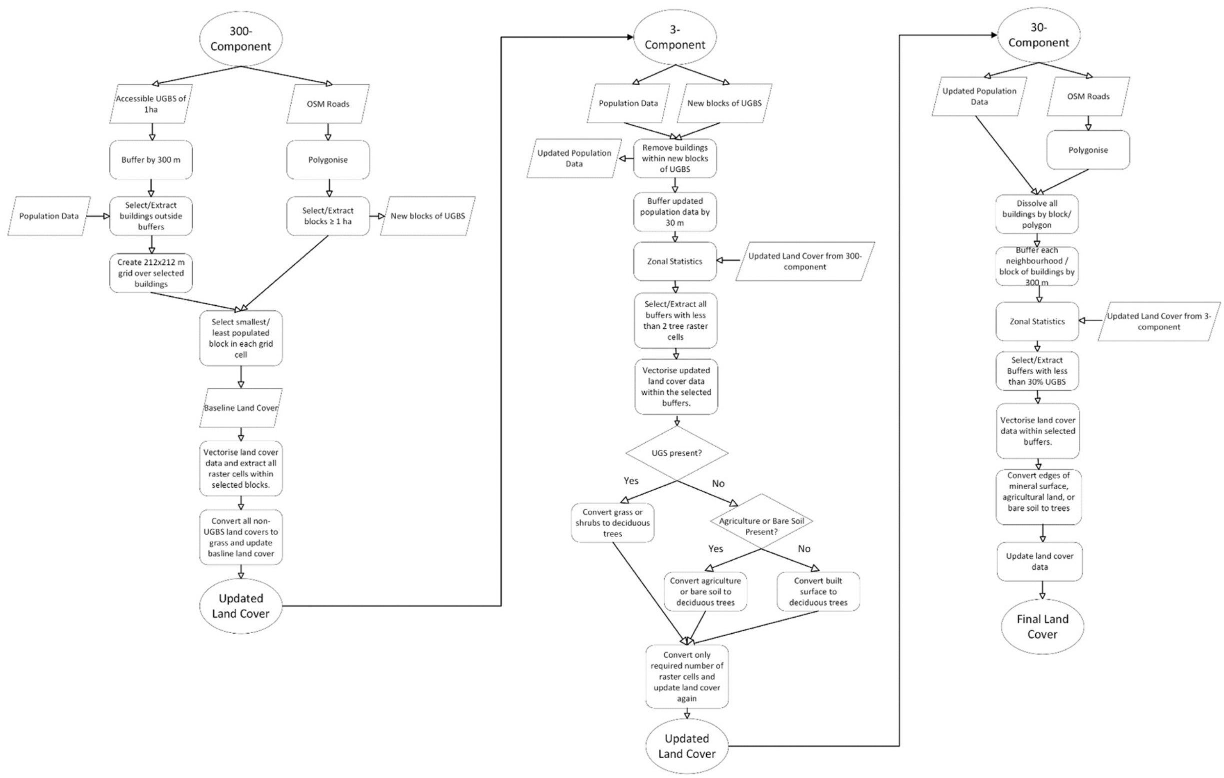

Fig. 2. Flow diagram of the rule-based approach to the 3–30–300 rule.

provide valuable ecosystem services. They improve citizens health and well-being, reduce air and noise pollution, eliminate surface runoff, and reduce surface temperatures (Armson et al. 2012, 2013; Hartig et al. 2014; Zhang and Dong, 2018; Bird et al. 2022; Miller et al. 2023; Kumar et al. 2024).

We take and expand this wider interpretation to include all blue space, alongside green spaces. Despite its importance for cities, urban blue spaces such as coastal areas, rivers, and lakes are often underutilised and not considered in planning and policymaking (Bolund and Hunhammar, 1999; Haase, 2015). We suggest that blue spaces should be considered alongside vegetation cover as they can provide similar benefits to green spaces, including restoration, facilitating social interactions, and lowering psychological distress (Völker and Kistemann, 2011; Nutsford et al. 2016; Ekkel and de Vries, 2017). Alongside mental health and well-being benefits, urban blue spaces also provide other valuable ecosystem services such as flood risk mitigation/storm water retention, air cooling, and habitat provision (Haase, 2015). We include urban blue spaces because they are ubiquitous in humid tropical and temperate zones, particularly in Europe (Bell et al. 2021), and are increasingly seen as equally important to green spaces in recent concepts such as the 15-minute city (see Liu et al. 2022).

Another consideration for this component is how a neighbourhood is defined. It is widely recognised that there is a lack of an agreed, clear, and consistent definition of a neighbourhood (Kearns and Parkinson, 2001; Baffoe, 2019). Some studies define them as allocentric zones, which are neighbourhoods delineated using administrative boundaries (Browning et al. 2023). However, this brings challenges as varying sizes of administrative boundaries can impact how well each unit meets the rule (Battisti et al. 2023).

Our study adopts more of an egocentric approach (Browning et al. 2023), where we define a neighbourhood as a fixed distance buffer around every block of buildings (process described in *Section 2.4* and in Fig. 2). A 300 m buffer represents a five-minute walk and this approach creates a more localised representation of individual neighbourhoods, providing a more refined-scale to measure compliance to the 30-component.

2.3.3. Definition of 300 m from GBS of 1 ha

For the 300-component, we use the definition of the World Health Organisation (WHO. 2017) and Konijnendijk (2023) who state that every citizen or home should be within 300 m of a public green space of at least 1 ha (0.01 km^2). Many other studies and urban policy guidelines have adopted similar thresholds, typically varying between 300 and 500 m from the nearest green space, to represent a leisurely five or ten-minute walk (Artmann et al., 2019; Konijnendijk, 2023) and a greenspace size of either 0.5, 1, or 2 ha (Kabisch et al. 2016; Konijnendijk, 2021, 2023; Battisti et al. 2023). The size of the greenspace is important as larger green spaces are associated with higher rates of recreational opportunities and preference (Cohen et al. 2010; Konijnendijk, 2023). However, achieving this rule, particularly in high-density cities or inner-city areas, is difficult.

2.4. Implementation and optimisation of the 3–30-300 rule

In this section, we describe the type of interventions introduced and how each of the components defined above are implemented in each of the three cities. To meet all three components, new green spaces (trees and grass) must be added. We add all new GBS to the high-resolution land cover data sequentially, updating the land cover after each component, and ultimately finish with two land cover maps (scenarios) for each city: a baseline and a 3–30–300 scenario (with all interventions). All baseline and 3–30–300 scenario land cover maps are openly available (Owen et al., 2024). Existing studies which have explored the 3–30–300 rule have evaluated each component independently. However, we believe that when implementing the rule in a real-world application, the components should be implemented sequentially. We propose that a logical implementation order is 300–3–30, since implementing each one in this order contributes also to meeting the remaining components.

