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Linking urban planning practices to health outcomes: A review on indicators of public space and land use, and their health relevance

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LIST OF ABBREVIATIONS

BS	Blue Space
CVD	Cardiovascular Diseases
DET	Data Extraction Tool
ES	Ecosystem Services
GS	Green space
LBW	Low Birth Weight
NCD	Non-Communicable Disease
PA	Physical Activity
PM	Particulate Matter
POS	Public Open Space
QL	Qualitative
QN	Quantitative
UN	United Nations
WHO	World Health Organization

EXECUTIVE SUMMARY

Introduction: According to the United Nations, by 2050 nearly 70% of the global population will be living in urban environments. Increasing awareness of the connections between cities and health has driven research towards the study of urban design and its metrics. However, the lack of communication between the public health and urban planning communities, and the absence of standardized indicators hinders the integration of 'health' into the urban planning agenda.

Aim: Identify existing urban planning health indicators with defined benchmarks to improve urban planning and public health practices.

Methods: A systematic review was performed. For review inclusion, studies had to provide an urban planning indicator with a defined benchmark and an established relation to human health. Selected studies were assessed with a data extraction tool on their relationship between the indicator, the health pathway and the associated health outcome.

Results: 18 indicators (7 quantitative, 11 qualitative) were identified within 54 eligible studies. Identified indicators were related to the natural or built environment. Natural environment indicators focused on (1) green space and (2) blue space, while built environment indicators related to (1) public open space, (2) urban environment, (3) city fabric and (4) land use.

Conclusions: Only few existing quantitative urban planning indicators have been identified that can potentially be used to integrate 'health' into urban planning policies. A distance of ≤300 m to a green space seems to be the most advanced and applied indicator in epidemiological studies, and was defined as a World Health Organization guideline. Qualitative indicators provide areas for discussion, as no health-promoting benchmarks have been defined yet. Collaborative research and practice of the public health and urban planning communities are needed to understand the relation between cities and health, and to provide standardized measures that enable health promoting urban planning outcomes.

Keywords: cities, built environment, green space, health, indicators, urban planning.

1. INTRODUCTION

According to the United Nations, by 2050 nearly 70% of the global population will be living in urban environments (United Nations, 2014). Worldwide, industrialization has driven humanity towards urban settings, as cities represent important drivers of socio-economic development. In cities, individuals have greater access to commercial activities, goods and services (including employment, education and health care) as well as enhanced opportunities for cultural and political participation (United Nations, 2014).

Nevertheless, urban settings can also have negative effects on the health and well-being of individuals, as well as on the social fabric of communities (Badland et al., 2014; Jacobs, 1961). Citizens are more prone to sedentary lifestyles and lower quality diets, as their jobs and means of transportation tend to require less physical activity, and their access to unhealthy food is easier (Cecchini et al., 2010; Ewing, Meakins, Hamidi, & Nelson, 2014; Oliver et al., 2015; Smit et al., 2016). Moreover, urban fabrics are typically made up of dense constructions with large amounts of public space being assigned to accommodating motor traffic. Consequently, only few public, green and blue spaces are available in cities that can be used for recreational and community activities. Social interactions happening in public open spaces (POS) have been shown to be a protective factor for mental health and well-being (WHO Europe, 2016).

With general space scarcity, city expansion and gentrification processes taking place, worldwide residents might be forced to relocate to suburban environments that are often sprawled and imply car-dependency and long commuting times. As a consequence, dense motor traffic in cities results in environmental pollution and poorer health outcomes. Indeed, high levels of air pollution in cities have been associated with premature mortality and different morbidities (Athens, Bekkedal, Malecki, Anderson, & Remington, 2008; Corburn, 2015; Nieuwenhuijsen, 2016). Likewise, noise pollution has been linked to mortality (Halonen et al., 2015), cardiovascular disease (CVD), hearing impairment, annoyance and sleep disturbance (Corburn, 2015; Koprowska, Łaszkiewicz, Kronenberg, & Marcińczak, 2018; WHO, 1999; WHO Europe, 2011). Moreover, cities have developed an increased temperature phenomenon known as the Urban Heat Island (UHI) effect, characterized by higher surface temperatures in urban areas rather than the surrounding rural areas (Jiao et al., 2017). The UHI has been associated with mortality, adverse health outcomes and negative environmental impacts (Corburn & Cohen, 2012; Taslim & Shafaghat, 2015).

Nowadays, urban planners have a great responsibility when it comes to designing cities and initiatives that are prepared for increasing urban populations and the challenges aforementioned. However, changing the way cities are planned, built, and managed requires a multidisciplinary approach (Giles-Corti et al., 2016), as the future development of cities should consider the interrelationship between the built environment and citizens' health and well-being (Marzbali, Abdullah, Javad, & Tilaki, 2016; Nieuwenhuijsen, 2016; Rydin et al., 2012).

Studies have tried to address the relationship between different natural and built environments and the development of health outcomes, providing a wide variety of relevant literature (Annerstedt van den Bosch et al., 2016; Gascon et al., 2016; Giles-Corti et al., 2016; Hooper, Boruff, Beesley, Badland, & Giles-Corti, 2018; Nieuwenhuijsen, Khreis, Triguero-Mas, Gascon, & Dadvand, 2017). However, when it comes to health-promoting urban planning practices, there is a lack of standardized and *quantitative* indicators that integrate health components into the planning process. Currently, epidemiological evidence fails to reach urban planners and policy-makers in an accessible way, resulting in 'health' still not being a priority issue on the urban planning agendas.

In the past, studies tried to identify indicators of urban planning, aiming to characterize the relation between urban living and health outcomes (Prasad et al., 2015; Webster & Sanderson, 2013a). However, to our knowledge, the quest for standardized indicators (Badland et al., 2014; Pineo, Glonti, & Rutter, 2018; Prasad et al., 2015; Rothenberg et al., 2015; Webster & Sanderson, 2013a), has so far not provided indicators with defined benchmarks.

Therefore, there is a need for indicators with defined benchmarks that connect urban planning practices with expected health outcomes, as there is a need for providing data-driven and evidence-based solutions. In order to provide a better understanding for the urban planning community on the potential health consequences of their planning practices, we aimed to systematically review the literature on existing urban planning health indicators with defined benchmarks.

2. METHODS

This review was performed following the PRISMA guidelines for reporting of systematic reviews (Moher et al., 2009). We focused on peer-reviewed articles published in Scopus, Science Direct and PubMed. The search was further complemented by grey literature (policy documents, manual searches and expert consultation) in order to provide a more robust identification of the relevant indicators. Two independent researchers (LDO and NM) performed all levels of screening and discrepancies were resolved by consensus.

2.1 Conceptual framework

A conceptual framework was developed for this project, in collaboration with a complementing research team (HV & DRR)[1] focusing on indicators of transport planning and their health relevance (see **Figure 1**). The idea behind this framework was to identify key categories of indicators of urban and transport planning to be captured with the defined and applied search term combinations and to be assessed on their health relevance.

2.2 Search terms

Search terms were defined and included 'urban planning', 'indicator' and 'health'. The search term combinations were adjusted in each database (see **Table 1**). Applied filters in Scopus and Science Direct were: 1) peer-reviewed journal articles (i.e. no books or book chapters), 2) time of publication between 2008 and 2018, 3) English language, and 4) restriction of certain research areas (e.g. no 'transportation' and no 'food'). Search term combinations and applied filters can be found in more detail in **Table 1**.

2.3 Eligibility criteria

For review inclusion the study had to contain: 1) a clearly defined urban planning indicator 2) with a defined benchmark and 3) an established relation to human health. To provide a more comprehensive overview of the study selection process the PRISMA Flow diagram was used and annexed to the results as **Figure 2.**

If an article studied multiple urban planning indicators, they were all reviewed and assessed on their indicator definition, the benchmark applied and their strength of evidence of being linked to human health outcomes.

2.4 Data extraction, synthesis and strength of evidence

Essential data of eligible studies were extracted into a Data Extraction Tool (DET) for descriptive and analytic synthesis. The DET included four different sections: 1) general information on the study (i.e. title, authors, year of publication, country), 2) discussed urban planning policy, 3) applied urban planning indicator with defined benchmark, 4) impact on human health (i.e. health pathways and health endpoints) (**Table 2**).

Additionally, the DET assessed the strength of evidence of the identified indicators. Using a scale from 1 to 5, indicators providing 1) an urban planning policy measure, 2) a clear definition, 3) a defined benchmark, 4) multiple applications across the literature and 5) recognition by international authorities, were considered the strongest ones.

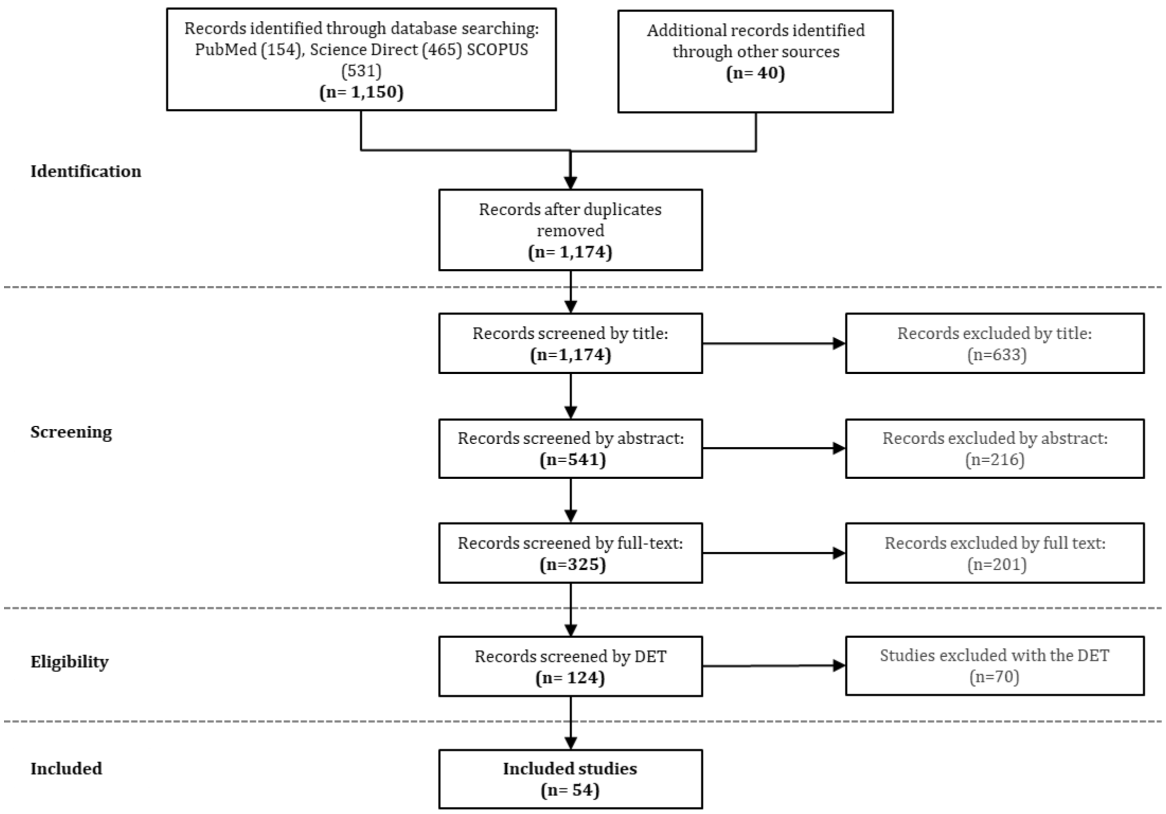
[1] HV and DRR developed a similar project focused on transport planning indicators and their health relevance as part of a different but complementary Master Final Project

The literature search, study selection, data extraction and synthesis were performed between January and May, 2018.

