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REVIEW AND SYNTHESIS

Denser and greener cities: Green interventions to achieve both urban density and nature

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Abstract

1. Green spaces in urban areas—like remnant habitat, parks, constructed wetlands, and street trees—supply multiple benefits.
2. Many studies show green spaces in and near urban areas play important roles harbouring biodiversity and promoting human well-being. On the other hand, evidence suggests that greater human population density enables compact, low-carbon cities that spare habitat conversion at the fringes of expanding urban areas, while also allowing more walkable and livable cities. How then can urban areas have abundant green spaces as well as density?
3. In this paper, we review the empirical evidence for the relationships between urban density, nature, and sustainability. We also present a quantitative analysis of data on urban tree canopy cover and open space for United States large urbanized areas, as well as an analysis of non-US Functional Urban Areas in OECD countries.
4. We found that there is a negative correlation between population density and these green spaces. For Functional Urban Areas in the OECD, a 10% increase in density is associated with a 2.9% decline in tree cover. We argue that there are competing trade-offs between the benefits of density for sustainability and the benefits of nature for human well-being. Planners must decide an appropriate density by choosing where to be on this trade-off curve, taking into account city-specific urban planning goals and context.

[Corrections added on 1 February 2023, after first online publication: In the Abstract, the text 'a doubling of density' has been changed to 'a 10% increase in density'].

5. However, while the negative correlation between population density and tree cover is modest at the level of US urbanized areas ($R^2 = 0.22$), it is weak at the US Census block level ($R^2 = 0.05$), showing that there are significant brightspots, neighbourhoods that manage to have more tree canopy than would be expected based upon their level of density. We then describe techniques for how urban planners and designers can create more brightspots, identifying a typology of urban forms and listing green interventions appropriate for each form. We also analyse policies that enable these green interventions illustrating them with the case studies of Curitiba and Singapore.
6. We conclude that while there are tensions between density and urban green spaces, an urban world that is both green and dense is possible, if society chooses to take advantage of the available green interventions and create it.

KEYWORDS
ecosystem services, energy use, land sharing, land sparing, landscape architecture, sustainability, tree canopy cover, urban planning

1 | INTRODUCTION

Urban growth is occurring faster than has ever been experienced in human history, with an additional 2 billion people expected in urban areas by 2050 (UNPD, 2018). In the next couple of decades, more homes will be built in cities around the world than currently exist in all of Europe (McDonald, 2008). The form of those new urban neighbourhoods has implications for numerous aspects of sustainability, from resource use to material efficiency to greenhouse gas emissions. This paper looks at the potential role of nature in urban neighbourhoods, and how different urban forms allow for different amounts of nature and sustainability. We ask how urban neighbourhoods can be designed to be both full of green spaces, for biodiversity and ecosystem service benefits, while also dense enough to confer some of the sustainability benefits of a more compact city. We primarily focus on urban density in this manuscript, but acknowledge that there are other aspects of urban form that are also important for sustainability and present a typology of urban forms relative to different kinds of green spaces.

While there have been reviews about the state of scientific knowledge for specific topics, this review attempts to synthesize results from what are arguably several distinct areas of study now: urban biodiversity and urban form; urban ecosystem services and urban form; urban sustainability and urban form; and discussion of specific types of green intervention to increase urban nature. Moreover, we have tried where possible to draw from quantitative assessments of how density relates to these different goals, to provide context and specificity for the literature review. To our knowledge, there are no other similar paper that quantitatively synthesizes these distinct areas of study.

In this paper, our overarching research question is: How can urban areas be both dense and green? We first review the scientific literature (Section 2) to understand the quantitative relationships between green spaces and the amount of biodiversity or ecosystem service provision in urban areas. Next (Section 3) we review the empirical data on the relationship between human population density and sustainability. In Section 4, we quantitatively analyse two recently published datasets from the United States, to determine if there is, on average, a trade-off between human population density and the number of green spaces. We also analyse trends for non-US cities using data from OECD countries. Next (Section 5) we investigate brightspots, defined as neighbourhoods that have at least three times more tree canopy than would be expected based upon their level of density. We identify a typology of urban forms and describe how they relate to possible green interventions that can increase green spaces (Section 6). Finally, we describe policies that enable these green interventions using two case studies: Curitiba and Singapore (Section 7).

1.1 | Defining urban population density

In this paper, we define 'urban form' as 'the physical characteristics that make up built-up areas, including the shape, size, density and configuration of settlements' (Redbridge Government, 2014). Urban density is one component of urban form, the concentration of people or building infrastructure within a certain urban area (Ng, 2009). It is a common measure in urban planning and landscape architecture, which is why we have chosen to focus on it here. Other components of urban form are discussed in more detail in Section 6.

In this paper we measure urban density as the number of people per square kilometre within an urban area. Definitions of urban vary between different databases and scientific papers use different definitions of urban depending on the context (Bay & Lehmann, 2017). In this paper, we generally follow the Functional Urban Area (FUA) definition, which defines a core area surrounded by a commuting zone (Dijkstra et al., 2019). However, for cities in the United States, in order to align spatially with census data, we follow the definitions of the U.S. Census Bureau (2010), which delimits core 'urbanized areas' surrounded by a commuting zone (Metropolitan Statistical Areas). Note that urbanized areas are not arbitrary political units, but are based on the density of human settlements, similar but not identical to the delineation of a core FUA.

Our paper discusses density and nature at three different scales: (1) the entire FUA or Metropolitan Statistical area, (2) the core FUA or urbanized area, (3) and the neighbourhoods scale (defined in the US as census blocks). For the US, we consistently present data using the urban area concepts defined by the US Census Bureau, whereas for other countries we present data using the FUA concept. Sections 2–4 focus primarily on scales #1 and #2, as that is scale at which overall relationships between urban density and sustainability has been most frequently studied. Sections 5 and 6 focus on green interventions at the neighbourhood scale (scale #3), as that is the scale at which landscape architects and urban planners often work when designing new developments. Sections 7 discusses policy options across these three scales.

Readers are cautioned that density statistics may look very different across these three scales, and depending on the urban area definition used. For instance, in 2010 the US Census Bureau estimated the density of the New York Metropolitan Statistical area (New York–Newark–Bridgeport, NY, NJ, CT, PA) was 1085 people/km^2, that of the New York City urbanized area was 2053 people/km^2, while specific neighbourhoods (US census blocks) in Manhattan like the Upper East Side exceed 50,000 people/km^2 (McDonald et al., 2021). For comparison, the OECD estimated the density of the New York City FUA as 829 people/km^2, while the core FUA population density was 1431 people/km^2 (Brezzi et al., 2012; OECD, 2021).

2 | URBAN GREEN SPACES, BIODIVERSITY AND HUMAN WELL-BEING

There are multiple types of nature in cities, which we will refer to collectively as green spaces. Our definition of 'green spaces' follows Aronson et al. (2017), and includes vegetated natural, semi-natural, and artificial ecological systems within and around a city. Some green spaces are not human creations, such as remnant patches of habitat in or near urban areas. Other green spaces are anthropogenic, such as parks, gardens, and vegetation planted along city streets. Note that in arid or semi-arid landscapes, green spaces may have vegetation that is appropriate to these climatic zones and may thus appear less green in colour. As will be discussed in more detail below, different kinds of green spaces support biodiversity and provide ecosystem service in different amounts and ways (McDonald, 2009).

2.1 | Urban nature and biodiversity

In this subsection, we briefly review the literature on the relationship between urban form and biodiversity, with a goal of identifying what density and urban form seem most able to support biodiversity.

It is helpful for purposes of analysis to divide the taxa present in urban areas into three groups (Fischer et al., 2015). *Urban avoiders* are species, often native to a location, which are unable to survive in urban areas due to habitat requirements or other susceptibility to the changes in conditions (abiotic and biotic) within urban areas. As a city expands, then, urban avoiders in general decline in abundance, or may be driven locally extinct. *Urban utilizer species*, can survive in urban areas, whether due to a wide range of possible habitat or due to behavioural adaptability. As an urban area expands, urban utilizers will persist locally or even increase in abundance. Finally, *urban dwelling species* are those that tend to arrive with human settlement and habitation and are often well-suited to life in an urban environment. As an urban area expands, the species richness and abundance of urban dwellers tends to increase. The overall change with urban growth in total species richness depends on the relative species richness in each group. In some cases, total species richness at the city scale may even increase with urban growth (Spotswood et al., 2021), if gains in urban dwellers outweigh losses of urban avoiders. However, at a global scale, because the species richness of urban avoiders generally declines with habitat destruction, urban growth has a net negative effect on global biodiversity (McDonald, M'Lisa Colbert, et al., 2018).