2.4.1. Intervention type and location - overview

For the 300-component, interventions must ensure that every person, and so every building, must be within 300 m of their nearest accessible green space of 1 ha. To meet this component, we identify the buildings which do not meet the guideline and subsequently select blocks of land to convert to GBS. In the selected blocks to convert, all non-GBS land cover are converted to grass, representing a large new area of public green space. Whilst new areas of public green spaces are unlikely to consist of only grassy areas, grass is implemented as it more closely represents the initial state of a new publicly accessible GBS. The selection process of these new blocks of GBS is outlined in *Section 2.4.3* and in Fig. 2.

To meet the 3- and 30- components, we add new trees. Deciduous trees were used as the default new tree type since deciduous trees are the dominant type in our study cities (Banzhaf et al. 2021). New trees were introduced, where possible, on land covers other than built surfaces (e.g. buildings, roads, etc.) such as agricultural land and bare soil. However, if necessary, we would implement new trees on the edges of built surfaces, such as the edges of roads and car parks.

All interventions in this rule-based approach are implemented to residential buildings within the urban footprint (urban footprint defined in *Section 2.2.1*) and with the intention of minimising the number of inhabitants impacted and the total amount of land cover change required, while still retaining a rule base that can be automated in GIS at city scale. However, some buildings currently not meeting one of the rules are at the edge of the boundary of the urban footprint. In these cases, some of the interventions may be implemented outside the urban footprint. All interventions were subsequently clipped to 300 m from the urban footprint boundary.

2.4.2. Ordering of the 300-, 3-, and 30-components

The 300-component is introduced first because it requires the most space, and open areas of vegetation, mainly consisting of grass, can more easily be converted to trees which would be necessary to satisfy the subsequent 3- and 30-components. The 3- and 30-components both require planting trees, however, of these two components, the 3-component is placed first as any new trees planted within 30 m of a property will also contribute to a neighbourhood's overall green and blue space cover in the 30-component.

2.4.3. Rule-base and process optimisation

In this section, the processes for implementing all rules are outlined in the flow diagram (Fig. 2) and described in the following text.

For the 300-component, we first identified the buildings that did not meet the rule by buffering all accessible green spaces greater than or equal to 1 ha by 300 m. We then selected all buildings in the negative space beyond these buffers. To identify possible areas which could be converted to GBS to meet the rule, we created candidate blocks of land by polygonising the OSM road layer to create discrete blocks of land separated by roads, and selected only those blocks equal to or greater than 1 ha (our target greenspace size). To avoid converting every block of land greater than 1 ha, we designed a selection process that minimised the land converted and the potential population affected. This was achieved by overlaying a 212 × 212 m grid over buildings which were not within 300 m of an existing green space and selecting the block with the smallest population and the smallest surface area within each grid cell to convert to GBS. The dimensions of the grid ensures that if any portion of a selected block intersects a given cell, when buffered by 300 m, it will serve any building within that cell.

For the 3- and 30-components, we also used buffers to identify the buildings/neighbourhoods which did not meet the rule. In the 3-component, we buffer every building by 30 m and in the 30-component, we buffer every neighbourhood by 300 m. For both components, we computed zonal histograms to count the number of cells from each land cover to identify buildings that had less than two tree raster cells, or neighbourhoods which had less than 30 % green and blue space cover. To meet each of the components, we then reclassified raster cells, preferably non-built land, to deciduous trees. To minimise the number of new trees implemented, our selection process only converted the required number of cells to meet the guideline thresholds and prioritised cells which were within multiple building/neighbourhood buffers, which meant that a single new tree in these cells would serve more than one building/neighbourhood.

3. Results

3.1. Existing conditions

Each city differs in the extent to which it currently meets each of the three components in the 3–30–300 rule. Paris nearly met the 3-component, Aarhus the 30- and 300-component, and Velika Gorica the 3- and 30-component. However, currently none of the cities fully achieve any of the three targets (Table 3).

The 3-component appears to be the easiest to achieve, with nearly three-quarters of all buildings in Aarhus, and nearly (but not quite) all buildings in Paris and Velika Gorica having visibility of three trees (Table 3). Similarly, for our 30-component, over two thirds of neighbourhoods in Paris and over 95 % of neighbourhoods in Aarhus and Velika Gorica have at least 30 % GBS cover in their neighbourhoods (Table 3). Despite widespread GBS across each city, the 300-component appears to be the hardest component to achieve, and also illustrates the biggest disparities across the three cities. Paris, as a result of high population density, notably less grass, and more built surfaces, has 56.6 *%pt. (percentage point)* and 39.2 *%pt.* fewer buildings that meet the 300-component, relative to Aarhus and Velika Gorica respectively (Fig. 1; Tables 1, 2, 3).

Although just over two thirds of all neighbourhoods in Paris, and 95 % of neighbourhoods in Aarhus and 98 % in Velika Gorica currently meet our version of the 30-component, it is worth testing the differences in compliance under different interpretations of this component of the rule (Table 4). Under the original definition of the 30-component and counting tree cover alone, there is a substantial decrease in the number of buildings and population that meet the guideline, with a maximum of just over 8 % of neighbourhoods meeting the threshold value in Paris. When the definition is expanded to include grass as well as tree cover, the maximum rises substantially from 8 % to 98 %, and even the lowest figure for Paris is 65.5 %.

3.2. Implementing the 3–30-300 rule

This section explores the implementation of the 3–30–300 rule. In each section, we calculate the number of people/buildings that currently do not meet the guideline and quantify the land that would need to be transformed to meet each respective component. As outlined in the methodology, each component is implemented sequentially and the revised order in our study is 300–3–30.

3.2.1. 300-component

As illustrated in Table 3 and Table 5, Paris has the lowest percentage of buildings and population within 300 m of an accessible GBS of 1 ha. In Paris alone, this equates to over 350,000 buildings and over 3.5

Table 3
Summary statistics of how well existing conditions in each city satisfy the 3–30-300 rule.

Current status with respect to 3–30-300 Rule (% achieved)	Paris	Aarhus	Velika Gorica
3-component (buildings)	96.9	73.2	99.6
30-component (neighbourhoods)	68.9	95.0	98.0
300-component (buildings)	39.4	96.0	78.6

Table 4
Comparison of the current situation of each city against different interpretations of the 30-component; the percentage of neighbourhoods with a 30 % cover of: tree canopy, green space (trees, grass, and shrub), and green and blue space combined.

Interpretations of the 30-rule	Paris	Aarhus	Velika Gorica
Tree canopy (% neighbourhoods)	8.3	2.6	0.0
All green spaces (% neighbourhoods)	65.5	94.1	98.0
All green and blues spaces (% neighbourhoods)	68.9	95.0	98.0

Table 5
Summary statistics of buildings and population that currently do not meet, and the land cover change required to meet the 300-component. Percentage of the total number of buildings or population in parentheses.