3. RESULTS

Initially, the literature search identified 1,190 studies: 1,150 were found in scientific databases and 40 articles were found in the grey literature. After eliminating duplicates, 1,174 studies were screened by title, 541 studies were screened by abstract, and finally 325 studies were screened by full-text. 124 studies were included to be fully assessed with the DET, and finally 54 were included in the review (**Figure 2**).

Figure 2. Flow diagram

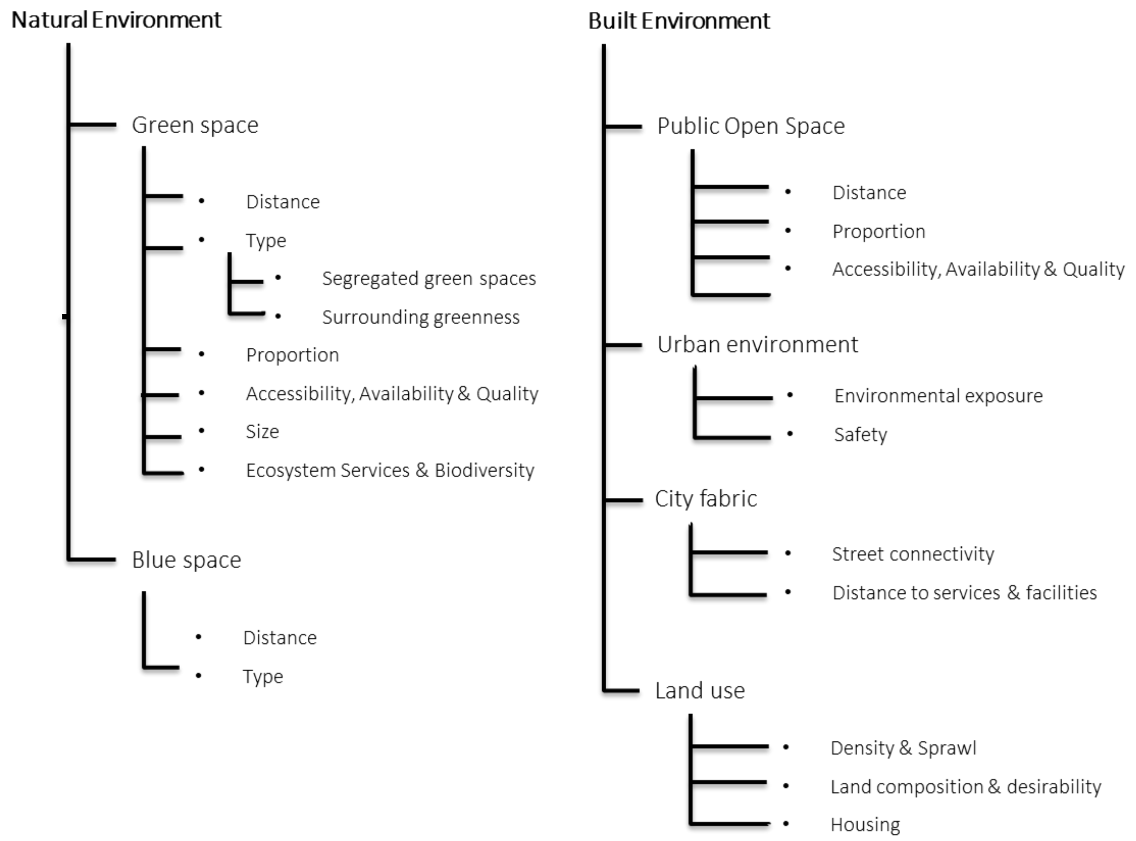


By the end of the screening procedure, 124 studies were included to be fully assessed with the DET, as these 124 studies appeared to comply with the primary literature review objective. A subsequent in-depth eligibility screening, including the application of the strength of evidence scale and determining indicators with a strength of evidence score ≥3 as eligible, resulted in 54 eligible studies that were finally included in the descriptive and analytic synthesis of this systematic review. The 54 eligible identified studies not only included an urban planning policy measure, an indicator and a relation to human health, but they also provided a defined benchmark, and in the best cases: 4) were applied multiple times across the identified literature and 5) were officially recognized by international authorities.

3.1. Descriptive results

From the 54 identified studies, 18 different urban planning indicators were pinpointed (see **Table 3**). Indicators were divided in two broad categories according to the environment they discussed: (1) natural environment and (2) built environment. These two broad categories had different subcategories according to the following taxonomy (**Figure 3**):

Figure 3. Taxonomy of identified urban planning indicators with health relevance



3.1.1. Natural environment

The identified natural outdoor environment indicators addressed (a) green space or (b) blue space. The green space subcategory was the main area of discussion and had six different indicators: 1) '*distance*' (n=30), 2) '*type*' (n=12) 3) '*proportion*' (n=9), 4) '*accessibility, availability & quality*' (n=9), 5) '*size*' (n=8), and 6) '*ecosystem services & biodiversity*' (n=7). Likewise, blue space was considered as a subcategory of natural environment and had two identified indicators, namely '*distance*' (n=4) and '*type*' (n=1).

3.1.2. Built environment

Measures connected to built environment were divided into four subcategories: (a) public open space (POS), (b) urban environment, (c) city fabric, and (d) land use. POS were measured by three different indicators: 1) '*distance*' (n=6), 2) '*proportion*' (n=1) and 3) '*accessibility, availability & quality*' (n=2). Urban environment had two indicators: 1) '*environmental exposures*' (n=8) and 2) '*safety*' (n=4). City fabric was measured by two different indicators: 1) '*street connectivity*' (n=5), and 2) '*distance to services & facilities*' (n=5). The land use subcategory was defined by three different indicators: 1) '*density & sprawl*' (n=6), 2) '*land composition & desirability*' (n=5) and 3) '*housing*' (n=2).

3.1.3. Study characteristics - setting and publication period

From the 54 identified studies, most of the studies were conducted in European settings (n=27). Other settings were North America (n=9), East Asia (n=5), Australia (n=5), Latin America (n=3) and West Asia (n=2). Three included WHO reports (n=3) were considered as global reviews and were not conducted within any specific regional setting.

Most included studies were recently published, as identified by the year of publication: 2018 (n=4), 2017 (n=12), 2016 (n=13), 2015 (n=5), 2014 (n=2), 2013 (n=2), 2012 (n=3), 2011 (n=1), 2010 (n=4), 2009 (n=5), 2008 (n=1), 2005 (n=1), 1999 (n=1). Despite the review inclusion criteria of study publication within the last 10 years (2008 to 2018), two older policy documents were identified through manual searches that were decided to be included, as they provided the international WHO guidelines for air and noise pollution. For more information on the settings and publication periods, see **Table 4**.

3.2 Analytic results

Information obtained from each study with the DET is summarized in **Table 5**. Studies providing more than one indicator, as it was usually the case, were assessed on all of the indicators they provided.

3.2.1 Natural environment

Indicators of *natural environment* focused on both, green space and blue space. The most common indicator of green space was '*distance',* followed by '*type*' and *'proportion'.*

The indicator of 1) '*distance*' to green space has been applied since 2009. '*Distance*' was measured by all studies (n=30) in terms of space (i.e. meters/ miles from a given location to the green space) (Akpinar, 2016; Annerstedt et al., 2012; Annerstedt van den Bosch et al., 2016; Aytur, Jones, Stransky, & Evenson, 2014; Bostrom, Shulaker, Rippon, & Wood, 2016; Browning & Lee, 2017; Christian et al., 2017; Coombes, Jones, & Hillsdon, 2010; Coppel &

Wüstemann, 2017; Dzhambov & Dimitrova, 2015; Ekkel & de Vries, 2017; Fang, 2017; Gómez et al., 2010; Grazuleviciene et al., 2015; Hooper, Knuiman, Foster, & Giles-Corti, 2015; Huang, Yang, Lu, Huang, & Yu, 2017; Kabisch, Strohbach, Haase, & Kronenberg, 2016a; Kaczynski et al., 2016a; Koprowska et al., 2018; Lackey & Kaczynski, 2009; Liu, Li, Xu, & Han, 2017; Maas et al., 2009; Ngom, Gosselin, Blais, & Rochette, 2016; Picavet et al., 2016; Schipperijn et al., 2010; Shen, Sun, & Che, 2017; Smith et al., 2017; Stigsdotter et al., 2010; WHO Europe, 2016; Wüstemann, Kalisch, & Kolbe, 2017). Six studies additionally measured '*distance'* in terms of time (minutes walking from a given location to the green space) (Bostrom et al., 2016; Coombes et al., 2010; Fang, 2017; Schipperijn et al., 2010; Shen et al., 2017; WHO Europe, 2016).

Concerning '*distance'* to green space, common buffers have been applied in European settings: ≤ 100 m, ≤ 300 m, ≤ 500 m and ≤ 1 km. However, 11 studies included distances >1 km in their analyses (Akpinar, 2016; Browning & Lee, 2017; Christian et al., 2017; Grazuleviciene et al., 2015; Hooper et al., 2015; Kaczynski et al., 2016a; Lackey & Kaczynski, 2009; Maas et al., 2009; Schipperijn et al., 2010; Shen et al., 2017; Stigsdotter et al., 2010). Four studies originating from North American settings used '*distance'* in terms of miles, namely ≤ 0.5 mi and ≤ 1 mi (Aytur et al., 2014; Bostrom et al., 2016; Kaczynski et al., 2016a; Lackey & Kaczynski, 2009). Finally, studies originating from Australian and Chinese settings explored '*distances'* of ≤ 400 m, ≤ 800 m, ≤1 km and ≤ 1.2 km (Christian et al., 2017; Fang, 2017; Hooper et al., 2015; Liu et al., 2017; Shen et al., 2017)

The proposed and applied benchmark for the indicator of '*distance'* by the WHO Regional Office of Europe is a '*distance'* ≤ 300 m to a green space (WHO Europe, 2016). As it can be seen in Table 5 this benchmark appears in the included studies since 2010, but has increasingly been applied since 2016.