One key finding of studies of urban biodiversity is that remnant habitat—vegetation native to the region that remains after urban expansion—is one of the most important type of green spaces for increasing and maintaining biodiversity (Figure 1). Other green spaces such as street trees, parks, or habitat on residential properties can also harbour important elements of biodiversity, so these other features are also important in determining urban biodiversity (Belaire et al., 2014; Daniels & Kirkpatrick, 2006; Lerman & Warren, 2011; Smith et al., 2014). A larger extent of habitat predicts a more diverse flora and fauna (Aronson et al., 2014; La Sorte et al., 2020). This is consistent with the often-studied species-area relationship in ecology, with more habitat area allowing the maintenance of a greater number of species.

Remnant habitat is often converted to urban land uses as urban areas grow. One debate in the literature has been framed as 'land sparing versus land sharing' (Soga et al., 2014). Land sparing in an urban context would be concentrating and limiting urban development, often by having greater human population density, thus sparing habitat on the fringes of the urban area. Land sharing would be interspersing urban areas with green spaces, and thus the total amount of urban area being greater and human population density being lower. In general, most urban studies find that land sparing produces higher total biodiversity than land sharing. Higher biodiversity or biomass was found to occur with land sparing for birds in a set of 9 European cities (Jokimäki et al., 2020), for trees in the UK (Collas et al., 2017), for insects in Japan (Soga et al., 2014), and for birds and bats in Australia (Caryl et al., 2016; Geschke et al., 2018; Sushinsky et al., 2013; Villasenor et al., 2017). There are exceptional cases where land sharing is better, however, such as for overwintering birds (Ibáñez-Álamo et al., 2020). Moreover, there are instances where other anthropogenic green spaces are crucial for supporting some taxa (Spotswood et al., 2021).

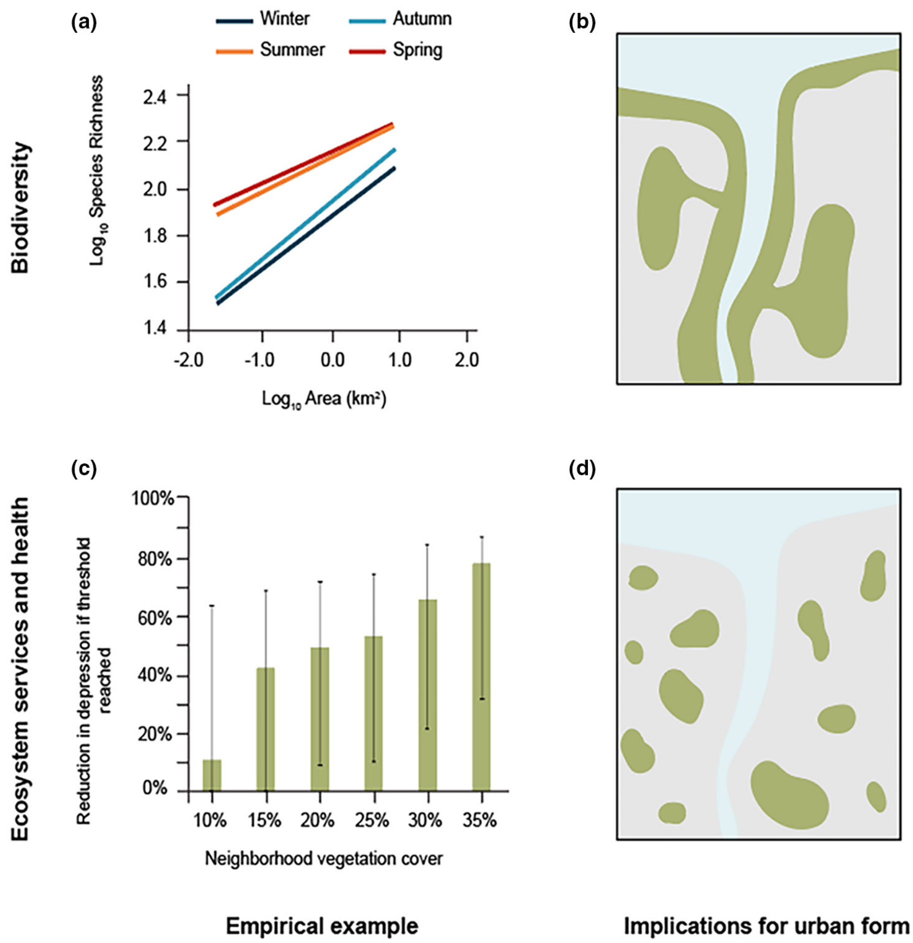

FIGURE 1 Relationship between nature, biodiversity, and ecosystem provision. (a) The relationship between habitat area and avian species richness in New York City (La Sorte et al., 2020). (b) Conceptual drawing of urban development (grey) near a waterbody (blue) in a matrix of remnant habitat (green), with important biodiversity areas protected with corridors between them (McDonald, 2015). Note that small green spaces within the urban area (not shown) can improve matrix quality and help maintain biodiversity as well (Forman, 2008). (c) Neighbourhood vegetation cover and the odds of having depression, from a study in southern England. Shown is the reduction in the odds of having depression, relative to the base case, if a vegetative cover threshold is exceeded (Cox et al., 2017). (d) Conceptual drawing of urban development (grey) near a waterbody (blue) in a matrix of green spaces (green), where each urban neighbourhood is surrounded by green spaces that can provide benefits to residents (McDonald, 2015).

Of course, other components of landscape structure also play a role in determining biodiversity (Fahrig, 2003). Edge effects between remnant habitat and urban areas significantly alter abiotic and biotic conditions (Cadenasso et al., 1997). Edge effects can be minimized by having larger patches of remnant habitat that have lower edge: area ratios (Woodroffe & Ginsberg, 1998). Fragmentation of remnant habitat into multiple patches may reduce connectivity between patches (Fagan, 2002). Loss of connectivity can be minimized by maintaining corridors between patches, although what is a viable corridor is taxa specific (Tischendorf & Fahrig, 2000).

Finally, the dominant paradigm of island biogeography (islands of habitat surrounded by an inhospitable matrix) does not reflect the reality of urban ecology. The quality of the urban matrix matters for determining what urban biodiversity can survive (Spotswood et al., 2019), and should be accounted for in urban biodiversity planning. All else being equal, an urban area that has anthropogenic features such as street trees, green facades and green roofs will have more biodiversity than an urban area without these green spaces. Urban green spaces can thus play an important role in improving matrix quality, and incentives and programs that increase vegetation on otherwise developed parcels can be green interventions with significant biodiversity benefit. Matrix quality can be measured in terms of how it enables connectivity (Ricketts, 2001) or in terms of providing habitat and resources to some taxa (Ruffell et al., 2017).

In sum, the literature suggests that the ideal urban form to maintain biodiversity globally is a compact, high-density city that minimizes remnant habitat conversion (Gagné & Fahrig, 2010; Jokimäki et al., 2020; Sushinsky et al., 2013). Large patches of remnant habitat should be maintained in and near urban areas, with corridors to connect these large patches when possible, while green spaces should be present in the urban matrix to improve matrix quality as much as possible (Forman, 2008).

2.2 | Urban nature and human well-being

There are a wide variety of ecosystem services which are important in urban contexts (Keeler et al., 2019; McDonald, 2015; Souza et al., 2021). Ecosystem services tend to be preferentially provided by certain types of green spaces (de Macedo et al., 2021). For instance, urban tree canopy cover is the green space most involved with air temperature regulation (Kroeger et al., 2018; McDonald et al., 2020). Stormwater mitigation is most associated with wetland features, whether constructed or natural, as that is where rainwater can collect and infiltrate into the soil (Venkataramanan et al., 2019). Recreation value requires people to visit a green space, which often requires substantial areas of anthropogenic land-uses such as walking trails and playing fields (McCormack et al., 2010).

Ecosystem services also occur at particular spatial scales (McDonald, 2009). The scale of an ecosystem service determines where green spaces must be present to help a particular beneficiary group. Some services like carbon sequestration are effectively global, for a tree planted anywhere ultimately reduces the carbon dioxide concentration of the atmosphere globally. Other services play out in watersheds, such as the way vegetation can prevent erosion and the transport of sediment into the stream (Romulo et al., 2018; Vogl et al., 2017). At the other extreme, some ecosystem services must be provided locally. For instance, the area of temperature mitigation typically extends a few hundred meters from vegetation (McDonald et al., 2016).

One particularly important group of ecosystem services are those related to human health. Multiple epidemiological studies show a strong overall correlation between nature exposure and human health (Rojas-Rueda et al., 2019). For example, one long-term cohort study found 12% lower all-cause mortality among female nurses with greater NDVI (a commonly used remotely sensed index related to vegetative greenness) within 250 m than those nurses with less greenness (James et al., 2016). Greater NDVI exposure has also been found to reduce stress and the incidences of certain diseases such as cardiovascular diseases.