	Paris	Aarhus	Velika Gorica
Number not meeting 300-component			
Residential Buildings	353,605 (60.6 %)	3,347 (4 %)	967 (21.4 %)
Population	3,646,461 (54.8 %)	13,479 (4 %)	4,044 (14 %)
After implementing 300-component			
Blocks converted to GBS	4,936	135	41
Buildings impacted	112,238 (19.2 %)	3,251 (3.9 %)	870 (19.3 %)
Population impacted	960,435 (14.4 %)	10,960 (3.3 %)	3,560 (12.3 %)
Land converted, km^2	88.8	15.1	2.1

million people not meeting the guideline (Table 5).

Across the three cities, a total of 5112 of our defined city blocks and a total of 106 km^2 are converted to GBS to meet the 300-component (Table 5). The city requiring the greatest changes is Paris. In Paris alone, meeting the 300-component could potentially require the removal or retrofitting of over 100,000 buildings and potentially impact over 950,000 citizens (Table 5), depending on how this is implemented.

Within the rule-base used, all buildings within the converted blocks are omitted from all subsequent rules, i.e. the land cover is assumed to change to a non-built surface (see the discussion for alternative options).

3.2.2. 3-component

Once the 300-component had been implemented, we then explored the changes needed to satisfy the 3-component. Over 9500, 21000, and 13 raster cells were converted to trees in Paris, Aarhus, and Velika Gorica respectively (Table 6).

The number of trees needed in each city is influenced by its urban form. For example, in Paris, due to the higher building density, the number of trees needing planting was notably less than the number of buildings which do not initially meet the 3-component (Table 1; Table 6). This is because for every new tree raster cell, the higher density means that a new tree is more likely to serve multiple buildings. Conversely, in Aarhus and Velika Gorica, on average, nearly one new tree raster cell is needed per building to satisfy the component (Table 6).

Differences in urban form between Paris and Aarhus also influenced the type of land cover that was converted to newly planted trees (Table 6). In both cities, most of the raster cells that are converted to trees were natural green spaces, including grass and shrubs, or agricultural land. However, in central Paris, due to less availability of natural green or blue spaces, or agricultural land and bare soil, substantially more built surface was converted there (Table 6).

3.2.3. 30-component

Following the implementation of new trees and grassy areas from the 300- and the 3-components and with the modification of the rule to include all GBS, more neighbourhoods now meet the 30-component.

Table 6
Summary statistics of the land cover change by type to meet the 3-component (after implementing the 300-component). Percentage of total* number of buildings or population in parentheses.

	Paris	Aarhus	Velika Gorica
Number not meeting 3-component			
Residential Buildings	16,006 (3.4 %)	21,675 (27 %)	12 (0.3 %)
Population	236,228 (4.1 %)	94,751 (29.3 %)	54 (0.2 %)
After implementing 3-component			
Raster cells converted to trees	9,601	21,242	13
Land Cover classes converted to trees (km^2)			
Built Surfaces	0.10	0.01	0.00
Natural Green Spaces	0.14	0.35	0.00
Agriculture and Bare Soil	0.00	0.17	0.00
Total	0.24	0.53	0.00

Notes:
* Total number of buildings and population refers to that after removing the buildings impacted by new blocks of new GBS

Compared to the initial status of each city in Table 3, Paris, Aarhus, and Velika Gorica now have approximately 25.5 %*pt.*, 2 %*pt.*, and 1.5 % *pt.* more neighbourhoods that meet the 30-component respectively. Despite a notable increase, Paris continues to have the lowest proportion of neighbourhoods meeting the 30-component while Velika Gorica requires the least change in land cover (Table 7).

As with the 3-component, in order to meet the 30-component, there were different changes to land use in the three cities. For example, in both Aarhus and Velika Gorica, a roughly equal amount of mineral surface, agricultural land, and bare soil would need to be converted (Table 7). However, in Paris, the type of land cover converted was more unbalanced. Nearly 95 % of all the land converted to meet the rule in Paris included built surfaces such as mineral surface and built parcel, totalling over 3 km^2.

3.3. Summary of total interventions

Overall, to satisfy the 3–30–300 rule in each city, substantial changes had to be made to increase the current level of GBS within the urban footprint: 12.6 % of Paris, 10 % of Aarhus, and 18.4 % of Velika Gorica were converted to GBS (Table 8). Most interventions were in Paris, which alone includes over 90 km^2 of new trees and grassy areas (Table 8). In each city, the largest intervention was the introduction of new areas of grass as a result of the 300-component in order to create

Table 7
Summary statistics of land cover change to satisfy 30-component. Percentage of total* number of neighbourhoods in parentheses.

	Paris	Aarhus	Velika Gorica
Number not meeting 30-component			
Neighbourhoods (% of total*)	1,585 (5.6 %)	219 (3 %)	1 (0.5 %)
After implementing 30-component			
Land cover classes converted to trees (km^2)			
Mineral surface and built parcel	3.22	0.34	0.01
Agricultural land	0.14	0.40	0.01
Bare soil	0.07	0.28	0.01
Total	3.43	1.02	0.03

Notes:
* Total number of neighbourhoods refers to those created after removing the buildings impacted by new blocks of new GBS

Table 8
Summary statistics of all interventions, showing total area (km^2) and percentage of urban footprint in parentheses.

	Paris	Aarhus	Velika Gorica
New tree areas	3.7 (0.5 %)	1.5 (0.9 %)	0.03 (0.3 %)
New grass areas	88.7 (12.1 %)	14.8 (9.1 %)	2.1 (18.1 %)
Total new GBS*	92.4 (12.6 %)	16.4 (10 %)	2.1 (18.4 %)

* Some interventions included in the calculation will have been implemented up to 300 m outside the urban footprint (see explanation in *Section 2.4.1*)

several new publicly accessible GBS of 1 ha.

In Paris and Aarhus, interventions occurred most commonly in the core inner-city centre, where high concentrations of built surfaces require the repurposing of several blocks of buildings into grass and a substantial increase in the presence of street trees (Fig. 3; Fig. 4). Despite much better overall existing status of GBS in Aarhus relative to Paris (Table 3), the inner-city centre contrasts with the land cover of surrounding areas, with a higher proportion of built surfaces and notably less green and blue spaces at present (Fig. 4a). Consequently, to meet the 3–30–300 rule, several blocks of buildings were repurposed as green spaces and most streets needed a substantial increase in tree canopy cover (Fig. 4b).

Whilst the total area of new GBS implemented is greatest in larger cities such as Paris and Aarhus, Velika Gorica had the highest proportion of the urban footprint that was changed to meet the rule. At least 18 % of the urban footprint was converted to new GBS, with interventions consisting primarily of new grassy areas (Table 8; Fig. 5).