The second most commonly applied indicator was 2) '*types'* of green space (n=12). '*Types'* of green space were understood either as a '*segregated green space'* (i.e. park) or '*surrounding greenness'*. In terms of '*types* of *segregated green spaces'* - parks, different studies discussed diverse typologies of parks relating to their size (Christian et al., 2017; Hooper et al., 2015), their natural categorization (e.g. countryside, natural small area, backyards, vacant lots, forests) (Ekkel & de Vries, 2017; Graça et al., 2018; Ngom et al., 2016; Schipperijn et al., 2010; Smith et al., 2017; Wüstemann et al., 2017), how they are being used for different activities (e.g. sports or fairs) (Graça et al., 2018; Ngom et al., 2016), and their 'ownership' relating to the difference between public or private spaces (Peña-Salmón & Rojas-Cadelas, 2009). Meanwhile, studies looking into '*type*s of *surrounding greenness'* focused on the number of trees (Bahadure & Kotharkar, 2018; Kardan et al., 2015), tree canopy cover (Wüstemann et al., 2017) and increases of residential greenness (Gascon et al., 2016b).

3) '*Proportion'* of available green space was measured in all studies (n=9) as m^2/ inhabitant (Akpinar, 2016; Fang, 2017; Hino, Reis, Sarmiento, Parra, & Brownson, 2011; Padilla, Kihal-Talantikit, Perez, & Deguen, 2016; Peña-Salmón & Rojas-Cadelas, 2009; Rey Gozalo, Barrigón

Morillas, González, & Moraga, 2017; Senanayake, Welivitiya, & Nadeeka, 2013; WHO, 2012; Wüstemann et al., 2017). Studies applying the '*proportion*' indicator used different benchmarks ranging from 3.25 – 52 m^2/ inhabitant; however five studies commonly used a benchmark of 9 - 10 m^2/ inhabitant (Akpinar, 2016; Padilla et al., 2016; Peña-Salmón & Rojas-Cadelas, 2009; Rey Gozalo et al., 2017; Senanayake et al., 2013).

The green space indicators of 4) '*accessibility*, *availability & quality*' focused mainly on the number of desired and undesired amenities and aesthetic features within a green space, such as the number of lights, water fountains, fitness zones or restrooms (Aytur et al., 2014; Bostrom, Shulaker, Rippon, & Wood, 2017; Kaczynski et al., 2016a), or the number graffiti (Dzhambov & Dimitrova, 2015; Kaczynski et al., 2016a). Moreover, '*availability*' was also measured by the percentage (%) of green space available and the number of persons practicing different activities in the green space (Huang et al., 2017; Ward Thompson, Aspinall, Roe, Robertson, & Miller, 2016). As for the '*quality*' of green space, there was an additional measure considering the characteristics of green space being "serene", "spacious", "wild", "cultural" and "lush" (Annerstedt et al., 2012).

Additionally, the indicators of 5) '*size*' of green space identified different '*sizes*' of green space and therefore is closely related to the '*type*' of green space indicator. A 2016 study from Canada discussed benefits from green spaces ranging between 2.5 m^2 (i.e. patches of green space and therefore relating to '*surrounding greenness*') to 720 km^2 of '*segregated green space*' (i.e. urban forests) (Ngom et al., 2016). Another study of the same year, applied a '*size*' of ≥ 2 hectares (Kabisch et al., 2016a). Other studies commonly explored '*sizes*' of ≥1 hectare (Annerstedt van den Bosch et al., 2016; Ekkel & de Vries, 2017; Huang et al., 2017) and one study explored benefits of green space '*sizes*' between ≤ 0.25 and ≤ 0.5 hectares (Smith et al., 2017). The WHO applies and recommends a greens space '*size*' of ≥ 0.5 hectare (WHO Europe, 2016).

Finally, 6) '*ecosystem services* & *biodiversity*' indicators were identified within the green space category. '*Ecosystem services*' were addressed through the Normalized Difference Vegetation Index (NDVI), a graphic indicator that detects photosynthetic properties of already existing vegetation, and quantifies the "greenness" of areas between -1 and 1, with the latter being the greenest level. (Ekkel & de Vries, 2017; Huang et al., 2017; Senanayake et al., 2013; Smith et al., 2017; WHO Europe, 2016). Another study related to '*ecosystem services*' reviewed the CO_2 absorption capacity of green space (Peña-Salmón & Rojas-Cadelas, 2009). Lastly, '*biodiversity*' in green spaces was discussed by one study through several features: tree density, tree species density, diameter of breast height, tree leaf area, tree leaf biomass, and the Simpson's diversity index on species dominance (a common index used in ecology to quantify the biodiversity of species in a habitat) (Graça et al., 2018). These structural variables of trees were considered by the ecosystem services they provided, mainly climate regulation, water flow regulation and air purification.

Only two natural environment indicators linked to blue space were identified, namely 1) '*distance*' and 2) '*type*' of blue space. Three studies proposed different buffers of '*distance*' from a given location to a blue space: ≤ 300 m; ≤ 500 m; ≤ 1 km (Smith et al., 2017), < 300 m; 300 m–1 km; 1–5 km; > 5 km (Schipperijn et al., 2010) and ≤ 1 km; 1–5 km; 5–20 km; 20–50 km; > 50 km (Wheeler, White, Stahl-timmins, & Depledge, 2012). One study studied a specific '*distance*' of ≤ 1600 m to a blue space (Christian et al., 2017). In addition, one of the studies distinguished between the different '*types*' of blue spaces: 'fresh inland water' referring to standing fresh water bodies like lakes and ponds or linear water bodies like rivers and canals and 'marine-coastal water' referring to salt water bodies like seas and oceans (Smith et al., 2017).

3.2.2 Built environment

Built environment indicator categories included: a) POS, b) urban environment, c) city fabric and d) land use.

For a) POS the most commonly applied indicator was 1) '*distance*' (from a given location to the POS). Studied '*distances*' ranged between ≤ 400 m and ≤ 1km (Bahadure & Kotharkar, 2018; Hino et al., 2011; Hooper et al., 2018, 2015; Koohsari, Kaczynski, Giles-Corti, & Karakiewicz, 2013; Sugiyama, Thompson, & Alves, 2009); '*distance*' to a POS was also measured by one study in terms of time, as ≤ 10 minutes' walk to the POS (Sugiyama et al., 2009). 2) '*Proportion*' was discussed by one study in terms of necessary 20-40 m^2/ inhabitant of *POS* (Bahadure & Kotharkar, 2018), while 3) '*accessibility, availability & quality*' were discussed as the presence of good quality walking paths leading to a *POS* (Sugiyama et al., 2009), the number of POS available in a given area (Koohsari et al., 2013), and the "pleasantness" of a POS according to the number of facilities provided (e.g. toilets and shelter) and its capacity of fulfilling different user needs and engaging users in different activities (Sugiyama et al., 2009).

The subcategory of b) urban environment was discussed through two indicators: 1) '*environmental exposures*' and 2) '*safety*'. Three studies of 1) '*environmental exposures*' focused on different *noise* exposure benchmarks, ranging between 45 and 65 dB according to different land uses and time of the day (Bahadure & Kotharkar, 2018; D'Alessandro & Schiavoni, 2015; Koprowska et al., 2018). To complement noise exposure indicators, the WHO official guidelines for community noise and night time noise were also included through the manual search (i.e. ≤ 55 dB day time and ≤ 40 dB night time) (WHO, 1999; WHO Europe, 2009). *Air pollution* was addressed in terms of over the threshold levels of particulate matter (PM), ozone, nitrogen oxides (NO_2) and sulfur dioxide (SO_2) by two studies (Athens et al., 2008; Senanayake et al., 2013), and by WHO official guidelines for air quality (i.e. $PM_{2.5}$: 10 μg/m^3 annual mean 25 μg/m^3 24-hour mean; PM_{10}: 20 μg/m^3 annual mean 50 μg/m^3 24-hour mean; O_3: 100 μg/m^3 8-hour mean; NO_2: 40 μg/m^3 annual mean 200 μg/m^3 1-hour mean; SO_2: 20 μg/m^3 24-hour mean 500 μg/m^3 10-minute mean) (WHO, 2005). Moreover, *water* *and metal pollution* were addressed by one study measuring the contaminating levels of nitrate in water (> 2 mg/L), and the risk of poisoning from radon and lead (percentage (%) of houses with higher lead risk, percentage of children with positive lead poisoning > 10 µg/dL, and radon levels > 4 pCi/L) (Athens et al., 2008). 2) 'S*afety'* was the second subcategory of urban environment (n=4). While two studies explored safety as the number of crimes within a population (Bahadure & Kotharkar, 2018; Sugiyama et al., 2009), three studies considered '*safety'* in terms of traffic safety, measuring both the number of accidents and fatalities as negative outcomes, and the number of traffic lights as a positive feature for traffic safety promotion (Bahadure & Kotharkar, 2018; Gómez et al., 2010; Hino et al., 2011).

c) City fabric as a category of built environment was explored by 1) '*street connectivity'* and 2) '*distance to services & facilities'.* For '*street connectivity',* defined indicators were the number of junctions present in an urban area, with more junctions relating to a higher *connectivity* (Coombes et al., 2010; Gómez et al., 2010; Hooper et al., 2015). Furthermore, a WHO expert consultation of 2012 discussed '*street connectivity'* in terms of number of cycle lanes constructed/ year (WHO, 2012), and an additional study explored the median length of blocks as an indication of neighborhood variables and street connectivity (Satariano et al., 2016). Indicators of 2) '*distance to services & facilities'* varied by the services or facilities that were considered (Bahadure & Kotharkar, 2018; Giles-Corti et al., 2016; Hooper et al., 2015; Padilla et al., 2016; Satariano et al., 2016). Transport planning indicators were specifically excluded in this present systematic review, but if considered as an urban planning feature of '*distance to services & facilities'*, a distance of ≤ 400 m to bus stop and ≤ 800 m to train stops were applied in two identified Australian studies (Giles-Corti et al., 2016; Hooper et al., 2015).