Researchers have proposed three key dimensions of nature exposure (Shanahan et al., 2015). The *Intensity* of the exposure might be affected by the amount or quality of nature, with seeing one single tree less intense than being surrounded by a dense tree canopy on all sides. The *frequency* of the exposure might be affected by the location of green spaces, with those with much more nature nearby their home and work more frequently interacting with it. Finally, the *duration* of nature exposure describes how long an individual typically spends interacting with nature in each session, with longer duration exposures expected to have a greater effect on human health. Taken together, these three dimensions describe the 'dose' of nature an individual receives. The dose–response curve of nature exposure is clearly positive (greater dose, greater health) although the exact functional form of this relationship is unclear.

The ideal urban form with respect to many aspects of ecosystem service provision (Figure 1) is thus different than was the case for biodiversity (Sushinsky et al., 2013), particularly where proximity and interaction is required for service delivery (McDonald, 2009; Tallis & Wolny, 2011). Many small clumps of green spaces, interspersed in the urban fabric (Stott et al., 2015), enable a greater and more equitable ecosystem service provision (Bratman et al., 2019; McDonald, 2015). Since different green spaces are best suited to different ecosystem services, a variety of types of green spaces will better meet human needs (Keeler et al., 2019). Ideally, these green spaces should be placed to deliver key ecosystem services to those beneficiaries who need them (Kremen, 2005). Similarly, green spaces should be placed to promote more intense, frequent, and long-duration exposure to nature (Shanahan et al., 2015).

3 | RELATIONSHIP BETWEEN DENSITY AND URBAN SUSTAINABILITY

This manuscript discusses how to reconcile green spaces in urban areas, and their many benefits to human well-being and health, with the other human needs determining urban density. Globally, an increasing fraction of humanity lives in urban areas, and one driver of this urbanization is the benefits of living at higher densities in cities rather than in rural areas (Knox & McCarthy, 2005). As discussed further below, urbanization increases economic productivity and innovation, and brings substantial benefits to those living in cities. Higher population density of urban areas, therefore, can bring with it many benefits. In this section, we explore these benefits of a dense urban lifestyle, contrasting not just rural versus urban areas but also denser urban neighbourhoods with less dense urban neighbourhoods.

3.1 | Benefits of density

Higher densities and an urban pattern of settlement are associated with greater economic productivity (Figure 2a). For instance, an analysis of European subnational regions found that greater population is associated with greater economic productivity (Pan et al., 2013). In this paper, we run a parallel analysis for all OECD FUAs, using the most recent economic and population data, focusing the statistical analysis on the relationship between population density and per-capita economic productivity (Brezzi et al., 2012; OECD, 2021). We find an equivalent relationship, with greater population density associated with greater per-capita economic productivity (Figure 2a). In US cities, a 10% increase in population density is associated with a 1.7% increase in per-capita GDP, while in other OECD countries it is associated with a 2.1% increase in per-capita GDP.

Density increases proximity among individuals and among firms, and proximity has several social and economic benefits to production (McDonald & Beatley, 2020). These benefits are sometimes classified as sharing, matching and learning (Andersson et al., 2007; Duranton & Puga, 2004). *Sharing* of infrastructure like roads or ports is easier when multiple users are in proximity.

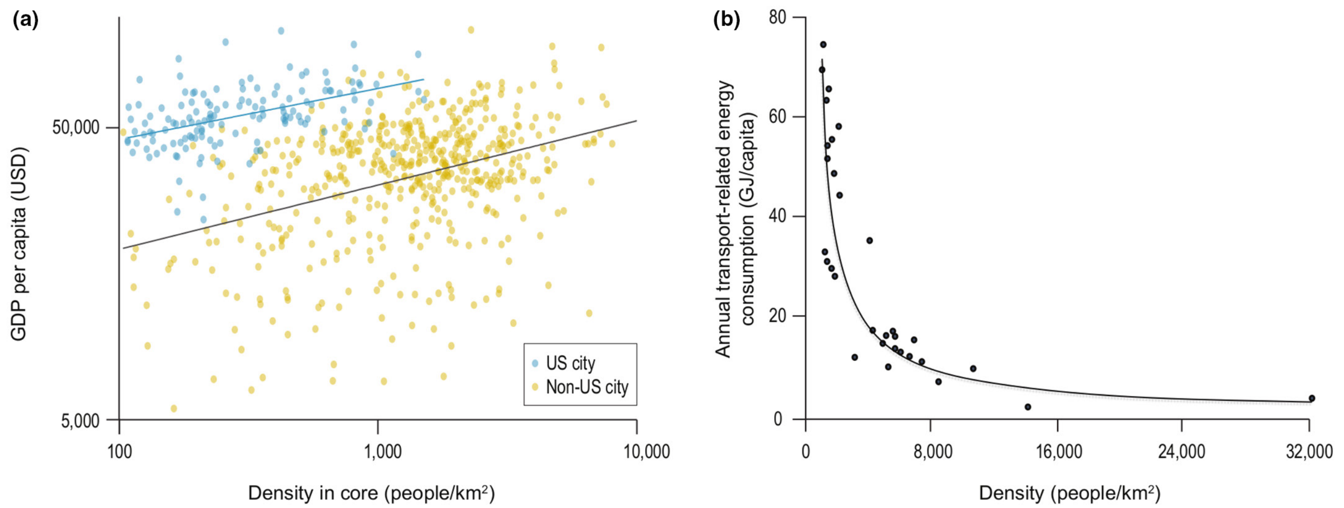

FIGURE 2 Relationship between density and sustainability. (a) Greater population density in OECD functional urban areas (FUA) is associated with greater per-capita economic activity. Shown here are the OECD data, which lists the core FUA population density (OECD, 2021). Our analysis methodology follows Pan et al. (2013), except we have subdivided US and non-US FUAs. (b) Greater population density in cities is associated with less transportation-related energy use, as the use of the private automobile per-capita declines (Newman & Kenworthy, 1989).

The proximity of people and firms also speeds up *Matching*, when two actors find a mutually agreeable collaboration (Andersson et al., 2007; Venables, 2010; Wheeler, 2001). Finally, the increased interaction in urban areas between individuals leads to *Learning*, the sharing of information.

Urban density is negatively correlated with vehicle miles travelled (Figure 2b). In low-density urban settlements, automobiles are often required for getting between destinations, which are often far apart, whereas in higher-density neighbourhoods, particular those oriented toward public transit, it is more possible to travel without car, and travel distances are shorter (Park et al., 2018). Fewer vehicle miles travelled leads to less energy for transport and fewer greenhouse gas emissions from internal combustion engines (Ewing et al., 2003), while more active transport leads to better health outcomes (Hamidi et al., 2018). For instance, Newman and Kenworthy found a negative relationship between urban density, measured at the municipal level, and transportation energy use (Newman & Kenworthy, 1989). Fitting a regression line to the data, we find that a 10% increase in urban density in their sample is associated with around an 8% decrease in transportation energy use. Thus, there is an important sense in which designing new neighbourhoods to be dense can be an important climate mitigation strategy for urban areas.

Importantly for the goal of maintaining remnant habitat, denser cities tend to be 'land sparing.' That is, the greater density leads to less land converted to urban land uses, all else being equal, and this can lead to less habitat loss. Specifically, compact cities need less land area per capita devoted to the road network, reducing total road area needed to support a given population. Similarly, there is less of a building footprint per capita, reducing the total building area needed to house a given population. Of course, other aspects of urban form relate to the degree of 'land sparing', such as the spatial configuration of road and building areas.

The characteristics of urban form essential to a well-functioning city go beyond just population density. One theory (Burton et al., 2003) that tries to enumerate these other characteristics is compact city theory. This theory argues that a compact city can promote beneficial interactions among residents and deliver several environmental benefits. Compact cities are generally at relatively high population density, but also support a mixture of land-uses and building types. There are other theories with similar but not identical goals, including 'green urbanism', 'new urbanism', and 'smart growth'. Recently the idea of the walkable city has become popular, such as the 15-min or 20-min city (Moreno et al., 2021). This is the length of time a short walk from one's house would take, and the idea is that all basic needs should be obtainable within this distance. We cannot in this short section cover this whole rich topic within urban planning but acknowledge that while density may be a necessary part of these urban planning paradigms, they also aim to influence other aspects of urban form.

3.2 | Some challenges with density

Dense neighbourhoods also have some less desirable attributes. We discuss the potential trade-off between density and green spaces in detail in the next section, but in this section our goal is to acknowledge the existence of a few other trade-offs. One common criticism of dense cities is that the cost of renting or buying a home is often greater than in less dense cities (Rérat, 2012). While the causal mechanisms behind this correlation are complex, part of it seems to be that the supply of housing in dense cities does not keep up with demand, raising prices. However, other studies have critiqued low-density suburbs for being exclusionary and unaffordable (Jackson, 1985), so being dense per se is not a sole determinant of the price of housing.