4. Discussion

None of the cities in this study currently meet any of the components of the 3–30–300 rule, although some were close. The three cities differed in which components were nearly met, Paris nearly met the 3-component, Aarhus the 30- and 300-component, and Velika Gorica the 3- and 30-component. For all study cities to meet the rule and strive towards spatially and socially equitable access of GBS, they would be required to make considerable changes to the current land cover. Our study shows that the changes required also varied spatially within cities, with most interventions required in core, inner-city centres, particularly in Paris and Aarhus.

Differences between and within cities could be a result of a multitude of factors including historical reasons, cultural character, financial reasons, infrastructural reasons, or spatial constraints such as shape, size, and density (Kabisch et al. 2016; Richards et al. 2022; Browning et al. 2023). The heterogeneity of each city and the amalgamation of these influencing factors is one of the key challenges to implementing a single, transferable, rule-based green initiative, such as the 3–30–300 rule.

A key constraint for cities seeking to achieve the 3–30–300 rule, particularly in higher density areas and compact cities, is the pressure for space (Kabisch et al. 2016; Browning et al. 2023). Particularly in Paris and Aarhus, core inner-city centre neighbourhoods' access to GBS appears notably lower than the city-wide average due to the higher concentration and density of built surfaces. Therefore, spatially, urban centres are likely to be the locations where it is hardest for cities to achieve the 3–30–300 rule.

Battisti et al. (2023) mention that the hardest component to achieve is the 30-component. Using the original definition of the 30-component, this study concurs as Table 4 shows that no neighbourhoods in Velika Gorica, and very few in Aarhus and Paris have more than 30 % tree canopy cover. However, in our study, as we include all GBS in our definition of the 30-component, the hardest component appears to be the 300-component. This is because interventions must consider how several hectares of new GBS could be incorporated. In contrast, the component with the highest current compliance and perhaps the easiest to achieve is the 3-component. Planting individual trees in urban centres is far more achievable, requiring much less space and can be achieved through planting both in public spaces such as along streets as well as on private residential land (Shakeel and Conway, 2014) such as domestic gardens.

To introduce new, large GBS such as those required in the 300-component, cities may need to be innovative, adaptable, and creative.

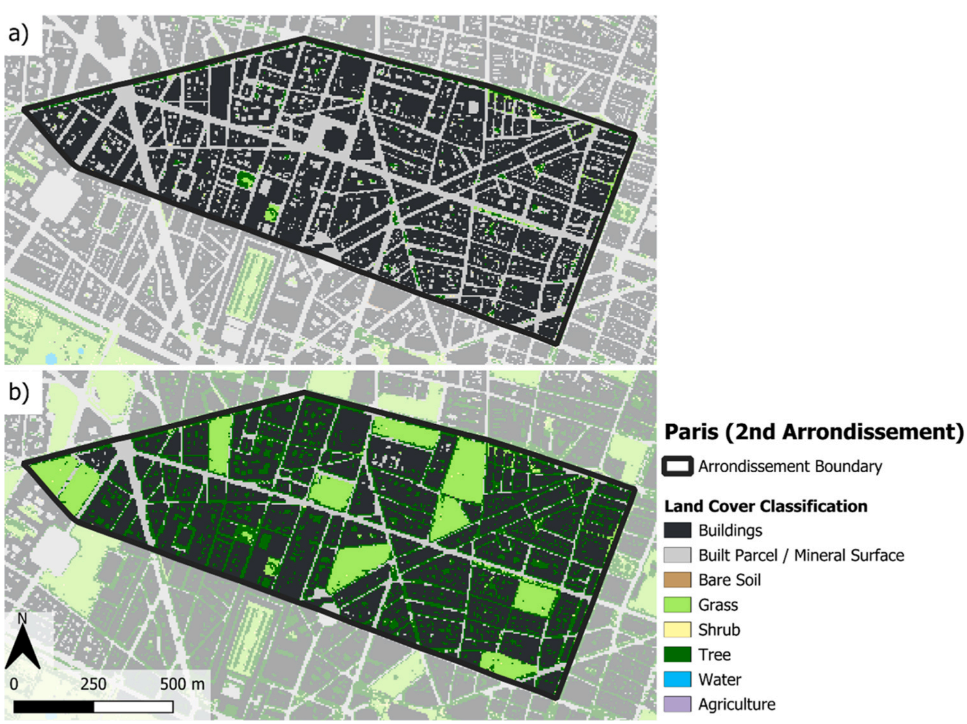

Fig. 3. Extent of changes to meet 3–30–300 rule in Paris' 2nd Arrondissement, showing a) the current land cover and b) implementation of the 3–30–300 rule, with many new parks and extensive new street trees.

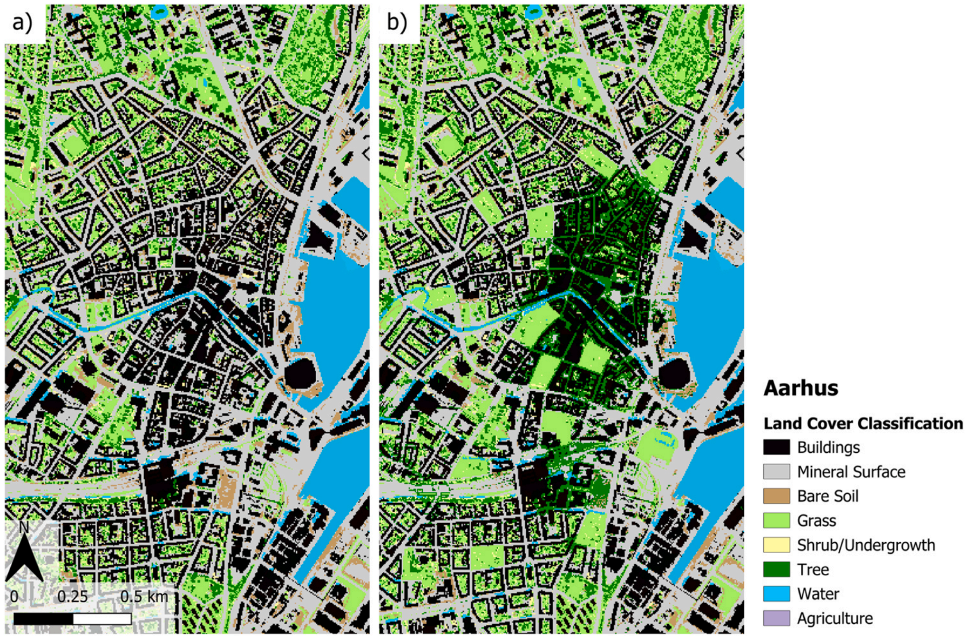

Fig. 4. Example of changes required in central Aarhus, showing a) Current landcover and b) after implementing the 3–30–300 rule.

Fig. 5. Example of changes required near the centre of Velika Gorica, showing a) current landcover and b) after implementing the 3–30–300 rule.