Finally, the built environment category of d) land use included three indicators. 1) '*Density & sprawl'* was measured in five different studies as the number of inhabitants (i.e. population density) or dwellings (i.e. dwelling density) in a given area (Bahadure & Kotharkar, 2018; Fang, 2017; Giles-Corti et al., 2016; Hino et al., 2011; Senanayake et al., 2013), or in one study as the degree of dispersion – calculated through information theory and the Shannon's entropy equation- within a given urban spatial unit (Mosammam, Nia, Khani, Teymouri, & Kazemi, 2017). 2) '*Land composition & desirability'* indicators were identified in five studies and included the number of shops, number of food markets, number of liquor stores, number of traffic lights and number of different land uses (e.g. commercial, residential, etc.) (Coombes et al., 2010; Giles-Corti et al., 2016; Hino et al., 2011; Hooper et al., 2015; WHO, 2012). 3) '*Housing'* referred to either the percentage (%) of urban slums in terms of land use (WHO, 2012) or the number of different housing types in a given area (Hooper et al., 2015).

3.3. Health pathways and endpoints

Table 5 summarizes information on the studies and their health relevance according to the information extracted with the DET. Although most of the health evidence seemed to be of fairly good quality, not all studies tackled specific health objectives. However, health pathways were determined in every study (even if indirectly implied) and from the 54 selected studies, 34 studies addressed detailed health endpoints, linked either to physical or mental health outcomes.

3.3.1 Natural environment

Indicators of natural environment addressed health outcomes associated with the exposure to green or blue space. The main health pathways linked to green and blue space exposure were: (a) increased levels of physical activity, (b) increased restoration and (c) higher social interaction. However, some studies explored further health pathways connected to green and blue space exposure like: (d) improved air quality (e) noise mitigation, (f) reduction of social inequalities and (g) increased service provision.

Furthermore, the WHO (2016) identified the following health pathways to understand the relation between nature and health:

> "Various models have been proposed to explain the observed relationship between green space and health. (Hartig, Mitchell, de Vries, & Frumkin, 2014) suggested four principal and interacting pathways through which nature or green space may contribute to health: improved air quality, enhanced physical activity, stress reduction and greater social cohesion. (Lachowycz & Jones, 2013) emphasized physical activity, engagement with nature and relaxation, and social activities and interactions as major pathways to health. (Villanueva et al., 2015) proposed a model that emphasizes respiratory health and resilience to heat-related illness, social capital and cohesion, and physical activity" (WHO Europe, 2016).

Taking into account the aforementioned pathways linked to green and blue space*s*, the selected studies explored different health endpoints. In general, the increased levels of (a) physical activity in green and blue space*s* were associated to the lower risk of developing non-communicable diseases (NCD). Recreational walking and increased levels of physical activity have been associated to the use of green space*s* (WHO Europe, 2016) not only by working age adults, but also by elder citizens with mobility disabilities (Aytur et al., 2014; Gómez et al., 2010). The main NCDs related to green space effects were reductions in cardiovascular diseases (CVD) (Aytur et al., 2014; Bostrom et al., 2017; Browning & Lee, 2017; Gascon et al., 2016; Huang et al., 2017; Kabisch, Strohbach, Haase, & Kronenberg, 2016b; Kardan et al., 2015; Koprowska et al., 2018; Ngom et al., 2016), diabetes type 2 (Bostrom et al., 2017; Ngom et al., 2016), cancers (Gascon et al., 2016) and obesity (Bostrom et al., 2017; Browning & Lee, 2017; Coombes, Jones, & Hillsdon, 2010). Nonetheless, increases in physical activity associated with green space exposure also showed to be beneficial in terms of improved mental health outcomes. Studies exploring increases in the levels of physical activity, studied health endpoints like reductions in stress and anxiety (Annerstedt et al., 2012; Annerstedt van den Bosch et al., 2016; Bostrom et al., 2017; Smith et al., 2017; WHO Europe, 2016) and lower risk of developing mental disorders (Kardan et al., 2015).

The health pathways of (b) the increased restoration effect and (c) higher social interaction associated with green and blue space exposure, were in particular linked to improved mental health endpoints such as lower levels of anxiety and stress (Akpinar, 2016; Huang et al., 2017; Liu et al., 2017; Peña-Salmón & Rojas-Cadelas, 2009; Smith et al., 2017; Ward Thompson et al., 2016; WHO Europe, 2016), and with higher levels of relaxation (Liu et al., 2017).

(d) Improved air quality was explored by several studies as a health pathway related to green space exposure. '*Distance'* to a green space –and "greenness" of space- as a proxy for whether a green space is present in or not, was associated to better air quality and therefore to better physical and mental health outcomes such as better self-reported health, faster recovery from surgery and lower levels of stress (Huang et al., 2017), as well as better pregnancy and delivery outcomes (Grazuleviciene et al., 2015), and to reductions in premature mortality (Gascon et al., 2016). The health pathway of (e) noise mitigation linked to exposure to green space was associated to positive physical and mental health outcomes such as better self-rated health, lower levels of annoyance and lower levels of sleep disturbance (Dzhambov & Dimitrova, 2015; Jabben, Weber, & Verheijen, 2014; Koprowska et al., 2018; Rey Gozalo et al., 2017).

Finally, there were two further health pathways related to natural environment exposure, namely (f) reduction of social inequalities and (g) service provision. The three studies exploring social inequalities in relation to green space exposure, did not study specific health outcomes, but reported positive associations between green space exposure and the reduction in social inequalities (Padilla et al., 2016; Shen et al., 2017; Wüstemann, Kalisch, & Kolbe, 2017). Moreover another study explored how green space access improved the provision of public services such as transport and schools (≤ 400m bus stop, ≤ 800m train station, ≤ 1600m to primary school), and therefore provided benefits in terms of physical and mental health (Hooper et al., 2015).

3.3.2 Built environment

Indicators of built environment addressed health outcomes associated with the exposure to POS, urban environment, city fabric and land use. The main health pathways discussed in the context of built environment features were: (a) higher social interaction, (b) improved liveability, sustainability and quality of life, (c) improved service provision and (d) reduced environmental pollution.

(a) Higher social interaction was linked to improvements in general health rather than being linked to specific health outcomes, except for one study that explored the reduction of NCDs associated with shorter '*distance'* to good quality POS (Sugiyama et al., 2009). In general, studies exploring '*distance*' and *'access'* to POS, '*street connectivity*' and '*density*' were the ones exploring the relationship between increased social cohesion and health benefits (as a proxy of *POS* being present in the proximity to be used for social interaction) (Fang, 2017; Koohsari et al., 2013; Sugiyama et al., 2009; WHO, 2012).

Other health pathways explored in terms of built environment were (b) improved liveability, sustainability and quality of life (Bahadure & Kotharkar, 2018; Koohsari et al., 2013; Sugiyama et al., 2009). These pathways were explored by three different studies, but were connected to different indicators of POS (i.e. '*distance', 'proportion', 'availability, accessibility & quality'*) urban environment (i.e. '*environmental exposure', 'safety'*), city fabric (i.e. '*distance to services & facilities'*) and land use (i.e. *'density and sprawl', 'land composition & desirability'*) (Bahadure & Kotharkar, 2018; Koohsari et al., 2013; Sugiyama et al., 2009). One study specifically linked improved liveability and life satisfaction with the reduction of specific physical and mental health endpoints, namely CVD, diabetes type 2, cancer, depression and anxiety (Sugiyama et al., 2009).

(c) Improved service provision was associated with indicators of land use (i.e. *'land composition & desirability'*) and city fabric (i.e. *'distance to services and facilities'*), as studies addressing higher provision of commercial and public services were associated with positive health outcomes (Giles-Corti et al., 2016; Hooper et al., 2015; Padilla et al., 2016). In particular, improvements in the provision of different types of services (e.g. commercial, healthcare, housing) was associated with the reduction in child and neonatal mortality (Padilla et al., 2016) and NCDs (Giles-Corti et al., 2016).

Moreover, (d) reductions in environmental pollution were connected to both physical and mental health improvements: reductions in hearing impairment (WHO, 1999; WHO Europe, 2009) lower risks of developing CVD, cardiopulmonary diseases and cancers (Athens et al., 2008; D'Alessandro & Schiavoni, 2015; Koprowska et al., 2018; WHO, 2005), and lower levels of insomnia, anxiety, annoyance and sleep disturbance (D'Alessandro & Schiavoni, 2015; Koprowska et al., 2018; WHO, 1999; WHO Europe, 2009).

4. DISCUSSION

In this study we explored existing indicators of urban planning and their health relevance. We identified 54 studies that apply urban planning indicators with a benchmark and a connection to human health. From the selected studies, 18 different indicators addressed the natural or built environment. These indicators were divided as *quantitative* (n=7) or *qualitative* (n=11) according to the measures discussed (See Table 2). While *quantitative indicators* provide specific and quantifiable benchmarks, *qualitative indicators* need further research and discussion as no health-promoting benchmarks have been defined yet, and optimal exposure levels are still unclear. There appears to be an increasing interest in developing metrics that help to better understand the links between urban life and human health, as it has been recognized by others (Pineo et al., 2018; Prasad, Gray, Ross, & Kano, 2016; Villanueva et al., 2015). However, few standardized indicators have been identified that provide useful information for both the urban planning and public health communities.

Urban development is a phenomenon that occurs heterogeneously worldwide. Cities are developing differently in different settings depending on different historical, socio-cultural, environmental, economic and political forces that shape the way that urban settings are built. Therefore, it is not easy developing and applying common planning measures to all of them. While Australian and North American cities are often low density settings that deal with high levels of urban sprawl that imply car-dependency (Giles-Corti et al., 2016; Hooper et al., 2015; Villanueva et al., 2015); Chinese cities face high population density levels and general space scarcity (Huang et al., 2017). In Latin America, the rise of megacities with over 10 million inhabitants (United Nations, 2014) has been accompanied by informal patterns of urban development and unequal distribution of green space and POS (Gómez et al., 2010); something similar to what Asian and African cities will be facing in the next decades, as their urban settings of 500.000 to 1 million inhabitants represent the fastest-growing cities worldwide (United Nations, 2014). In Europe, urban development has been so different in each region, that while Nordic cities have high levels of green space exposure associated to the richness of surrounding natural forests (Kabisch et al., 2016a), Southern Mediterranean cities face a trade-off between compactness and high population density, and lower '*proportion'* of green space per inhabitant (Kabisch et al., 2016a).

For this reason, the "one size fits all" approach is so challenging. Cities are complex systems and their urban features are the result of centuries of planning and interventions (Kabisch et al., 2016a). Urban planners should work with specific prescriptions and local health indicators that fit into the context, but they could also highly benefit from universal tools that promote global health. Standardized indicators might be able to provide broader pictures that help future planners in their task worldwide. In fact, having a minimum set of standards that incorporate public health into the urban planning practices would be very useful for reducing inequalities within urban development.

Integrated, multidisciplinary approaches of the health and urban planning sectors are essential for creating healthier cities with improved health outcomes dwellers (Giles-Corti et al., 2016). As it was recognized by Webster and Sanderson, "the health of people living in towns and cities is strongly determined by their living and working conditions, the quality of the physical and socio-economic environment and the quality and accessibility of health care services" (Webster & Sanderson, 2013b). For this, we encourage the health sector to advocate for urban planning practices that promote healthier and more sustainable cities.