Density can also have some negative effects on quality of life (Cramer et al., 2004). A greater density is often correlated with greater exposure to air pollution from traffic (Davies et al., 2009). Of course, there are solutions to this environmental problem, such as emission controls or zero-emissions vehicles or increased mass transit. Dense cities also tend to have more noise pollution, from more traffic but also from the industrial and commercial land uses (Yuan et al., 2019). Again, other mitigation measures are imaginable, such as sound barriers.

Finally, the increased crowding and interaction in dense cities seems to pose a mental health strain. McDonald and Beatley (2020) refer to this as the urban psychological penalty, the tendency for certain mental health disorders to increase with density. For instance, there are greater rates of stress in urban settings, whether measured with surveys or with cortisol levels (Hartig et al., 2014). Several diseases such as schizophrenia are more prevalent at high densities (Lewis et al., 1992). While other aspects of urban form, including the presence of green spaces, can mitigate these benefits, it is fair to say that for some individuals, life in a high-density city may pose some mental health challenges.

4 | TRADE-OFFS BETWEEN DENSITY AND NATURE PROVISION

In Section 2, we described how having an abundance of green spaces within and near urban areas helps maintain biodiversity and provides important ecosystem services. A separate body of research into urban sustainability suggests that having dense cities delivers, on balance, multiple benefits for sustainability (Section 3). The ideal urban neighbourhood then should have an abundance of green spaces, within and nearby, and be dense. But is this ideal possible?

There are potential trade-offs between human population density and the number of green spaces. For instance, Westerink et al. (2013) present data suggesting that some compact cities in Europe have less accessible open space. They found that people were willing to live in the less dense suburbs and accept a longer commute if it afforded them access to more open space and parks. Moreover, this potential trade-off between density and remnant habitat is implicit in the 'land sparing versus land sharing' formulation (Soga et al., 2014). Denser, 'land sparing' development is assumed to reduce biodiversity within the urban area but help avoid habitat loss at the urban fringes.

In order to assess the extent of this trade-off empirically, we estimated tree cover and population density, utilizing an already published dataset of urban tree canopy cover at 2 m resolution for the 100 largest urbanized areas in the United States, which contain 167 million people in 5723 municipalities and communities (McDonald et al., 2021). Climate plays a role in determining tree canopy cover and ecosystem service provision (cf. Richards et al., 2022), and in our dataset for the US, cities in humid locations have more tree cover than cities in drylands (arid or semi-arid climates) (Figure 3a). For urbanized areas in humid climates, there is a negative association between density and tree canopy cover ($R = 0.47$). This trend presumably occurs because at higher population density there is more impervious surface cover of things like pavement and concrete, which limits the possibilities for planting trees in soil. Note that for urbanized areas in drylands, there is no statistically significant relationship between density and tree canopy cover.

Another important kind of green space is the amount of open space near residents, particularly the amount of publicly accessible parks (Figure 3b). We draw data from Spotswood et al. (2021), which integrated several data layers to map protected areas across all US urbanized areas. To estimate the fraction of the land that is in an undeveloped land cover, we use the United States National Land Cover database of 2016. Human population density and the fraction of land that is open space are negatively associated. Interestingly, the fraction of open space that is protected increases with population density. In denser city centers, a large fraction of open space is protected, while in lower density suburbs, there is a greater amount of open space that is disproportionately on non-protected lands.

Our sample of cities with high-resolution tree cover was from the United States. To assess where similar trends hold for a global sample of cities, we used data on OECD FUAs (excluding US cities, to avoid double counting). Trends for tree cover are similar to the US urbanized area sample (Figure 4). Density in core FUAs is negatively associated with tree canopy cover ($R = 0.33$), with a 10% increase in density associated with a 2.9% decrease in tree cover. There is no significant association between density and percent protected area in OECD FUAs.

Available studies from the literature show a similar trend with density. A study of 386 European cities found a decrease in per-capita green space provision at higher population densities (Fuller & Gaston, 2009), and a study of 111 Southeast Asian cities found that cities with higher population density have lower absolute and per-capita green space (Richards et al., 2017). Other studies have examined other potential explanatory variables related to urban green space, including level of economic development among countries (Huang et al., 2021) and within a country, China (Chen & Wang, 2013; Zhao et al., 2013), as well as change in green space provision over time (Huang et al., 2017; Zhao et al., 2013).

Thus, at the urbanized area or FUA level, higher human population density is associated with less tree cover and (at least for US cities) less percent open space. The competing desires—for nature but also for the benefits of biodiversity—suggests that there may be on average a trade-off between these two objectives. Three caveats are in order however.

First, the scientific knowledge of the shape of this trade-off curve remains imprecise. While there have been many papers that have examined aspects of this trade-off between nature and density, there are relatively few quantitative results. One partial exception is a qualitative study by UN-HABITAT that considered trade-offs around density, urban sustainability, and quality of life and suggested

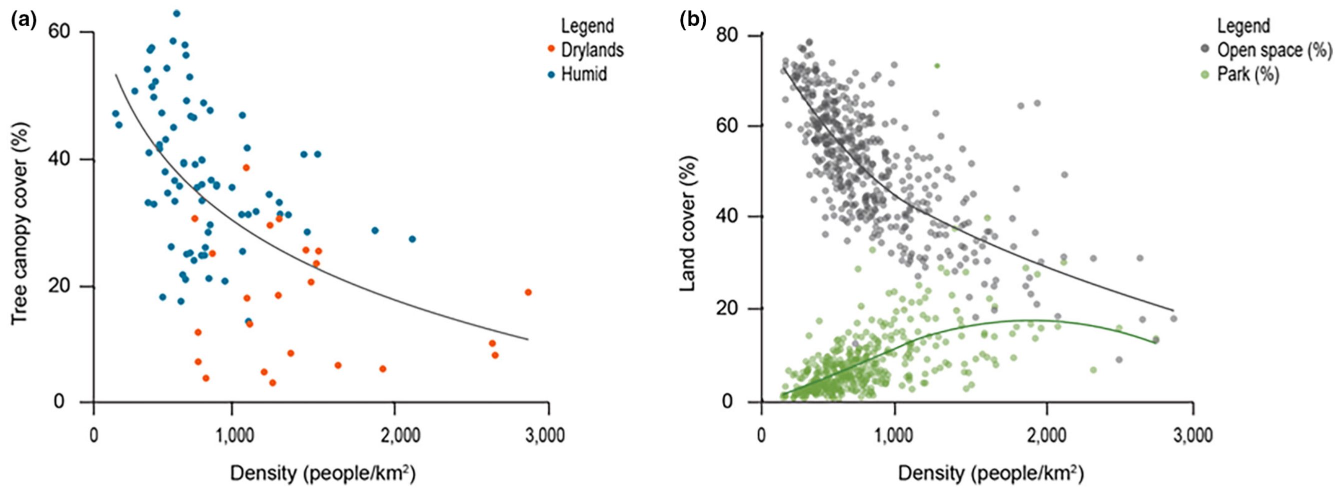

FIGURE 3 Trade-offs between density and nature in U.S. urbanized areas. (a) Population density in the 100 largest urbanized areas (U.S. Census Bureau, 2010) is negatively associated with tree canopy cover. Urbanized areas are divided into two climate types, based on their scores on the aridity index. Best-fit line is a log-linear regression. Data adapted from McDonald et al. (2021). (b) Population density in US urbanized areas is negatively associated with the amount of undeveloped 'Open space' nearby. However, the amount of publicly accessible protected area ('Park') appears relatively uncorrelated with density. Denser urbanized areas therefore have less open space but a greater fraction of it is publicly accessible. Best-fit lines are smoothing splines. Data adapted from Spotswood et al. (2021).