Some cities have already exemplified this by placing parks on top of existing large infrastructures. For example, in Paris, the railway station, Gare Montparnasse is entirely covered by a 3.5 ha Atlantic Park (Maldonado, Melissa, 2000). In Rotterdam, novel large-scale green and blue areas such as roof parks over railway yards have been introduced (Tillie and van der Heijden, 2016). In Hamburg, the city is building a giant green roof cover over sections of the A7 motorway crossing Hamburg city, the largest of its kind in Germany, with the aim to reduce noise and air pollution and increase connectivity and recreational benefits (Hansestadt Hamburg, 2023).

Reinventing the way buildings are designed and used in the future can also offer opportunities for increasing GBS in dense urban settings. For example, in Singapore, they are overcoming the lack of ground-level spaces by utilizing the vertical space and will integrate 200 ha of building greenery into high-rise buildings by 2030 (Kosorić et al. 2019). This will be achieved by creating whole floors of 'garden' within tower blocks, often on multiple levels up the height of a building. These solutions show that it is possible to retain buildings, while simultaneously providing additional green space, in ways that might satisfy the 3–30–300 guidelines. However, many existing buildings are not built to a specification that allows this sort of retrofit, making widespread implementation challenging.

To explore more realistic implementations of the rule as it is likely to be interpreted by city planners, our study modifies some of the components to take account both the wider interpretation of GBS and recognising the benefits also provided by other types of GBS beyond just trees (Jones et al. 2022a). The components could be adapted further, where appropriate. We suggest that one of these key modifications should be the recognition of smaller GBS in core, inner-city areas. In these areas, space is at a premium, and facilitating new green spaces greater than 1 ha may not be achievable. Whilst the size of greenspace is associated with higher rates of recreational opportunities and preference (Cohen et al. 2010; Konijnendijk, 2023), in intensively built cities, more pocket-sized parks could be implemented. Pocket parks are a newer form of GBS created from residual land and are accessible and attractive to local communities (Labuz, 2019; Gkentsidis et al. 2021; Rosso et al. 2022) and easier to implement. More pocket parks could effectively distribute the psychological, physiological, and physical benefits of GBS to urban inhabitants by increasing possible recreational activities and encounters with nature (Rosso et al. 2022) where large GBS are unattainable. It is possible that several of these smaller parks could provide equal services to residents and compensate for the lack of larger green spaces (Ekkel and deVries, 2017). However, such smaller parks would not provide the same benefits for biodiversity (Strohbach et al. 2013; Beninde et al. 2015) and may not provide similar levels of co-benefits such as cooling or noise mitigation (Hutchins et al. 2021).

A key strength of the 3–30–300 rule is its emphasis on equity. While existing greening initiatives in the three study cities have already achieved improvements in green space cover, their placement is often targeted for specific purposes (e.g. improving groundwater quality, increasing biodiversity, or reducing hot-day temperatures), and these may not have considered social aspects explicitly. Often, a targeted approach is necessary or desirable, for example to reduce localised surface water flooding. The 3–30–300 rule may achieve equity of access to GBS but still fail to address problems in specific locations so these approaches should not be seen as contradictory, rather they should be seen as complementary.

4.1. Limitations and considerations

This section reflects and considers a number of limitations and challenges of measuring and implementing the 3–30–300 rule. A methodological challenge is that the guidelines set in Konijnendijk (2023) are only guidelines and thus do not include clear-cut methods on how to implement them (Battisti et al. 2023). Therefore, studies with different definitions and interpretations of the rule, as well as different methodological approaches, could yield different results. This limitation applies particularly to the 3-component, where the visibility of trees from a building is challenging to define. In our study, we adopted a proximity-based approach, where we assume that the presence of trees within a pre-defined distance is visible. This definition presents several limitations as it relies on the assumption that firstly, all trees within that distance are visible, and secondly, a single 5 m raster cell could contain more than one tree. Without a very sophisticated, and computationally expensive, line-of-sight analysis we cannot accurately delineate or measure the visibility of individual trees (Larkin and Hystad, 2019; Wu and Kim, 2021). Our method also excludes larger trees that would be visible from a distance, e.g. above roof tops.

As well as methodological approaches, this study and the 3–30–300 rule pose future challenges and implications for planning. One of the most prominent challenges of this rule will be deciding how and where interventions are implemented. Our rule base has some simple optimisation steps to identify and prioritise areas for change, but it does not consider if and how green infrastructure could be added in those locations (for example, if existing infrastructure could be retrofitted) and so would need to be far more sophisticated when implementing such an approach in reality. Furthermore, the location of proposed GBS should be considered carefully, to avoid potential disbenefits. The placement of new GBS solely to meet threshold requirements may fail to acknowledge interacting factors. For example, in enclosed streets (street canyons) such as those in central Paris and Aarhus, an increase in street trees could reduce wind speeds and dispersion and consequently increase local pollutant concentrations (Kumar et al. 2019). Therefore, placement of interventions should be designed to meet the requirements of the rule whilst also maximising biodiversity and other benefits (Beninde et al. 2015; Fletcher et al. 2022), and minimising adverse outcomes. However, there may be trade-offs between optimum locations for one service and optimum locations for others (Jones et al. 2022b).

Another limitation is that the quality of new and existing GBS are not considered. This is a limitation because in this study, we assume that inhabitants will use their nearest park and that by meeting the guideline thresholds, inhabitants will have equitable access to GBS. This is not always the case, especially if the parks lack adequate facilities or are perceived as unsafe (Zhou and Kim, 2013). As well as proximity, policymakers and planners must also consider the quality of new and existing green space by measuring characteristics such as their facilities, amenities, accessibility, and safety (Kabisch et al. 2016; Konijnendijk, 2023).

Implementing the 3–30–300 rule is expected to have positive implications for socioeconomic equity with the potential to tackle current environmental justice issues of the disparity in access to GBS and their associated ecosystem services. However, efforts to meet the rule can present new challenges for planners. For example, neighbourhoods where the rule can most easily be applied, may be home to more affluent residents, potentially increasing socioeconomic inequalities. Alternatively, regreening which benefits deprived neighbourhoods can lead to 'green gentrification' whereby the arrival of more affluent people increases property prices (Cavicchia, 2021) and displaces existing residents (Zuk, 2014). However, since the 3–30–300 rule aims to increase green space equity across the whole city, green gentrification effects are unlikely as they tend to be caused by highly localised improvement of the urban landscape.

4.2. Conclusions

Overall, the long and short-term functions provided by GBS are largely beneficial to both human and environmental health and well-being (Kumar et al., 2019). Equitable access to GBS is increasingly important due to urbanization and climate change induced pressures. This is why transferrable guidelines such as the 3–30–300 rule can encourage cities, national governments, and international organisations to develop successful urban greening initiatives (Konijnendijk, 2021). The 3–30–300 rule can be seen as complementary to existing targeted GBS interventions which may be necessary to address specific problems, adding an equity lens to urban green space planning. To further encourage the implementation of such initiatives, future studies should aim to measure and quantify the ecosystem service benefits provided by the 3–30–300 rule, to provide evidence on their effectiveness in addressing urban challenges.