Through this study, we identified different indicators that can help urban planners and public health officers in their planning practices. The selected indicators need further studies, but they are also useful tools to measure the health consequences of interventions, as they provide general concepts to keep in mind during the planning process. We identified 7 *quantitative* measures that might provide an initial set of indicators, but that require further analysis and better established benchmarks (see **Table 6**).

There are commonalties among the *quantitative indicators*, as the different studies tend to explore similar '*distance'* benchmarks like the ≤ 300 m distance to green space or ≤ 400 m distance to POS. Here 'distance' serves as proxy for ensuring that green space and *POS* are present in direct residential proximity and can be accessed and used within a realistic walking distance by the residents, which in return provides health benefits. Nevertheless, there is also a diversity of benchmarks proposed for all *quantitative indicators*, as studies tend to propose benchmarks associated with their contexts. For instance, a study exploring physical activity of the elderly in England took ≤ 700m (10 min walking) as a benchmark for '*distance*', taking into consideration the gait speed of older people (Sugiyama et al., 2009). Likewise, North American studies use '*distances'* to green space in terms of 0.5 and 1 mile, as maximum distances people are willing to travel to use the *green space* regularly (Bostrom et al., 2016; Kaczynski et al., 2016b)

Measures of '*distance*', '*proportion',* '*size'* (to/ of green, blue or POS or to/ of services and facilities) and '*environmental exposures'* (air, noise and water pollution) were considered as *quantitative indicators* because studies provided specific benchmarks for these indicators (see **Table 6**). '*Distance'* to green space was the indicator with the largest number of related epidemiological studies. The official benchmark provided by the WHO in 2016 established a '*distance*' of ≤ 300 m to a green space, for the green space to be used and for its users to receive health benefits through the different proposed health pathways (WHO Europe, 2016). However, this benchmark of ≤ 300 m appears in the selected studies since years before (Annerstedt et al., 2012; Grazuleviciene et al., 2015; Schipperijn et al., 2010; Stigsdotter et al., 2010), as both a defined measure and a buffer of analysis.

Studies suggest three main health pathways by which green space*s* provides health benefits, namely the stimulation of physical activity to and in green space*s* (as *'distance' i*s a proxy to determine the access within a reasonable time/space) (Akpinar, 2016; Annerstedt van den Bosch et al., 2016; Aytur et al., 2014; Bostrom et al., 2017; Browning & Lee, 2017; Coombes et al., 2010; Ekkel & de Vries, 2017; Gómez et al., 2010; Hooper et al., 2015; Huang et al., 2017; Ives et al., 2017; Kabisch et al., 2016b; Lackey & Kaczynski, 2009; Ngom et al., 2016; Smith et al., 2017; WHO Europe, 2016), increases in social cohesion by 'seeing' and 'interacting' with people (Ekkel & de Vries, 2017; Fang, 2017; Huang et al., 2017; WHO Europe, 2016; Wüstemann et al., 2017) and restoration effects through 'viewing' and 'experiencing' nature (Akpinar, 2016; Ekkel & de Vries, 2017; Huang et al., 2017; Liu et al., 2017; Smith et al., 2017; WHO Europe, 2016). Nevertheless, some authors discussed on the potential benefits of different distances, and put into question the ≤ 300 m benchmark, as they have demonstrated both: health benefits beyond that threshold (Browning & Lee, 2017; Dzhambov & Dimitrova, 2015; Lackey & Kaczynski, 2009; Maas et al., 2009; Sugiyama et al., 2009; Wüstemann et al., 2017), and not real associations to health benefits within that distance as it might happen in New Zealand cities where there is an excess of green space. The indicator of required ‘*proportion*’ of available green space or POS lacks consistency and proportions of 3.25 – 52 m^2/ inhabitant have been proposed. A series of studies applied a benchmark of around 10 m^2/ inhabitant. However, it is unclear where this benchmark originates from, because no source document could be identified, and the actual existence of this “guideline” needs to be clarified.

In terms of *quantitative indicators*, WHO guidelines have played an important role in promoting standardized benchmarks for different aspects of urban planning. They did not only establish the indicator of ‘*distance*’ to a green space, but they also quantify the specific benchmark from which ‘*environmental exposures*’ start becoming detrimental to health (e.g. air pollution levels of $PM_{2.5}$: 10 µg/ m^3 annual mean, PM_{10}: 20 µg/m^3 annual mean, NO_2: 40 µg/m^3 annual mean; noise levels of ≤ 55 dB day time and ≤ 40 dB night time) (WHO, 1999, 2005; WHO Europe, 2009). Despite the fact, that there are no safe levels of pollution and adverse health effects have occurred under the established thresholds, an achievable set of target values is important for urban planners to have in mind during the planning process and develop interventions (e.g. reduce motor traffic, promote active and electric transport, develop green spaces as passive air, noise and heat pollution control, plan for adequate water treatment plants, etc..) that aim at complying with this minimum set of recommendations and in return provide health benefits.

Identified *qualitative indicators* (e.g. residents/ km^2 as a measure for population density, number of facilities a park should have as a measure of ‘*quality*’) that do not provide benchmarks yet, as optimal levels for health promotion have not been determined, need further research and discussion to identify tendencies for favourable health outcomes (e.g. identify optimal levels of population density or optimal number of features to promote physical activities in parks and reduce the risk of NCDs).

Qualitative indicators of natural environment were indicators of ‘*type*’, ‘*accessibility, availability & quality*’, and ‘*ecosystem services & biodiversity*’ of the green and blue space. The *type* of *green* or blue space studied has different effects on health according to the health pathways explored. The ‘*type*’ of green space can take different natures, as green space does not necessarily need to be understood as a ‘*segregated green area*’, but can also be ‘*surrounding greenness*’. Different studies explored the importance of increasing greenness close to residential areas (Bahadure & Kotharkar, 2018; Gascon et al., 2016; Graça et al., 2018; Kardan et al., 2015; Wüstemann et al., 2017), but few provided a clear definition of the term “greenness”. What is “greenness” and what would be the ideal level of it for health promotion? Artificial indicators like the number of trees per city block have been proposed (e.g. 10 trees for improved health perception and 11 trees for reduction in cardio-metabolic conditions) (Kardan et al., 2015), however, the scientific evidence base behind this indicator might be questioned. Furthermore, a clear separation of ‘planning’ and ‘performance’ indicators has turned out to be difficult. Despite identifying and including indicators of NDVI and air, noise and water pollution guidelines, it is questionable whether these indicators are rather measuring performance of urban planning practices than helping urban planners in the planning process to develop health-promoting interventions. In the discussion between planning and performance measures, different indicators have been included in this study, even when their value is associated to the performance evaluation rather than to exclusively the urban planning practice (e.g. NDVI, air and noise pollution).

Public service provision is an important feature that partially determines the use of POS, but it depends highly on whom the users are and their needs (e.g. playgrounds for children, public bathrooms for elderly people, sport facilities for younger people, etc.). *Qualitative indicators* of '*availability, accessibility* & *quality*' should be considered as soft indicators, reminding urban planners to also have in mind the quality of public spaces, amenities and the aesthetic appeal, but recognizing the importance of further exploring them, since benchmarking remains a difficult task in this context.

In the case of *safety*, 'safer environments' are related to lower numbers of incidents and to a more positive perception of POS. However, no benchmarks have been proposed to determine what really a 'safe environment' consists of. A couple of *qualitative indicators* such as the presence of lights (Hino et al., 2011) and safe walking trails (Sugiyama et al., 2009) have been mentioned in this context, and should be considered in an urban planning process. 'S*afety'* as a consequence of urban planning practices has been studied in terms of both criminality (Bahadure & Kotharkar, 2018; Sugiyama et al., 2009) and traffic safety (Bahadure & Kotharkar, 2018; Gómez et al., 2010; Hino et al., 2011), but no specific benchmarks provide quantitative information to promote precise interventions.

Mixed land use and housing are important for desirability, social cohesion and reducing commuting times (considering residential areas within commercial zones and closer distances to services and facilities) but as potential indicators, they still need more supporting research that could quantify the optimal distribution of land uses, the number of people per community and their living arrangements. A key question related to the further study of *qualitative indicators* is also related to the definition of concepts like "desirability", "diversity", "liveability", and how to measure them.

4. 1. Strengths and limitations

To our knowledge, this is the first review assessing the validity of individual urban planning indicators and their benchmarks, rather than just listing them or providing tools and indices. We identified a great variety of urban planning indicators and sometimes it was difficult to classify and analyse them. However, we developed taxonomy to organize them and we tried to go one level deeper by exploring and providing quantifiable indicators.

Our review sheds light on the health relevance of urban planning indicators and suggests that performance benchmarks for optimal health promotion need to be determined. However, across the reviewing process we encountered the following limitations that need consideration: a lack of clear definitions of indicators (like the overlapping definitions of *'distance', 'accessibility' and 'availability'*, or the 10m^2/inhabitant '*proportion'* of green space that has not really been set as a WHO guideline), artificial recommendations provided without strong supporting evidence (e.g. having 11 trees per city block for decreasing cardio-metabolic conditions) and the idea of applying standardized indicators that disavow different local realities, as it could happen when the ≤ 300 m '*distance*' to green space tries to be applied to United States cities where people go to the park by car.

Natural open space, green space, blue space and POS are urban planning concepts that appear to be relevant for human health outcomes (Gascon et al., 2016; Hooper et al., 2015; Sugiyama et al., 2009; WHO Europe, 2016). However, these concepts are often difficult to differentiate because of an overlap in their definitions or a lack of clear distinctive features. For this review, we distinguished and assigned green space as a feature of the natural environment and POS as a feature of the built environment. However, we acknowledge that a POS can contain vegetation and a green space can contain construction. The same definition problem applies for blue space, as blue space is not always clearly distinguishable from other types of natural environments like green space, and a green space can in fact contain blue space and vice versa. Less ambiguous definitions on the different urban planning features are urgently needed.

Furthermore, this study explored peer reviewed studies published in three scientific databases during the last ten years (2008-2018). Information extracted from these databases was useful and complemented by policy documents, but limited as it excluded books and older publications. We might have also missed a lot of relevant indicators present in grey literature such as local policy documents. However, literature on urban planning and health is in a developing process, as this an area of interest that has developed recently and is increasingly gaining momentum (Prasad et al., 2015).

Selected search terms and screening practices focused on identifying existing indicators rather than identifying relevant health pathways and mechanism that explain the relationship between urban planning features and public health outcomes. Taking 'indicators' as the main quest, we might have missed a lot of studies that actually explored indicators without specifically calling them like that.