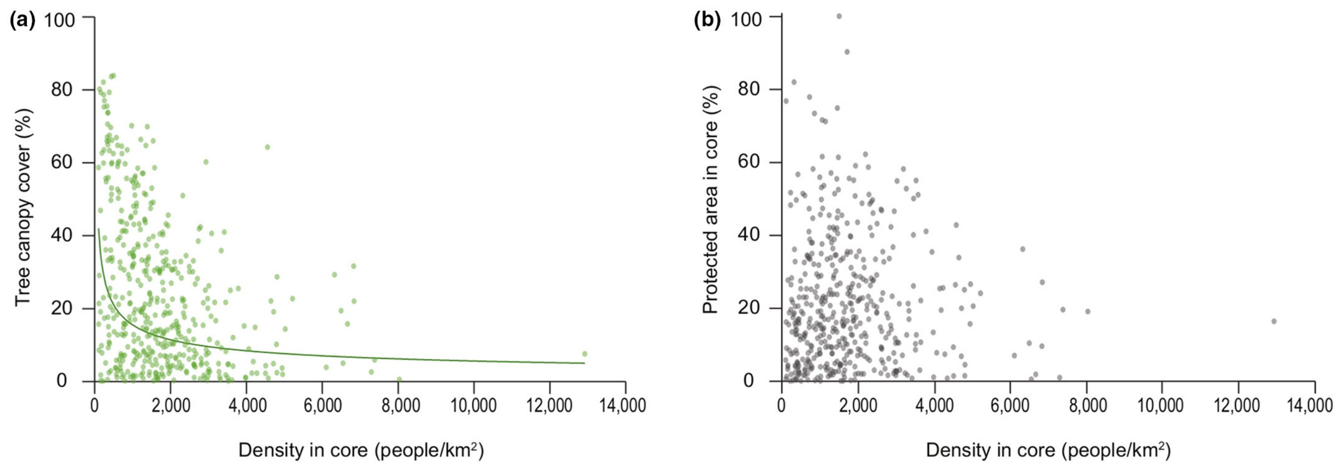

FIGURE 4 Trade-offs between density and nature in OECD functional urban areas (FUAs). (a) Population density is negatively associated with tree canopy cover. Best-fit line is a log–log regression. Data from the OECD atlas of regions and cities (Brezzi et al., 2012; OECD, 2021). (b) Population density in core FUAs is not significantly associated with the percent protected area in core FUAs.

1500–4500 people/km^2 as a reasonable compromise among trade-offs (UN-HABITAT, 2012).

Second, in different planning contexts and different urban areas, the relative importance of different benefits would vary, shifting the optimal solution. For instance, in a planning context that puts strong emphasis on greenhouse gas mitigation there may be a push toward greater urban area density, even at the expense of green spaces.

Third, when planners choose where to be along this trade-off curve between density and nature, it is important to keep in mind the issue of spatial scale. The distribution of green spaces within a city is also important. For any FUA at a given target density, there must be neighbourhoods and buildings that are greater than this density, often by orders of magnitude, to make up for areas within the FUA that are more sparsely settled or left as open space. An important consideration, in practice, then is who has closest access to urban nature, who might benefit most from it, and ultimately how equitable this is across society. These are city-level factors that must be considered by urban planners to ensure the best outcomes are achieved for both people and nature.

5 | DENSITY IS NOT DESTINY

By creative green interventions at the neighbourhood scale, one can avoid a strict trade-off between density and green space amount at the urbanized area or FUA level. The trade-off curves shown in Figures 3 and 4 are only the average relationship at the urbanized area level of analysis. There is significant variation around this mean at the level of neighbourhoods. For instance, Figure 5 shows the census block-level variation in urban tree canopy cover versus population density for one US city, San Francisco. At the US census block scale, while there is a statistically significant relationship between population density and urban tree canopy cover, the R^2 is only 0.05, implying that 95% of the variance in tree cover is not explained by density. The trade-off between population density and urban tree canopy cover at the US block-level is perhaps best thought of as variation in the range of possible urban tree canopy covers. At low densities (0–2000 people/km^2), the range of possible tree covers is quite wide, with observed values of 0% to above 85% urban tree canopy covers. Conversely, in very dense blocks (>10,000 people/km^2), blocks are observed with canopy covers ranging from 0% to 40%. While US block-level human population density does impose some constraints on the amount of tree canopy cover, there is a large window of possibilities. Similar arguments could be made for the relationship of other types of green spaces to density.

We assembled information on urban form, density, and green space for a few core FUAs (Figure 6). It is apparent that density is not destiny. Victoria-Gasteiz, for instance, has 1/7 the density of Barcelona but similar green space and tree canopy cover. There are also different patterns for green space and tree cover. Barcelona, for instance, which has the highest density of this small set of cities, has an urban tree canopy cover that exceeds that of London, the next most dense city. Washington, DC has the highest tree canopy cover of this sample of cities (43%), but significantly less green space than Vitoria-Gasteiz, a city of similar density.

Given the large variation in observed patterns of urban form, density, and green space, one question for those planning and designing at the neighbourhood scale thus becomes: How does one maximum the number of green spaces at a given density?

An examination of the outliers in Figure 5 is instructive. We define *brightspot* neighbourhoods as those that contain more green spaces given their density than at least three times the average tree canopy cover of other neighbourhoods of that density. Examination of brightspot neighbourhoods suggests there are two main pathways to creating a brightspot, which are not mutually exclusive.

First, brightspots often have a low built-area ratio for their population density. This can happen for a variety of reasons, and we discuss below specific interventions that can achieve this goal. But all

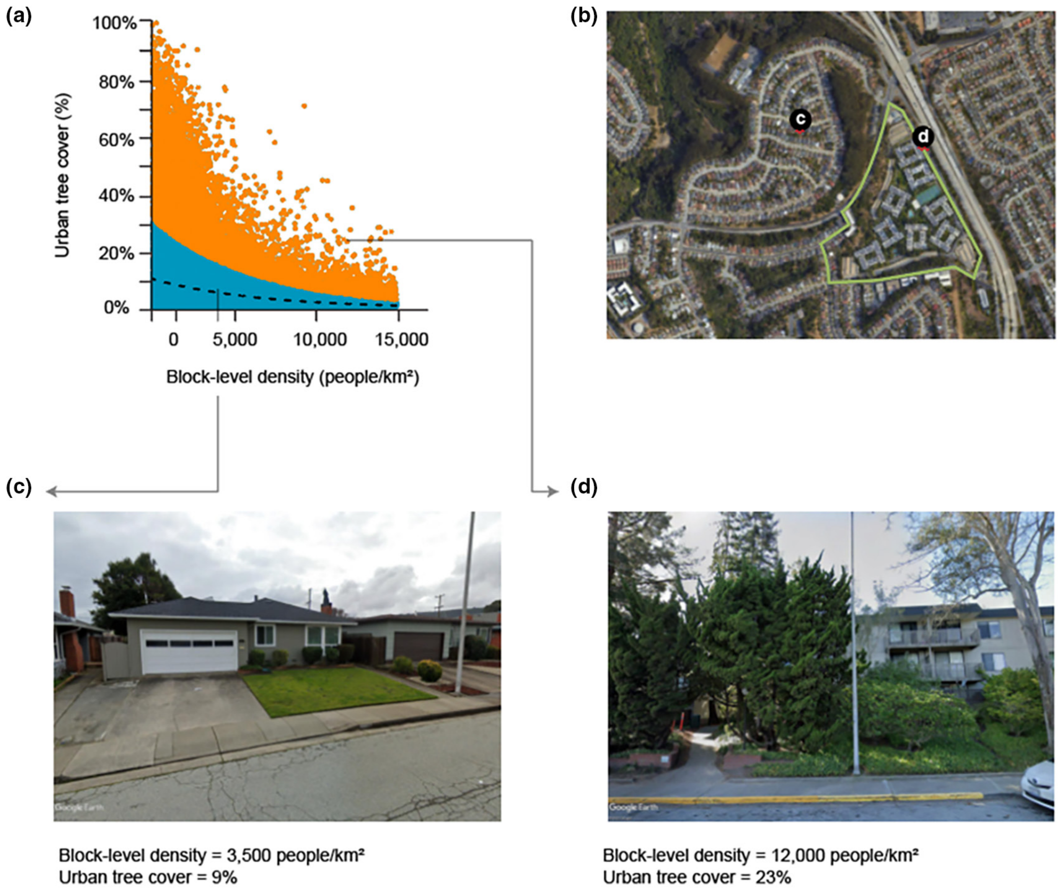

FIGURE 5 San Francisco urbanized area brightspots. (a) While urban tree cover is negatively correlated with population density, at the US Census block scale this correlation is weak. Of interest are brightspots, areas of relatively high density and urban tree canopy cover. Brightspots are shown in orange and are defined as blocks that have more than three times the urban tree canopy predicted given their density, using a log-linear regression. (b) An aerial photo of one brightspot (outlined in green, and labelled with 'd'), which lies next to a typical neighbourhood (labelled with 'c'). (c) Street view of typical neighbourhood. (d) Street view of brightspot.