CRediT authorship contribution statement

Kate Farley: Writing – review & editing. **Gregor Levin:** Writing – review & editing, Data curation. **Marianne Zandersen:** Writing – review & editing. **Ellen Banzhaf:** Writing – review & editing. **Alice Fitch:** Writing – review & editing, Methodology, Conceptualization. **Danial Owen:** Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Julius Knopp:** Writing – review & editing, Visualization, Data curation. **David Fletcher:** Writing – review & editing, Methodology, Conceptualization. **Laurence Jones:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Gwendoline Grandin:** Writing – review & editing, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Armson, D., Stringer, P., Ennos, A.R., 2012. The effect of tree shade and grass on surface and globe temperatures in an urban area. Urban For. Urban Green. *11* (3), 245–255.
Armson, D., Stringer, P., Ennos, A.R., 2013. The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban For. Urban Green. *12* (3), 282–286.
Artmann, M., Kohler, M., Meinel, G., Gan, J., Ioja, I.C., 2019. How smart growth and green infrastructure can mutually support each other—a conceptual framework for compact and green cities. Ecol. Indic. *96*, 10–22.
Atelier Parisien d'Urbanisme (2015): Hauteur vegetation 2015. https://opendata.apur.org/datasets/Apur::hauteur-vegetation-2015/about [last accessed on 6th December 2023].
Baffoe, G., 2019. Understanding the neighbourhood concept and its evolution: A review. Environ. Urban. ASIA *10* (2), 393–402.
Banzhaf, E., Wu, W., Luo, X., Knopp, J., 2021. Integrated Mapping of spatial urban dynamics—a European-Chinese exploration. Part 1—methodology for automatic land cover classification tailored towards spatial allocation of ecosystem services features. Remote Sens. 13 (9), 1744.
Barboza, E.P., Cirach, M., Khomenko, S., Iungman, T., Mueller, N., Barrera-Gómez, J., Rojas-Rueda, D., Kondo, M., Nieuwenhuijsen, M., 2021. Green space and mortality in European cities: a health impact assessment study. Lancet Planet. Health *5* (10), e718–e730.
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* (15), 12085.
Bell, S., Fleming, L.E., Grellier, J., Kuhlmann, F., Nieuwenhuijsen, M.J., White, M.P., 2021. Urban blue spaces: planning and design for water, health and well-being. Routledge.
Beninde, J., Veith, M., Hochkirch, A., 2015. Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. Ecol. Lett. 18 (6), 581–592.
Bird, D.N., Banzhaf, E., Knopp, J., Wu, W., Jones, L., 2022. Combining spatial and temporal data to create a fine-resolution daily urban air temperature product from remote sensing land surface temperature (LST) data. Atmosphere 13 (7), 1152.
Bolund, P., Hunhammar, S., 1999. Ecosystem services in urban areas. Ecol. Econ. 29, 293–301.
Breuste, J., Haase, D., Elmqvist, T., 2013. Urban landscapes and ecosystem services. In: Wratten, S., Sandhu, H., Cullen, R., Costanza, R. (Eds.), Ecosystem Services in Agricultural and Urban Landscapes. Wiley & Blackwell, Oxford, pp. 83–104.
Browning, M., Locke, D.H., Konijnendijk, C., Labib, S.M., Rigolon, A., Yeager, R., Bardhan, M., Berland, A., Dadvand, P., Helbich, M. and Li, F., 2023. Measuring the 3-30-300 Rule to Help Cities Meet Nature Access Thresholds. EcoEvoRxiv [Preprint].
C40, 2015. *Cities100: Paris – Green Spaces Keep the City Cool.* https://www.c40.org/case-studies/cities100-paris-green-spaces-keep-the-city-cool/ ACCESSED [16-04-2024].
Cohen, D.A., Marsh, T., Williamson, S., Derose, K.P., Martinez, H., Setodji, C., McKenzie, T.L., 2010. Parks and physical activity: why are some parks used more than others? Prev. Med. *50*, S9–S12.
Conway, T.M., Yuan, A.Y., Roman, L.A., Heckert, M., Pearsall, H., Dickinson, S.T., Rosan, C.D., Ordóñez, C., 2023. Who participates in green infrastructure initiatives and why? Comparing participants and non-participants in Philadelphia's GI programs. J. Environ. Policy Plan. *25* (3), 327–341.
Cruz-Sandoval, M., Ortego, M.I., Roca, E., 2020. Tree ecosystem services, for everyone? A compositional analysis approach to assess the distribution of urban trees as an indicator of environmental justice. Sustainability *12* (3), 1215.
Daland, S., 2023. An investigation of the 3-30-300 rule in a Swedish context.
Département des Hauts-de-Seine (2012): Cadastre vert - Masses vertes. https://opendata.hauts-de-seine.fr/explore/dataset/cadastre-vert-masses-vertes/information/?disjunctive.commune [last accessed on 6th December 2023].
Ekkel, E.D., de Vries, S., 2017. Nearby green space and human health: Evaluating accessibility metrics. Landsc. Urban Plan. *157*, 214–220.
Fletcher, D.H., Garrett, J.K., Thomas, A., Fitch, A., Cryle, P., Shilton, S., Jones, L., 2022. Location, location, location: modelling of noise mitigation by urban woodland shows the benefit of targeted tree planting in cities. Sustainability 14 (12), 7079.
Fletcher, D.H., Likongwe, P.J., Chiotha, S.S., Nduwayezu, G., Mallick, D., Md, N.U., Rahman, A., Golovátina-Mora, P., Lotero, L., Bricker, S., Tsirizeni, M., 2021. Using demand mapping to assess the benefits of urban green and blue space in cities from four continents. Sci. Total Environ. 785, 147238.
Geofabrik, 2023. OpenStreetMap Data Extracts. Online at http://download.geofabrik.de/ Accessed 01 August 2023.