5. CONCLUSIONS

This review identified indicators of urban planning with the scope of providing the urban planning community with a better understanding of the potential health consequences of their practices. Providing insight on the health impacts of urban planning metrics offers a leverage point for urban planners to work towards the design of more liveable and healthier cities.

We identified 18 indicators of which 7 were of quantitative nature and 11 were of qualitative nature. While the identified *quantitative indicators* provided a first set of benchmarks that urban planners can now try to consider in their planning practices with regards to expected health effects, *qualitative indicators* provide a starting point for discussion but need to be investigated further on their health relevance and the optimal level of exposure for health promotion needs to be determined (e.g. density, mixed land use, quality of green space, quality of POS etc.). Further studies are needed in both cases, as benchmarks ought to be established, clearly defined and supported by relevant scientific evidence, having in mind that not necessarily "one size fits all" applies and different indicators with different benchmarks are needed in different settings.

According to the WHO, health indicators have become widely used in many fields and play a key role in the policy making process, as they are important performance measurement tools and can inform decision-makers about challenges that require action from different disciplines (WHO, 2002). In particular, indicators of urban planning provide a relevant framework to discuss the impact of city design on the health of a community. They represent useful metrics that support the integration of health into the urban planning policy process, and their use is beneficial because it promotes more evidence-based solutions.

However, urban planning indicators related to health tend to be proposed for specific settings and they have a limited impact. There is a lack of consensus on the type of measures that ought to be collectively used, and standardization is an ongoing debate (Pineo, Glonti, & Rutter, 2018; WHO, 2002). Several studies identified in this review explored measures that could be further investigated and used in wider settings, but collaborative research of the public health and urban planning communities is needed to provide standardized measures that guarantee health promoting urban planning outcomes.

Furthermore, standardization as an ongoing debate should be further explored in order to provide useful tools for the public health and urban planning communities. However, the separation between both disciplines calls for a more collaborative research and practice in order to understand the relation between urban planning and health and to provide standardized measures that guarantee health promoting urban planning outcomes.

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ANNEXES

Figure 1. Conceptual framework: Health indicators for Urban and Transport Planning

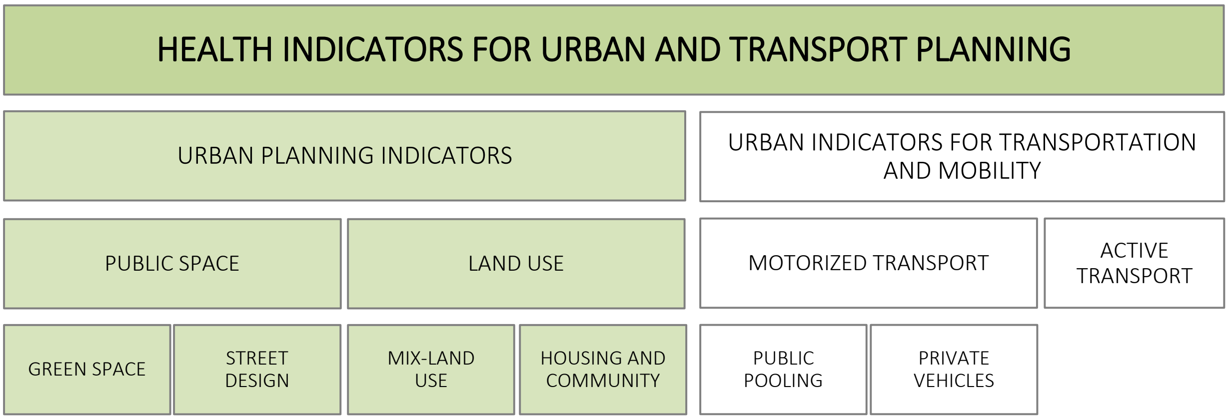

Figure 2. Flow diagram

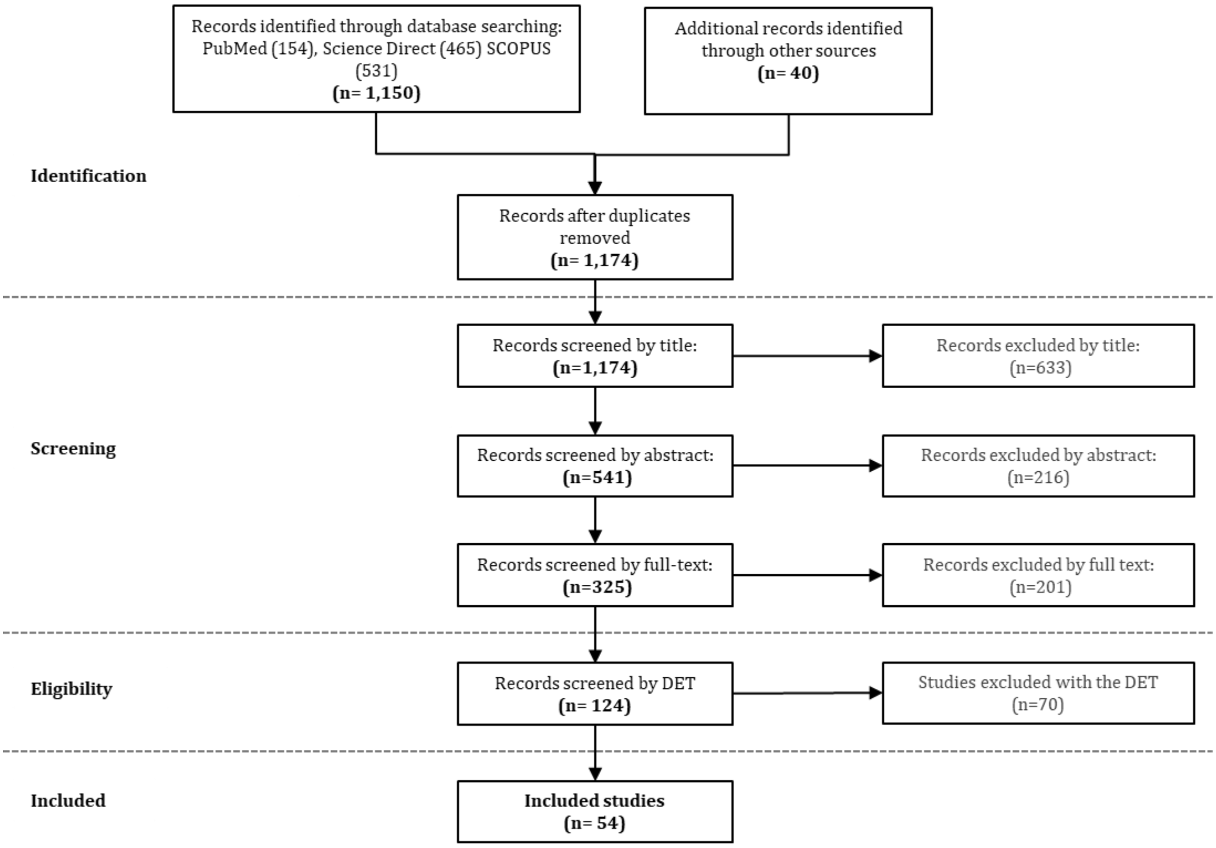

Figure 3. Taxonomy of identified urban planning indicators with health relevance

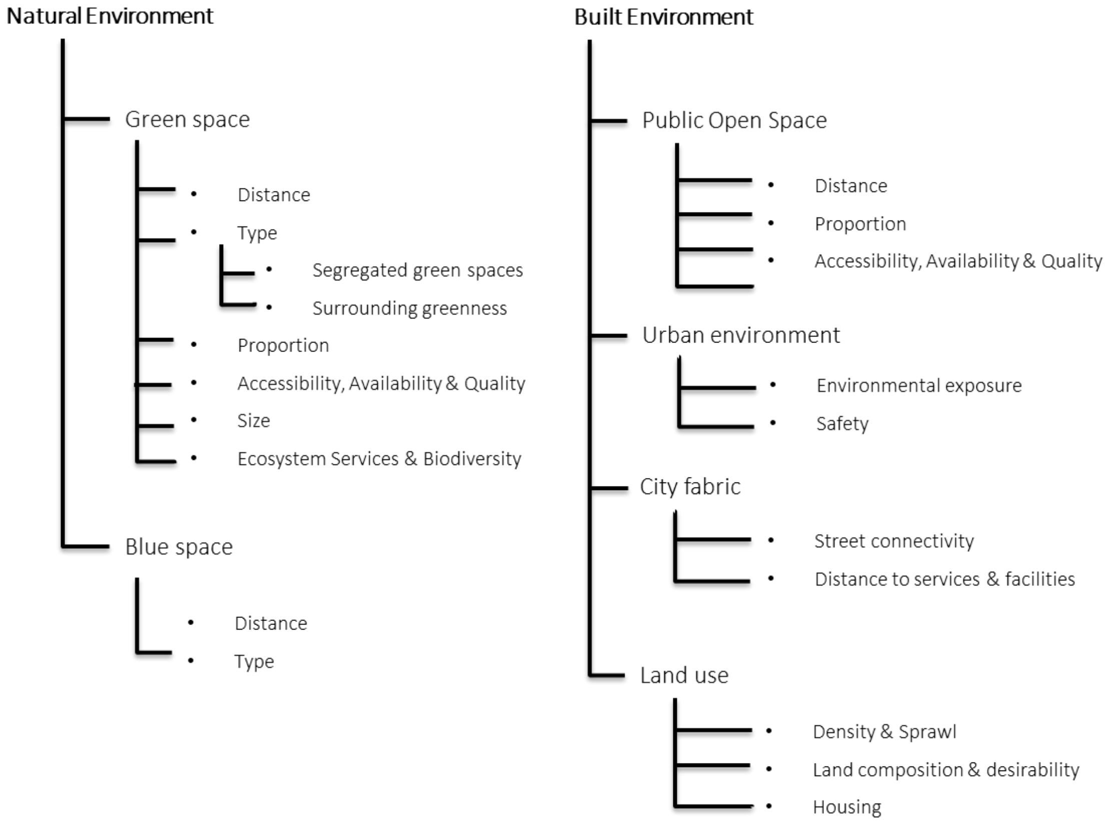

Table 1. Search terms and keyword combinations

Database	Keyword combination	Filters
PubMed	1. Indicator AND Urban Health AND City Planning 2. Indicator AND Urban Health AND Green Space	By Best Match
Science Direct	(Indicator OR measure OR benchmark OR threshold OR health indicator) **AND** (Public space OR land use OR green space OR street design OR mix-land use OR housing OR community) **AND** (Urban health OR health OR well-being) **AND** (urban planning OR city planning OR built environment OR healthy city) **AND NOT** (rural OR food OR transport OR energy).	Publication Year: 2008-2018 Publication Type: Only articles
Scopus	(Indicator OR measure OR benchmark OR threshold OR health indicator) **AND** (Public space OR land use OR green space OR street design OR mix-land use OR housing OR community) **AND** (Urban health OR health OR well-being) **AND** (urban planning OR city planning OR built environment OR healthy city) **AND NOT** (rural OR food)	Publication Year: 2008-2018 Publication Type: Only articles. Subject area exclusion: agriculture and biological science, energy, business management and accounting, computer science, physics and astronomy, (3) Document type exclusion: books