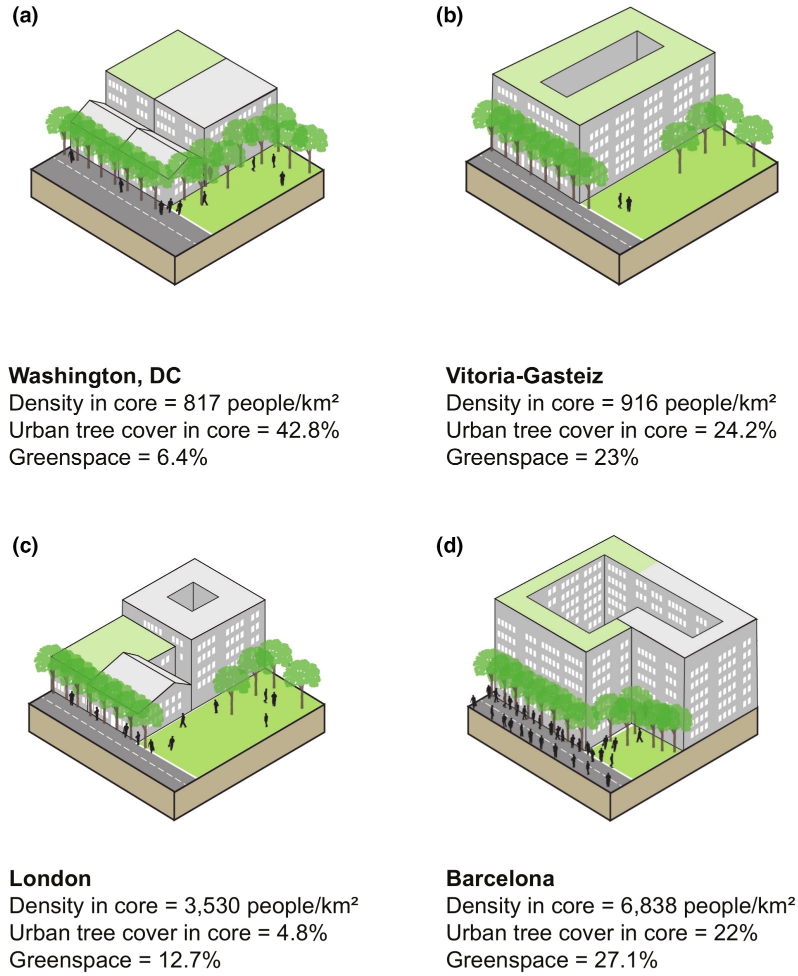

FIGURE 6 Global examples of different urban forms. Schematic drawings illustrating the urban form typical of a few cities, and the corresponding population density (core of functional urban area, FUA), percent greenspace (i.e. protected area), and percent tree canopy (core of FUA). Numerical data taken from OECD data (2021). These examples are not meant to be a statistically representative sample of cities, merely to illustrate a variety of urban forms and green space configurations.

else being equal, neighbourhoods with a lower built area ratio have more residential space for green spaces such as parks. Conversely, neighbourhoods with a higher built-up ratio use much of their land surface on human-dominated uses and have less space for nature. The first overarching pathway, therefore, to being a brightspot is to shrink the overall footprint of built-up area within a neighbourhood. Following the literature, we will call this the 'land sparing' strategy, since land must be spared from development to allow space for nature.

Second, brightspots sometimes incorporate green spaces that are on top of (or overhanging) built-up areas. Street trees for instance can be planted in a small strip of permeable surface but can substantially overhang pavement and other developed land. Green roofs are directly on top of a developed surface, by definition. This vertical stacking of nature on top of built-up area avoids a strict trade-off between more built-area-ratio (BAR) and more green spaces. Similarly, if for whatever reason there are vacant parcels that are undevelopable in the current neighbourhood context, restoring these to be green spaces does not compete with development for space. The second overarching pathway, therefore, is to maximize the sharing of space between nature and developed areas as much as possible. Following the literature, we call this the 'land sharing' strategy, since land is shared between nature and developed areas.

6 | URBAN FORM DETERMINES WHAT IS POSSIBLE AT THE NEIGHBOURHOOD AND PARCEL SCALES

One main reason for the large variation, at any given density, in US Census block-level tree canopy cover and open space is the variation in urban form. There are many different typologies and ways of measuring urban form (Redbridge Government, 2014). There is the *Intensity* of development, which can be measured by population density but also other measures such as floor-to-area ratio (FAR) or built-area-ratio (BAR). There is the *Scale* and *Grain* of development, such as the size of city blocks or buildings and the scale at which they recur. There are measurements of *Land use*, such as the relative proportion of residential versus commercial or industrial buildings at a site. *Transport* networks can take various shapes, and these shapes also play a crucial role in determining urban form.

One important dimension of *Land use* is building type(s). Again, this dimension can be classified in many ways, and we use a relatively simple terminology in this paper. Single-family detached homes use the most space per-capita of any building type but are commonly found in city suburbs and exurbs. Single-family attached homes (e.g. row houses) are a slightly denser pattern of residential settlement, often with characteristic small lawns and other open space immediately behind the row of buildings. Multi-unit apartment buildings have the greatest density and can be many stories tall in some cases. Multi-family buildings can take several forms (Per & Mozas, 2015): they can be point buildings, organized primarily around their vertical circulation with open space on all sides; they can be bar buildings, organized around a linear hallway on every floor; they can be towers (essentially point buildings above a certain height); or can be residential towers atop a multistory plinth that contains commercial or other uses. Commercial land-uses can similarly be found in large, multistory buildings, especially in the central business district, whereas industrial buildings tend to be massive flat single-story buildings or complexes of buildings.

Each of these building types can be arranged in a variety of urban forms. Zoning codes influence the way buildings on adjacent lots interact to form an urban block: when buildings are built such that similarly-sized abutting buildings enclose a shared set of open spaces in the block's interior, they may collectively form areas for green spaces around buildings (Bürklin & Peterek, 2017). Thus, for each of the building types there is a broad range of population densities and configurations that are possible. For instance, a single-family detached home with five residents could be placed on a large lot (e.g. 500 m^2) or a small lot (e.g. 150 m^2). These lot sizes imply a population density, at this parcel scale, of 100 people/ha and 333 people/ha, respectively, a difference of more than a factor of three. Commercial or industrial buildings do not have a direct link to residential population density, but the intensity of built form can be assessed in other ways such as FAR or BAR.

Of special importance in determining urban form and the residual space left for green spaces is the *Transport* network, and specifically the amount of road area. In older cities where the transport network was developed primarily to support walking or horse-drawn vehicles, the amount of road is relatively little. London, for instance, has on average 1.5 m of road per inhabitant (Dingil et al., 2018). Conversely, in cities that were designed with a large transport network, often created with the personal automobile in mind, this factor can be much larger. Atlanta, for example, has on average 8 m of road per resident (Dingil et al., 2018). Parking spaces for cars are also an important aspect of urban form. In many parcels, the inclusion of parking lots near multi-family apartments can consume a significant fraction of the parcel.

The *Intensity* of development, along with its *Scale* and *Grain* and the shape of the *Transport* network, determine the opportunities for green spaces that are independent of building typology—parks, riparian corridors and vacant lands. Such green spaces are possible to introduce in new districts but difficult to shoehorn into existing districts, simply because it is costly to remove buildings and transport infrastructure once constructed. Other green interventions such as green roofs are possible to add even within existing urban districts, both as retrofits to existing buildings and when doing new construction. Green roofs have additional benefits beyond biodiversity, including stormwater mitigation and energy efficiency (McDonald, 2015).

7 | INTERVENTIONS TO BECOME DENSE AND GREEN

In the previous section, we discussed the various urban forms, and how these forms shape the potentialities for green spaces in and near urban areas. We also began discussing a few green interventions that might add more green spaces to new and existing neighbourhoods. In this section, we more formally present a broader set of green interventions (Table 1), identified during our review of the literature on urban form and green spaces (Section 6). Key citations are included during the description of each green intervention below. The feasibility of each green intervention varies by the urban form typology presented in the previous section, with some green interventions only being possible for certain urban forms.

Below, we discuss each green intervention in turn, illustrating the use of green interventions with two contrasting case studies, Curitiba and Singapore. Both have been written about frequently in the planning literature (see citations below), but we wanted to suggest an interesting distinction between them. From Curitiba we highlight the use of green interventions that spare space for nature, in the sense that development opportunity is foregone on a site or neighbourhood to allow green spaces. From Singapore we highlight the use of green interventions that share space between people and nature, in the sense that these interventions increase green spaces without necessarily limiting the footprint of the developed area. While this dichotomy is useful for presenting the types of green interventions, we acknowledge that reality is considerably more complex, with both case study cities using a broad mix of the green interventions shown in Table 1.

7.1 | Curitiba: Innovative planning that spares space for nature

Curitiba is the largest city in southern Brazil. It is known for urban innovations that have been later adopted by other cities around the world, such as Bus Rapid Transit (BRT). The city has faced a dramatic urban growth since the 1970s, when the population was only 600,000, increasing to a population of approximately 2 million in 2020. Curitiba has a strong planning tradition with integration of land use with urban services, such as housing, green areas and especially transportation. The city has a radial growth along the arteries of Bus Rapid Transit (BRT) coupled with avenues.