Gkentsidis, A., Chatzidimitriou, A., Tellios, A., 2021. The Influence of Pocket Parks on Microclimate Conditions and Pedestrian Comfort in Urban Neighborhoods. Mod. Environ. Sci. Eng. *7*, 554–561.
Grad Velika Gorica., n.d. https://vg.pipgis.hr/ (last accessed: 18th December 2023).
Grazuleviciene, R., Dedele, A., Danileviciute, A., Vencloviene, J., Grazulevicius, T., Andrusaityte, S., Uzdanaviciute, I., Nieuwenhuijsen, M.J., 2014. The influence of proximity to city parks on blood pressure in early pregnancy. Int. J. Environ. Res. Public Health *11* (3), 2958–2972.
Haaland, C., Bosch, C.K.V.D., 2015. Challenges and strategies for urban green-space planning in cities undergoing densification: a review. Urban For. Urban Green. 14 (4), 760–771.
Haase, D., 2015. Reflections about blue ecosystem services in cities. Sustain. Water Qual. Ecol. *5*, 77–83.
Hansestadt Hamburg "Ausbau A 7 & Deckel - Gesamtprojekt - Hamburger Deckel - Ausbau A 7." [Extention of A 7 and roof cover project - Hamburg roof cover - Extestion A 7]. https://www.hamburg.de/fernstrassen/ziele-und-nutzen/. Accessed December 20, 2023.
Hartig, T., Mitchell, R., De Vries, S., Frumkin, H., 2014. Nature and health. Annu. Rev. Public Health *35*, 207–228.
Huang, Q., Yang, M., Jane, H.A., Li, S., Bauer, N., 2020. Trees, grass, or concrete? The effects of different types of environments on stress reduction. Landsc. Urban Plan. *193*, 103654.
Hutchins, M.G., Fletcher, D., Hagen-Zanker, A., Jia, H., Jones, L., Li, H., Loiselle, S., Miller, J., Reis, S., Seifert-Dähnn, I., Wilde, V., 2021. Why scale is vital to plan optimal nature-based solutions for resilient cities. Environ. Res. Lett. 16 (4), 044008.
Institut Paris Region, 2020b. *Plateforme open data de L'Institut Paris Region*. Available at: https://data-iau- idf.opendata.arcgis.com/datasets/iau-idf::espaces-verts-et-bois%C3%A9s-surfaciques-ouverts-ou-en-projets-douverture-au-public-d%C3%AEle-de-france-3/about (Last Accessed: 18 December 2023).
Institut Paris Region., 2020a. Le «MOS+», un premier pas vers une observation moins binaire du ZAN. Note rapide n° 855, June 2020. https://www.institutparisregion.fr/fileadmin/NewEtudes/000pack2/Etude_2370/NR_855_web.pdf [last accessed 6th of December 2023].
Instutit d'Aménagement et d'Urbanisme d'Ile-de-France (Institute for Town Planning in Ile-de-France).
Jones, L., Anderson, S., Læssøe, J., Banzhaf, E., Jensen, A., Bird, D.N., Miller, J., Hutchins, M.G., Yang, J., Garrett, J., Taylor, T., 2022a. A typology for urban Green Infrastructure to guide multifunctional planning of nature-based solutions. Nat. -Based Solut. 2, 100041.
Jones, L., Fletcher, D., Fitch, A., Kuyer, J., Dickie, I., 2024. Economic value of the hot-day cooling provided by urban green and blue space. Urban Forestry & Urban Greening, 128212.
Jones, L., Reis, S., Hutchins, M., Miller, J., He, B., Seifert-Dähnn, I., Xu, C.Y., Hagen-Zanker, A., Yu, J., Lin, T., Jia, H., 2022b. Airsheds, watersheds and more–The flows that drive intra-extra-urban connections, and their implications for nature-based solutions (NBS). Nat. -Based Solut. 2, 100040.
Jones, L., Vieno, M., Fitch, A., Carnell, E., Steadman, C., Cryle, P., Holland, M., Nemitz, E., Morton, D., Hall, J., Mills, G., 2019. Urban natural capital accounts: Developing a novel approach to quantify air pollution removal by vegetation. J. Environ. Econ. Policy 8 (4), 413–428.
Kabisch, N., Strohbach, M., Haase, D., Kronenberg, J., 2016. Urban green space availability in European cities. Ecol. Indic. *70*, 586–596.
Karteris, M., Theodoridou, I., Mallinis, G., Tsiros, E., Karteris, A., 2016. Towards a green sustainable strategy for Mediterranean cities: Assessing the benefits of large-scale green roofs implementation in Thessaloniki, Northern Greece, using environmental modelling, GIS and very high spatial resolution remote sensing data. Renew. Sustain. Energy Rev. *58*, 510–525.
Kearns, A., Parkinson, M., 2001. The significance of neighbourhood. Urban Stud. *38* (12), 2103–2110.
Knopp, J. (2022). High resolution land cover 2016 Velika Gorica (Version v1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7107514.
Knopp, J.M., Levin, G., Banzhaf, E., 2023. Aerial data analysis for integration into a green cadastre–an example from Aarhus, Denmark. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. vol. 16, 6545–6555. https://doi.org/10.1109/JSTARS.2023.3289218.
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). Preprints, 2023051760. https://doi.org/10.20944/preprints202305.1760.v1.
Konijnendijk, C., 2021. The 3-30-300 rule for urban forestry and greener cities. Biophilic Cities J. *4* (2), 2.
Konijnendijk, C.C., 2023. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. J. For. Res. *34* (3), 821–830.
Kosorić, V., Huang, H., Tablada, A., Lau, S.K., Tan, H.T., 2019. Survey on the social acceptance of the productive façade concept integrating photovoltaic and farming systems in high-rise public housing blocks in Singapore. Renew. Sustain. Energy Rev. *111*, 197–214.
Kumar, P., Debele, S., Khalili, S., Halios, C.H., Sahani, J., Aghamohammadi, N., De Fatima Andrade, M., Athanassiadou, M., Bhui, K., Calvillo, N., Cao, S.-J., Coulon, F., Edmondson, J.L., Fletcher, D., Dias De Freitas, E., Guo, H., Hort, M.C., Katti, M., Kjeldsen, T.R., Lehmann, S., Locosselli, G.M., Malham, S.K., Morawska, L.,