Table 2. Data Extraction Tool (DET)

General information	Title	Development of an urban green space indicator and the public health rationale	Urban Green Spaces and health, a review of evidence
	Type of literature	Epidemiological study	Report - Guideline
	Authors	Annerstedt et al.	WHO Regional Office for Europe
	Year	2016	2016
	Setting	Sweden, Lithuania, Netherlands	Europe
	Specific location	Malmö, Kaunas, Utrecht	-
	Sample size	EEA European Population dataset.	-
Discussed urban planning policy	Urban planning policy discussed	Developing and testing a green space indicator for public health	Urban green space indicators and health
	Key findings	Main objective: to propose a harmonized method for an urban green space indicator (UGSI) to be applied in Europe.	Studying the indicator of GS and its mechanisms to provide health benefits
Relevance of the indicator	Indicators	Distance to GS	Distance to GS
	Clear definition	X	X
	Measure discussed	X	X
	Benchmark	≤ 300m Min. size 1ha	≤ 300m or ≤ 15min walk Min. size 0.5ha NDVI > 0
	Strength of the study/ multiple use	X	X
	International recognition	X	X
Impact on health	Health exposure pathways	↑ GS ↑ PA ↑ Stress relief	↑ GS ↑ PA ↑ Air quality ↓ Stress ↑ Social cohesion
	Specific health endpoints	↓ Stress	↓ Stress ↑ Immune system response ↑ Restoration ↓ NCDs
	Health outcome	↑ Physical and mental health	↑ Physical and mental health

Table 3. Indicators and literature

Environment	Policy	Indicators	Type	Number of relevant studies	Full list of relevant studies
Natural Environment	Green Space	Distance	QN	30	Koprowska et al, 2018; Smith et al, 2017; Huang et al, 2017; Ekkel & De Vries, 2017; Christian et al, 2017; Bostrom et al, 2017; Liu et al, 2017; Fang, 2017; Coppel & Wüstemann, 2017; Shen et al, 2017; Wüstemann et al, 2017; Browning & Lee, 2017; Annerstedt Van Den Bosch et al, 2016; Kabisch et al, 2016; WHO Europe, 2016; Picavet et al, 2016; Kaczynski et al, 2016; Ngom et al, 2016; Akpinar, 2016; Dzhambov & Dimitrova, 2015; Grazuleviciene et al, 2015; Hooper et al, 2015; Aytur et al, 2014; Annerstedt Van Den Bosch et al, 2012; Schipperijn et al, 2010; Stigsdotter et al, 2010; Gómez et al, 2010; Coombes et al, 2010; Maas et al, 2009; Lackey & Kaczynski, 2009
		Type	QL	12	**Closed green space**: Graça et al, 2018; Smith et al, 2017; Ekkel & De Vries, 2017; Christian et al, 2017; Ngom et al, 2016; Hooper et al, 2015; Schipperijn et al, 2010; Peña-Salmon & Rojas-Caldelas, 2009 **Surrounding greenness**: Bahadure & Kotharkar, 2018; Wüstemann et al, 2017; Gascon et al, 2016; Kardan et al, 2015
		Proportion	QN	9	Rey Gozalo et al, 2017; Fang, 2017; Wüstemann et al, 2017; Padilla et al, 2016; Akpinar, 2016; Senanayake et al, 2013; WHO, 2012; Hino et al, 2011; Peña-Salmon & Rojas-Caldelas, 2009
		Accessibility, Availability & Quality	QL	9	Huang et al, 2017; Bostrom et al, 2017; Liu et al, 2017; Kaczynski et al, 2016; Ward Thompson et al, 2016; Dzhambov & Dimitrova, 2015; Aytur et al, 2014; Jabben et al, 2014; Annerstedt Van Den Bosch et al, 2012
		Size	QN	8	Graça et al, 2018; Smith et al, 2017; Ekkel & De Vries, 2017; Huang et al, 2017; WHO Europe, 2016; Annerstedt Van Den Bosch et al, 2016; Kabisch et al, 2016; Ngom et al, 2016
		Ecosystem Services & Biodiversity	QL	7	**Biodiversity**: Graça et al, 2018 **ES:** Smith et al, 2017; Huang et al, 2017; Ekkel & De Vries, 2017; WHO Europe, 2016; Senanayake et al, 2013; Peña-Salmon & Rojas-Caldelas, 2009
	Blue Space	Distance	QN	4	Smith et al, 2017; Christian et al, 2017; Wheeler et al, 2012; Schipperijn et al, 2010
		Type	QL	1	Smith et al, 2017
Built Environment	Public Open Space	Distance	QN	6	Hooper et al, 2018; Bahadure & Kotharkar, 2018; Hooper et al, 2015; Koohsari et al, 2013; Hino et al, 2011; Sugiyama et al, 2009
		Accessibility, Availability & Quality	QL	2	Koohsari et al, 2013; Sugiyama et al, 2009
		Proportion	QN	1	Bahadure & Kotharkar, 2018
	Urban environment	Environmental exposure	QN	8	Koprowska et al, 2018; Bahadure & Kotharkar, 2018; D'Alessandro & Schiavoni , 2015; Senanayake et al, 2013; WHO Europe, 2009; Athens et al, 2008; WHO, 2005; WHO, 1999
		Safety	QL	4	Bahadure & Kotharkar, 2018; Hino et al, 2011; Gómez et al, 2010; Sugiyama et al, 2009

	City fabric	Street connectivity	QL	5	Satariano et al, 2016; Hooper et al, 2015; WHO, 2012; Gómez et al, 2010; Coombes et al, 2010
		Distance to services & facilities	QL	5	Bahadure & Kotharkar, 2018; Padilla et al, 2016; Giles-Corti et al, 2016; Hooper et al, 2015; Satariano et al, 2016
	Land use	Density & Sprawl	QL	6	Bahadure & Kotharkar, 2018; Fang, 2017; Giles-Corti et al, 2016; Mosammam et al, 2016; Senanayake et al, 2013; Hino et al, 2011
		Land composition & desirability	QL	5	Giles-Corti et al, 2016; Hooper et al, 2015; WHO, 2012; Hino et al, 2011; Coombes et al, 2010
		Housing	QL	2	Hooper et al, 2016; WHO, 2012

QL: Qualitative indicator (n=11) QN: Quantitative indicator (n=7)

Table 4. Selected studies, year of publication and settings

Author	Year	Setting
Koprowska et al, 2018	2018	Poland
Hooper et al, 2018	2018	Australia
Graça et al, 2018	2018	Portugal
Bahadure& Kotharkar, 2018	2018	India
Smith et al, 2017	2017	Spain, Netherlands, Lithuania, England
Huang et al, 2017	2017	Global review
Ekkel & De Vries, 2017	2017	Netherlands
Christian et al, 2017	2017	Australia
Bostrom et al, 2017	2017	USA
Liu et al, 2017	2017	China
Fang, 2017	2017	China
Browning & Lee, 2017	2017	Global review (USA)
Rey Gozalo et al, 2017	2017	Spain
Coppel & Wüstemann, 2017	2017	Germany
Shen et al, 2017	2017	China

Author	Year	Setting
Wüstemann et al, 2017	2017	Germany
Padilla et al, 2016	2016	France
Giles-Corti et al, 2016	2016	Global review (Australia)
Annerstedt Van Den Bosch et al, 2016	2016	Sweden, Lithuania , Netherlands
Gascon et al, 2016	2016	Global review (Europe)
Kabisch et al, 2016	2016	Europe
WHO Regional office Europe, 2016	2016	Global review (Europe)
Picavet et al, 2016	2016	Netherlands
Mosammam et al, 2016	2016	Iran
Satariano et al, 2016	2016	USA
Ward Thompson et al, 2016	2016	Scotland
Ngom et al, 2016	2016	Canada
Kaczynski et al, 2016	2016	USA
Akpinar, 2016	2016	Turkey
D'Alessandro & Schiavoni , 2015	2015	Europe
Dzhambov & Dimitrova, 2015	2015	Bulgaria
Grazuleviciene et al, 2015	2015	Lithuania
Kardan et al, 2015	2015	Canada
Hooper et al, 2015	2015	Australia
Aytur et al, 2014	2014	USA
Jabben et al, 2014	2014	Netherlands
Senanayake et al, 2013	2013	Sri Lanka
Koohsari et al, 2013	2013	Australia
Annerstedt Van Den Bosch et al, 2012	2012	Sweden
Wheeler et al, 2012	2012	England
WHO, 2012	2012	Global review
Hino et al, 2011	2011	Brazil
Schipperijn et al, 2010	2010	Denmark

Author	Year	Setting
Stigsdotter et al, 2010	2010	Denmark
Gómez et al, 2010	2010	Colombia
Coombes et al, 2010	2010	England
Peña-Salmon & Rojas-Caldelas, 2009	2009	Mexico
Maas et al, 2009	2009	Netherlands
Lackey & Kaczynski, 2009	2009	Canada
Sugiyama et al, 2009	2009	England
WHO Regional office Europe, 2009	2009	Global review (Europe)
Athens et al, 2008	2008	USA
WHO, 2005	2005	Global review
WHO, 1999	1999	Global review