Curitiba has well-integrated and functional green and blue urban infrastructure. The planning of Curitiba set aside land for natural parks (‘Preserve remnant patches’ and ‘Create managed parks’ strategy in Table 1), and as a result has 35 parks and more than 1000 conservation areas (Gustafsson & Kelly, 2016). The Curitiba urban plan aims at a gradual decline in density as you move away from the transportation arteries, but parks and other green areas cover a large part of the city with easy access through the efficient urban transportation system.

TABLE 1 Urban forms and green interventions

Green intervention	Single-family detached	Rowhouse	Multi-unit	Multi-unit over plinth	Industrial	Transport
Land sparing interventions (interventions generally take space from development)						
Preserve remnant patches	Low[a]	Low[a]	High	Medium	Medium	Medium
Maintain riparian corridors	Low[a]	Low[a]	High	Medium	Medium	Medium
Create managed parks	Low[a]	Low[a]	High	Medium	Medium[b]	Low
Build home gardens/backyards	High[c]	Medium[c]	Low	Low		
Create stormwater GI	High	High	Medium	Low	Medium	High[d]
Land sharing interventions (interventions do not generally take space from development)						
Greening vacant lands	High	Medium	Low	Low	Medium	
Instal green roofs/facades	Low[e]	Low[e]	Medium	Medium	High[f]	
Increase vegetation around perimeter	Low	Low	Medium	Low	Low	
Increase vegetation along streets/ROW						High

[a]Constrained by available space.
[b]Occasional opportunities to convert large industrial areas to parkland.
[c]Setbacks already set; available space gets smaller over time.
[d]Opportunity for widespread deployment; constrained by maintenance.
[e]Constrained by roof shape & structural limits of existing roofs.
[f]Typically large roof areas substantially increase potential benefits.
Within different urban forms, there are different green intervention types that are possible. This table shows a simple typology of urban forms (columns) crossed with a typology of possible green interventions (rows). The rating (high/medium/low) describes the degree to which that green intervention is possible with that urban typology class. Cells that are blank are where a green intervention is generally not possible or applicable within a typology class.

The city government has innovated and used green and blue infrastructure for other strategic functions, such as flood prevention, biodiversity protection, water quality conservation and carbon reduction. Public parks and lakes were planned along the rivers and lowlands ('Maintain riparian corridors' strategy in Table 2) which protect the city from risks of flooding during the heavy rains, common in many Brazilian cities during the rainy season. Curitiba has also created several incentives for greening private land. It has a system of Transferable Development Rights (TDRs) for protection of green areas in private land, besides social housing and heritage conservation. The TDRs make possible a good balance between density and green areas. The city also provides incentives for the creation of private natural heritage reserves (RPPN), and Curitiba is the city in Brazil with the largest number of RPPNs.

7.2 | Land sparing green interventions

For biodiversity preservation, maintaining remnant habitat patches over time is one key step (Table 1), especially for cities with sufficient governance capacity to plan and regulate land-use (Huang et al., 2018). This is especially true for urban avoider species, which may have been endemic to a particular locality and might be lost with the expansion of urban habitat (McDonald, M'Lisa Colbert, et al., 2018). Strategies to maintain remnant habitat patches (Table 2) can involve an outright ban on the conversion of nature habitat or implemented through zoning codes or development permitting regulations. Such a ban can be controversial politically, and more commonly, the public sector is involved in purchasing or setting aside land for public parks. For instance, in Curitiba, forest patches such as Bosque do Barigui (Lat −25.4167°, Long −49.3070°) were protected, providing relatively large patches of habitat within the urban fabric. Another way to finance land protection is through the sort of TDR system used in Curitiba, which discourages land conversion on some privately held land while compensating landowners through the creation of development rights with monetary value elsewhere.

Another important step for maintaining biodiversity is maintaining corridors of habitat in riparian areas (Table 1). These riparian areas are relatively high in biodiversity, often harbouring rare flora or fauna, and are long linear features that can be important for connectivity, for people and biodiversity. In many cities, various building and zoning codes prevent development near rivers (Table 2), while flood insurance programs theoretically make development in flood prone areas more expensive. These policies have the net effect of maintaining riparian habitat and reducing flood risk for people and property. Urban planners therefore often think of riparian corridors as linear features that can connect a row of parks or protected areas with walkways. For instance, Parque das Águas (Lat −25.4391°, Long −49.1464°) and other parks form a chain along the Iguaçu River in Curitiba, maintaining this river corridor and avoiding development in a flood prone area.

Another type of green intervention is to plan for and create parks and other green spaces, even on land that has been cleared and no longer maintains remnant habitat (Table 1). In many cities, setting

TABLE 2 Policies to support green interventions

Green intervention	Site-level policies	City-level policies	Main variables to improve ecosystem function
Land sparing interventions			
Preserve remnant patches	Zoning rules that discourage habitat conversion	Protect habitat in open spaces; tradable development rights.	• Patch size • Habitat quality • Invasive species suppression • Habitat heterogeneity
Maintain riparian corridors	Setback rules to protect riparian areas; building restrictions in floodplains	Protect/restore habitat along river corridors; urban planning to maintain connectivity of riparian corridors	• Width • Connectivity • Natural banks rather than channelized • Water quality
Create managed parks	Requirement for developers to set aside land for public parks	Urban planning to create public park network throughout city	• Park size • Vegetation type + structure • Intensity of human use + management
Build home gardens/ backyards	Green area fraction or other similar rules that require some portion of parcels to be green	Tree canopy protection ordinances; Programs to promote native plant plantings and high biodiversity gardens.	• Reduction of pesticide/herbicide application • Proportion of native planting • Addition of structural complexity (tree/shrub planting) • Reduction of organic matter removal
Create stormwater GI	Zoning and building rules that require stormwater capture onsite for new development or redevelopment	Impervious surface fees; municipal rain-garden programs	• Scale of implementation • Vegetation type • Proportion of native planting • Structural complexity
Land sharing interventions			
Greening vacant lands	Zoning and building codes that easily allow vacant/ underutilized lots to be converted to green areas	Public sector funds or private-sector incentives to green vacant lots	• Patch size • Soil type + compaction • Vegetation type + structure • Successional stage
Instal green roofs/facades	Building codes that allow greater density with green features; green area fraction rules.	Public sector funding for the creation of green roofs	• Soil depth (Intensive rather than extensive) • Soil type (influences nesting, stormwater mitigation) • Soil topography (influences habitat, heterogeneity) • Addition of structural complexity (grasses, forbs) • Proportion of native planting, mutualisms

TABLE 2 (Continued)

Green intervention	Site-level policies	City-level policies	Main variables to improve ecosystem function
Increase vegetation around perimeter	Building rules that require vegetation in setbacks and other required perimeter areas around a building; green area fraction	Programs to promote native plant plantings and high biodiversity gardens.	• Reduction of pesticide/herbicide application • Proportion of native planting • Addition of structural complexity (tree/shrub planting) • Reduction of organic matter removal
Increase vegetation along streets/ ROW	Programs/incentives to encourage citizen maintenance of vegetation in front of their homes	Municipal tree planting and maintenance programs	• Proportion of native planting • Design of tree pit • Longevity of trees • Degree of replacement upon mortality

This table shows possible policies to promote green interventions, at the site-scale or city-level scale. Note that these are just a selection of some of the most common policies, there are other possible policy routes to achieve the same outcome. Also shown are the main variables that can modulate the biodiversity and ecosystem function of the green intervention.

aside land for a park is a requirement when new neighbourhoods are proposed by developers (Table 2). Similarly, urban planners when creating a new district plan often include space for a park as a matter of best practice. Parks often contain distinct features that reflect the culture and context in which they are located. For example, Curitiba has Praça Osório (Lat −25.4331°, Long −49.2761°) and other plazas, often centered around a pedestrian area or fountain but ringed with trees and other natural features, a common way of constructing plazas in Brazil.

In many cities a large fraction of open space is private, and so the creation of home gardens and backyards on private land is an important way to provide green spaces to individual households (Table 1). This is especially true in suburbs or exurbs at low population density (Figure 3), when the majority of open space may be private. Many cities encourage the creation of gardens and backyards, intentionally or not, by limiting the BAR or FAR on the development of new parcels (Table 2). This forces a lower density pattern of settlement, which often allows more space for gardens and backyards. More directly, some cities have begun setting zoning and building codes around a 'green area fraction', a proportion of a parcel that must be green (including backyards and gardens, but also typically including green roofs). At a municipal level, many cities have tree and other vegetation protection ordinances, which make the clearing of these green spaces more difficult for developers. For instance, Curitiba and many other cities require permits from the city for removal of large, existing trees.