Parajuli, R., Rogers, C.D.F., Yao, R., Wang, F., Wenk, J., Jones, L., 2024. Urban heat mitigation by green and blue infrastructure: drivers, effectiveness, and future needs. Innovation, 100588.

Kumar, P., Druckman, A., Gallagher, J., Gatersleben, B., Allison, S., Eisenman, T.S., Hoang, U., Hama, S., Tiwari, A., Sharma, A., Abhijith, K.V., 2019. The nexus between air pollution, green infrastructure and human health. Environ. Int. *133*, 105181.

Labuz, R., 2019. Pocket park–a new type of green public space in Kraków (Poland) (February). In: IOP Conference Series: Materials Science and Engineering, Vol. 471. IOP Publishing, 112018 (February).

Larkin, A., Hystad, P., 2019. Evaluating street view exposure measures of visible green space for health research. J. Expo. Sci. Environ. Epidemiol. *29* (4), 447–456.

Li, X., Zhang, C., Li, W., Kuzovkina, Y.A., Weiner, D., 2015. Who lives in greener neighborhoods? The distribution of street greenery and its association with residents' socioeconomic conditions in Hartford, Connecticut, USA. Urban For. Urban Green. *14* (4), 751–759.

Lin, M., Lin, T., Sun, C., Jones, L., Sui, J., Zhao, Y., Liu, J., Xing, L., Ye, H., Zhang, G., Li, X., 2020. Using the Eco-Erosion Index to assess regional ecological stress due to urbanization–A case study in the Yangtze River Delta urban agglomeration. Ecol. Indic. 111, 106028.

Liu, D., Kwan, M.P., Kan, Z., Wang, J., 2022. Toward a healthy urban living environment: Assessing 15-minute green-blue space accessibility. Sustainability *14* (24), 16914.

Maldonado, Melissa, 2000. Le Jardin Atlantique. Paris. *Stud. Hist. Gard. Des. Landsc.* 20 (4), *297–312*. https://doi.org/10.1080/14601176.2000.10435629.

Miller, J.D., Vesuviano, G., Wallbank, J.R., Fletcher, D.H., Jones, L., 2023. Hydrological assessment of urban Nature-Based Solutions for urban planning using Ecosystem Service toolkit applications. Landsc. Urban Plan. 234, 104737.

Neuvonen, M., Sievänen, T., Tönnes, S., Koskela, T., 2007. Access to green areas and the frequency of visits–a case study in Helsinki. Urban For. Urban Green. *6* (4), 235–247.

Nieuwenhuijsen, M.J., Dadvand, P., Márquez, S., Bartoll, X., Barboza, E.P., Cirach, M., Borrell, C., Zijlema, W.L., 2022. The evaluation of the 3-30-300 green space rule and mental health. Environ. Res. *215*, 114387.

Nutsford, D., Pearson, A.L., Kingham, S., Reitsma, F., 2016. Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. Health Place *39*, 70–78.

O'Brien, L., De Vreese, R., Kern, M., Sievänen, T., Stojanova, B., Atmiş, E., 2017. Cultural ecosystem benefits of urban and peri-urban green infrastructure across different European countries. Urban For. Urban Green. *24*, 236–248.

Ordóñez, C., Labib, S.M., Chung, L., Conway, T.M., 2023. Satisfaction with urban trees associates with tree canopy cover and tree visibility around the home. npj Urban Sustain. *3* (1), 37.

Owen, D., Fitch, A., Fletcher, D., Knopp, J., Banzhaf, E., Wu, W., Jones, L., 2024. 5m land cover for baseline and 3-30-300 scenarios in Paris, Aarhus, and Velika Gorica. [Data set]. Zenodo. https://doi.org/10.5281/zenodo.11067493.

Pretzsch, H., Biber, P., Uhl, E., Dahlhausen, J., Rötzer, T., Caldentey, J., Koike, T., Van Con, T., Chavanne, A., Seifert, T., Du Toit, B., 2015. Crown size and growing space requirement of common tree species in urban centres, parks, and forests. Urban For. Urban Green. *14* (3), 466–479.

REGREEN., 2020. *The City of Velika Gorica: Building a green mindset through NbS*. https://www.regreen-project.eu/news/the-city-of-velika-gorica-building-a-green-mindset-through-nbs/ ACCESSED [16-04-2024].

REGREEN, n.d. *Aarhus*. https://www.regreen-project.eu/urban-living-lab/aarhus/ ACCESSED [16-04-2024].

Richards, D.R., Belcher, R.N., Carrasco, L.R., Edwards, P.J., Fatichi, S., Hamel, P., Masoudi, M., McDonnell, M.J., Peleg, N., Stanley, M.C., 2022. Global variation in contributions to human well-being from urban vegetation ecosystem services. One Earth *5* (5), 522–533.

Rosso, F., Cappa, F., Spitzmiller, R., Ferrero, M., 2022. Pocket parks towards more sustainable cities. Architectural, environmental, managerial and legal considerations towards an integrated framework: A case study in the Mediterranean region. Environ. Chall. *7*, 100402.

Sahraoui, et al., 2016. A comparison of in situ and GIS landscape metrics for residential satisfaction modelling. Appl. Geogr. 74 (2016), 199–210. https://doi.org/10.1016/j.apgeog.2016.07.011.

Shakeel, T., Conway, T.M., 2014. Individual households and their trees: Fine-scale characteristics shaping urban forests. Urban For. Urban Green. *13* (1), 136–144.

Sikorska, D., Łaszkiewicz, E., Krauze, K., Sikorski, P., 2020. The role of informal green spaces in reducing inequalities in urban green space availability to children and seniors. Environ. Sci. Policy *108*, 144–154.

Strohbach, M.W., Lerman, S.B., Warren, P.S., 2013. Are small greening areas enhancing bird diversity? Insights from community-driven greening projects in Boston. Landsc. Urban Plan. 114, 69–79.

Tillie, N., van der Heijden, R., 2016. Advancing urban ecosystem governance in Rotterdam: From experimenting and evidence gathering to new ways for integrated planning. Environ. Sci. Policy *62*, 139–144.

Ulrich, R.S., 1984. View through a window may influence recovery from surgery. science *224* (4647)), 420–421.

United Nations., 2015. General Assembly Transforming our world: the 2030 Agenda for Sustainable Development, 21 October 2015. https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf [last accessed 30th of October 2023].

Völker, S., Kistemann, T., 2011. The impact of blue space on human health and well-being–Salutogenetic health effects of inland surface waters: a review. Int. J. Hyg. Environ. Health *214* (6), 449–460.

Weber, F., Kowarik, I., Säumel, I., 2014. A walk on the wild side: perceptions of roadside vegetation beyond trees. Urban For. Urban Green. *13* (2), 205–212.

WHO, 2017. Urban green spaces: A brief for action. World Health Organization, Regional Ofce for Europe. Bonn. https://www.who.int/europe/publications/i/item/9789289052498 [last accessed 11th of December 2023].

World Economic Forum., 2022. *The best way to keep cool in heatwaves? Plant 170,000 trees, according to Paris*. https://www.weforum.org/agenda/2022/08/paris-trees-climate-change/ ACCESSED [16-04-2024].

Wu, L., Kim, S.K., 2021. Health outcomes of urban green space in China: Evidence from Beijing. Sustain. Cities Soc. *65*, 102604.

Young, R.F., 2011. Planting the living city: Best practices in planning green infrastructure—Results from major us cities. J. Am. Plan. Assoc. *77* (4), 368–381.

Zhang, Y., Dong, R., 2018. Impacts of street-visible greenery on housing prices: evidence from a hedonic price model and a massive street view image dataset in Beijing. ISPRS Int. J. Geo-Inf. *7* (3), 104.

Zhou, X., Kim, J., 2013. Social disparities in tree canopy and park accessibility: a case study of six cities in Illinois using GIS and remote sensing. Urban For. Urban Green. *12* (1), 88–97.

Zuniga-Teran, A.A., Staddon, C., de Vito, L., Gerlak, A.K., Ward, S., Schoeman, Y., Hart, A., Booth, G., 2020. Challenges of mainstreaming green infrastructure in built environment professions. J. Environ. Plan. Manag. *63* (4), 710–732.