Finally, cities increasingly create stormwater green infrastructure (GI), green spaces that have as one of their primary purposes to encourage rainwater to infiltrate into the soil and thus mitigating the quantity or quality of surface stormwater runoff (Table 1). Stormwater GI may be a part of remnant patches, riparian corridors, or parks. In Curitiba, for instance, many of the protected areas are along riparian corridors, and serve a purpose of helping manage stormwater. Alternatively, it may be in small, constructed wetlands designed primarily to detain stormwater, sometimes in the public right of way such as in sidewalk berms and sometimes in backyards. Construction of such stormwater GI may be required by zoning or building rules or incentivized by the creation of an impervious surface fee or other financial incentives to increase landscape permeability (Table 2).

7.3 | Singapore: A dense city that shares space with nature

The Island City-state of Singapore has long been referred to as a Garden City. Today, Singapore stands out as an example of a high-density city with a focus on green space creation and maintenance. Singapore's current population of 5.5 million occupies a land area of 710 km^2 (essentially the entire island is a part of the FUA), resulting in a density of around 7800 persons/km^2. An estimated 47% of the island nation is in green cover, a percentage that has risen while population growth has increased.

Singapore has invested in nature in many ways and through many different initiatives, including 350 parks and 4 nature reserves; a program for converting engineered hard-surface streams into habitat-rich natural systems (an example of the 'Greening vacant lands' strategy in Table 1), the most notable example being Bishan-Ang Mo Kio Park (Lat 1.364°, Long 103.8441°); extensive tree planting and public landscaping throughout the city ('Increase vegetation along streets/ROW' strategy in Table 1); more than 360 km of pathways and trails in its Park Connector Network; more than 300 km in its Natureways network of wildlife corridors; and more than 1600 community gardens through its Community in Bloom program. A recently adopted Green Plan 2030 lays out ambitious plans and targets for the future, including new therapeutic gardens and a million tree-planning goal, among others (Choo, 2017).

Singapore has been especially noted for its innovations in vertical greenery, as most new growth and development in the city happens through high-rise towers. Through its Landscaping for Urban Spaces and High-Rises (LUSH) program, new buildings must replace ground-level nature with nature in the vertical spaces above. Many high-rise buildings commonly include sky parks, greenwalls and rooftop gardens and trees ('Install green roofs/facades' in Table 1). Under its landscape replacement policy developers must at least replace the nature one-for-one, but increasingly new green buildings in the city are including much more than that. Recent examples include the ParkRoyal Hotel (Lat 1.2858°, Long 103.8461°), providing 200% replacement nature, and the Oasia Downtown Hotel (Lat 1.2759°, Long 103.8442°), which replaces ground level nature by some 1200%, including through a living facade that boasts 14 varieties of flowering vines. Singapore NParks has a Skyrise Greenery division to support vertical greening. There are financial subsidies and annual Skyrise Greenery Awards to recognize design innovation and industry leaders.

7.4 | Land sharing green interventions

Often cities have lands that are underutilized and that can be converted into a green space without directly competing with development (Table 1). This kind of vacant land is not common in a densely settled city like Singapore, although the restoration of streams that were previously lined with concrete like in Bishan-Ang Mo Kio Park is one example. Another example in Singapore is reclaimed land, which may be allowed to naturally reforest for several decades even if it is ultimately slated for development for housing (Gaw & Richards, 2021). In many shrinking or deindustrialized cities like Detroit, there is more vacant land that can be reused. In these cities, there are often public sector funds and incentives for the private sector to green vacant lots, as well as changes to the zoning and building codes that make creative reuse of previously developed sites possible (Table 2).

Green roofs and facades are a straightforward example of sharing space between human development and green spaces, in the sense that a square meter of green roof or green facade does not reduce developable area in a city (Table 1). Singapore has a strong system of incentives for creating green roofs, using a combination of regulatory mandates as well as public sector financing. Some cities use the zoning and building code to create value in green roofs, rather than using public sector financing (Table 2). For instance, in Chicago developers that construct a building with a green roof get an increase in the FAR allowed by regulations, increasing the amount of developable space and providing a real monetary benefit to developers, which often outweighs the cost of green roof construction.

Another example of sharing space between human development and green spaces is the maximization of vegetation around the perimeter of buildings and other developed features on a parcel (Table 1). Taken to an extreme, building and zoning codes that require large setbacks and create large perimeter spaces may decrease developable space, but even in dense urban areas there tend to be perimeter spaces that can become green spaces that provide significant benefits to those living in and using a building. Cities often require building perimeters to be properly landscaped or set requirements for the green area fraction required when developing a parcel (Table 2). Municipal programs, or those of non-profit groups, can seek to promote native plantings and increase the biodiversity value of these perimeter areas.

One of the most important ways to increase green spaces in a city is to increase vegetation along streets and other parts of the public right of way (Table 1). This is particularly important for urban tree canopy cover, which can overhang over impervious surfaces like concrete and pavement, leading to a straightforward example of sharing space between human development and green spaces. This shading of impervious surfaces by trees also has important benefits for reducing the urban heat island effect and helping mitigate the flow of stormwater into stormwater systems. A substantial fraction of the area of a city can be in the public right of way of the Transport system. For instance, Manhattan in New York City has around 36% of its area in the public right of way, and an UN-Habitat report suggests new neighbourhoods have at least 30% of their area in the public right of way to ensure adequate transport (UN-Habitat, 2013). As this land is already publicly owned, it represents an enormous opportunity for green spaces, if they can be made consistent with the other transportation needs of the right of way. In most cities, tree planting in the right of way is the responsibility of the public sector (Table 2). For instance, in Singapore there is now a goal of planting an additional 1 million trees, many (but not all) along roads. The maintenance of tree canopy cover, however, varies, with some cities placing this under municipal control, while others try to enlist volunteer nearby private landowners to help maintain trees in the public right of way.

8 | TOWARD A DENSER AND GREENER URBAN FUTURE

Our research found evidence, both in the literature and in empirical data for the United States and the OECD, of a negative association between human urban population density and the number of green spaces. This negative association with density appears to occur for urban tree canopy cover as well as (for the US) open space. The association is at moderate strength at the FUA or urbanized area scale but is relatively weak at the US Census block (neighbourhood) scale. We emphasize therefore that this association is not a strict trade-off at the neighbourhood scale, and there are neighbourhoods that contain more or less nature for a given population density.

There are countervailing relationships that one could use to argue for or against urban population density. Urban planners must of course consider the unique local goals and context when evaluating the appropriate target population density for a project. Different local goals or preferences might lead to different selected target population densities. Finally, significant variation in density at the neighbourhood scale leaves many opportunities for green spaces even in urbanized areas with relatively high urbanized-area population density.

We listed in this paper multiple green interventions, ways to create neighbourhoods that are dense and green. These are proven interventions, implemented in multiple places around the world. The interventions that are applicable in each neighbourhood or parcel depends on the urban form as well as the political, social and economic context. Planners and policymakers can choose which specific green interventions make sense, given that local context (Mansur et al., 2022). There is also significant scope for new, yet undiscovered innovations that could promote both biodiversity and human outcomes. In a sense, there can be no excuse for designing neighbourhoods that lack abundant nature: the tools are out there to create dense and green spaces to live in.

Nevertheless, many urban areas are not achieving this potential. For instance, one global study suggested only 13% of urban dwellers have enough urban tree canopy near their homes to achieve mental health benefits (McDonald, Beatley, et al., 2018). This relatively low amount of urban nature persists despite a global trend toward less dense urban areas since the 1970s (Güneralp et al., 2020). Given the clear importance of urban density toward sustainability and reducing greenhouse gas emissions, this is a worrying trend. There is thus an urgent need for cities to create urban neighbourhoods that are both dense and green. Indeed, encouraging data from Denmark show it is possible for cities to increase both in density and greenness over time, with the right urban planning policies (Samuelsson et al., 2020). Humanity is building the urban neighbourhoods of the future, today. As a species, we will choose the future urban world we get. Another urban world, both verdant and lively and dense, is possible, if we choose to take advantage of the available green interventions and create it.

AUTHOR CONTRIBUTIONS

Robert I. McDonald, Erica Spotswood and Erin Beller conceived of the project, and organized a working group of all co-authors; Robert I. McDonald and Erica Spotswood led the project; Myla F.J. Aronson and Nicholas Pevzner created Tables 1 and 2; Timothy Beatley and José Antonio Puppim de Oliveira created case studies of Singapore and Curitiba, respectively; Lauren Stoneburner and Stephanie Panlasigui analysed data in Figures 4 and 5; Micaela Bazo and Joe Burg designed the figures; and all co-authors participated in the writing of the manuscript.

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CONFLICT OF INTEREST

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DATA AVAILABILITY STATEMENT

All data shown in this paper are derived from previously published datasets, as listed in the methodology. Copies of all derived datasets we used in our analysis can be found on Dryad Digital Repository https://doi.org/10.5061/dryad.s4mw6m99g.

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