Table 5. Indicators and benchmarks

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
Natural environment	Green space	Distance	≤ 300m	Koprowska et al, 2018	Studying objective and subjective noise exposures in relation to urban GS availability	↑ GS ↓ Noise	↓ CVD ↓ Annoyance ↓ Sleep disturbance ↓ Cognitive impairment	↑ Physical and mental health
			≤100m ≤300m* ≤500m ≤1km	Smith et al, 2017	Studying quantitative indicators of natural environment exposure in different cities of Europe	↑ GS ↑ Restoration effect ↑ PA ↑ Social contact	↓ Stress*	↑ Physical and mental health
			≤ 300m	Huang et al, 2017	Studying the health benefits provided by GS in 28 megacities, through indicators of availability and accessibility	↑ GS ↑ Restoration effect ↓ Air pollution ↓ Noise ↓ Heat effect (UHI) ↑ PA ↑ Social contact	↓ CVD ↑ Mental health ↑ Self-reported health ↑ Recovery from surgery ↓ Stress	↑ Physical and mental health
			≤ 300m	Ekkel & De Vries, 2017	Reviewing GS accessibility measures	↑ GS ↑ PA ↑ Social cohesion ↑ Restoration effect		↑ Physical and mental health
			≤ 400m to small/medium size GS ≤ 1600m to district/regional GS	Christian et al, 2017	Studying the relationship between neighborhood environment attributes and walkability	↑ GS ↑ BS ↑ PA (walking)	↓ NCDs	↑ Physical and mental health
			≤ 0.5mile ≤ 10min walk	Bostrom et al, 2017	Studying the implementation and measurement of fitness zones in GS to increase PA	↑ GS ↑ PA	↓ CVD ↓ Obesity ↓ Type 2 diabetes ↓ Stress	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			≤ 1km	Liu et al, 2017	Studying the association between socio-demographic, environ- mental, and individual factors with regards to their impact on GS visitation	↑ GS ↑ Restoration effect ↑ PA	↑ Relaxation	↑ Physical and mental health
			≤ 400 m ≤ 800*m 5 to 10 min walk	Fang, 2017	Studying GS accessibility using two thresholds and exploring changes over time	↑ GS ↑ Social interaction		↑ Physical and mental health
			≤ 250 m	Coppel & Wüstemann, 2017	Studying the relationship between access to GS and self-reported health	↑ GS	↑ Self-rated health	↑ Physical and mental health
			≤ 1200 m 15 to 20 min walk*	Shen et al, 2017	Studying disparities in access to GS and the spatial mismatches among public GS provision and use	↑ GS ↓ Social inequalities		↑ Physical and mental health
			≤ 500 m	Wüstemann et al, 2017	Studying access to GS and environmental inequalities in German cities	↑ GS ↓ Social inequalities ↑ Social cohesion ↓ Air pollution ↓ Heat stress		↑ Physical and mental health
			Buffers: ≤250m, 250 to 499m, 500 to 1000m, 1000 to 1999m*	Browning & Lee, 2017	Studying buffers of distance to understand the effect of GS on health	↑ GS ↑ PA	↓ CVD ↑ Birth outcomes ↓ Low Birth Weight ↓ Asthma/ allergic rhinitis ↓ Overweight ↑ General health	↑ Physical and mental health
			≤ 300m	Annerstedt Van Den Bosch et al, 2016	Developing and testing a GS indicator for public health	↑ GS ↑ PA ↑ Stress relief	↓ Stress	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			300 m to 500 m	Kabisch et al, 2016	Studying GS availability in 299 European cities, and the development of a GS availability indicator	↑ GS ↑ PA	↓ CVD ↓ Mortality ↑ Mental health	↑ Physical and mental health
			≤ 300m ≤ 15min walk	WHO Regional office Europe, 2016	Studying the indicator of GS and its mechanisms to provide health benefits	↑ GS ↑ PA ↑ Air quality ↓ Stress relief ↑ Restoration effect ↑ Social cohesion	↓ NCDs ↓ Stress ↑ Immune system response ↑ Restoration	↑ Physical and mental health
			≤ 125m ≤ 1km*	Picavet et al, 2016	Studying GS proximity and PA, and several health indicators	↑ GS ↑ PA ↓ Blood pressure (urban) ↑ Blood pressure (rural)	↓ NCDs ↓ Hypertension*	↑ Physical and mental health
			≤ 200 m to transport stop	Ngom et al, 2016	Studying the effects of type and proximity to GS in cardiovascular and diabetes morbidity	↑ GS ↓ Air pollution ↑ PA	↓ CVD* ↓ Diabetes ↓ Hypertension	↑ Physical and mental health
			≤ 1 mile	Kaczynski et al, 2016	Developing a Park index to explore the potential for GS use	↑ GS		↑ Physical and mental health
			≤ 250m; 250m to 500m 500m to 1km* 1km to 3km 3km to 5km > 5 km	Akpinar, 2016	Studying users' perceptions and preferences in urban greenways	↑ GS ↑ PA ↑ Restoration effect		↑ Physical and mental health
			≤ 1km	Dzhambov & Dimitrova, 2015	Studying the effect of GS on noise sensitivity and noise annoyance	↓ Noise	↓ Noise annoyance ↑ Noise sensitivity	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Buffers: <300m* 500m* 300m to 1km >1km	Grazuleviciene et al, 2015	Studying how greenness levels and distance to GS affect birth outcomes	↑ GS ↓ Air pollution	↑ Pregnancy outcomes ↓ Low birth weight ↓ Preterm delivery	↑ Physical and mental health
			Local GS ≤ 200m; Small-Medium-Large ≤ 400m; District GS: 600m to 1 km; Regional GS ≤ 2.5km	Hooper et al, 2015	Studying specific design features that showed the strongest associations with PA behaviours	↑ Service provision ↑ GS ↑ PA		↑ Physical and mental health
			≤ 0.5 mile	Aytur et al, 2014	Studying measures of PA in outdoor community recreational environments, to enhance their usability, focused on people with mobility limitations	↑ GS ↑ PA	↓ CVD	↑ Physical and mental health
			≤300m	Annerstedt Van Den Bosch et al, 2012	Studying the effect of GS qualities on mental health	↑ GS ↑ PA ↑ Stress relief	↑ Mental health	↑ Physical and mental health
			≤ 300m ≤ 15 min walk Buffers: <300m* 300m to 1km 1 to 5km > 5km	Schipperijn et al, 2010	Studying the factors that influence the use of GS	↑ GS ↑ BS		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Buffers: <300m* 300m to 1km >1 km	Stigsdotter et al, 2010	Studying the associations between GS and health, health-related quality of life and stress	↑ GS	↓ Stress* ↑ Self-rated health* ↓ Bodily pain ↑ General health ↑ Mental health ↑ Physical functioning ↑ Limitations due to emotional problems ↑ Limitations due to physical health ↑ Social functioning ↑ Vitality	↑ Physical and mental health
			≤ 500m	Gómez et al, 2010	Studying the association between built environment and walking patterns of elderly people	↑ GS ↑ PA	↓ NCDs ↓ Bone fracture	↑ Physical and mental health
			≤ 800 m ≤ 10min walk	Coombes et al, 2010	Studying the association between access to GS, PA and the odds of being overweight or obese	↑ GS ↑ PA	↓ Overweight ↓ Obesity	↑ Physical and mental health
			1km* 3km	Maas et al, 2009	Studying the relationship between GS proximity and morbidities	↑ GS	↓ Morbidity ↓ Anxiety ↓ Depression*	↑ Physical and mental health
			0.5 mile (750 m) Buffers: 0m to 375m; 376m to 750m* 751m to 1500m 1501m to 2250m >2250m	Lackey & Kaczynski, 2009	Studying the proximity to GS and the relationship to PA	↑ GS ↑ PA		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
		Type	*Natural space:* Agricultural areas, Allotments & urbanizations, Civic & institutional, Motorways & tree-lined streets, Private gardens & backyards, Parks, public gardens & woodlands, Vacant lots & wasteland and Other green spaces. *Surrounding greenness:* Green corridors (>3 trees in rows)	Graça et al, 2018	Studying how different types of urban green spaces influence ES delivery	↑ GS ↑ ES: ↑Air quality ↑ ES: ↓Water runoff ↑ ES: ↑Climate regulation		↑ Physical and mental health
			Surrounding greenness: 50 trees/ha trees/ inhabitants (1 full grown tree/10 inhabitants)	Bahadure & Kotharkar, 2018	Studying measures of sustainability at the neighborhood level based on composite indicators	↑ Mixed-land use ↑Sustainability		↑ Physical and mental health
			Natural space: Urban green, forests, rural	Smith et al, 2017	Studying quantitative indicators of natural environment exposure in different cities of Europe	↑ GS ↑ Restoration effect ↑ PA ↑ Social contact	↓ Stress*	↑ Physical and mental health
			Natural space: Countryside, blue space, small natural area	Ekkel & De Vries, 2017	Reviewing GS accessibility measures	↑ GS ↑ PA ↑ Social cohesion ↑ Restoration effect		↑ Physical and mental health
			Natural space: Small-pocket size (≤0.5ha), Medium (>0.5ha to ≤5ha), District (>5ha to ≥15 ha), Regional (≥15 ha), Blue space	Christian et al, 2017	Studying the relationship between neighborhood environment attributes and walkability	↑ GS ↑ BS ↑ PA (walking)	↓ NCDs	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Natural space and surrounding greenness: Tree canopy ≥ 30%, Tree height ≤ 5m) Green Urban Areas (public GS) and Forests	Wüstemann et al, 2017	Studying access to GS and environmental inequalities in German cities	↑ GS ↓ Social inequalities ↑ Social cohesion ↓ Air pollution ↓ Heat stress		↑ Physical and mental health
			Surrounding greenness: 10% increase in residential greenness	Gascon et al, 2016	Reviewing the effects of proportional increases of greenness in health	↑ GS ↑ PA ↓ Air pollution↓ Noise ↓ Heat	↓ All causes mortality ↓ CVD mortality* ↓ Lung cancer mortality	↑ Physical and mental health
			Natural space: GS with natural functions GS with sport facilities GS used for fairs and other activities GS crossed by walking or cycling tracks GS crossed by roads GS accessible by public transportation GS surface area illustrating its size Distance to any type of GS	Ngom et al, 2016	Studying the effects of type and proximity to GS in cardiovascular and diabetes morbidity	↑ GS ↓ Air pollution ↑ PA	↓ CVD* ↓ Diabetes ↓ Hypertension	↑ Physical and mental health
			Natural space: Local, Small-Medium-Large GS, District GS and Regional GS	Hooper et al, 2015	Studying specific design features that showed the strongest associations with PA behaviors	↑ Service provision ↑ GS ↑ PA		↑ Physical and mental health
			Surrounding greenness: Number of trees/ city block 10 trees/ city block 11 trees/ city block	Kardan et al, 2015	Studying the effect of street greenery on health	↑ GS ↑ Interaction with the environment	↑ Perceived health* ↓ Cardio metabolic disorders ↓ Mental disorders	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Natural space: Blue space, park, forest, open natural area	Schipperijn et al, 2010	Studying the factors that influence the use of GS	↑ GS ↑ BS		↑ Physical and mental health
			Natural space: Public GS (public services, roads, natural) Private GS (productive and private/residential)	Peña-Salmon & Rojas-Caldelas, 2009	Studying a methodological proposal for planning urban GS based on a sustainability perspective	↑ GS ↑ Social contact	↓ Stress	↑ Physical and mental health
		Proportion	16.6m2/ inhabitant; 10 to 15m2/ inhabitant	Rey Gozalo et al, 2017	Studying the relationship between GS use and noise	↑ GS ↑ Noise satisfaction ↑ Restoration effect		↑ Physical and mental health
			8.1 m2/ inhabitant	Wüstemann et al, 2017	Studying access to GS and environmental inequalities in German cities	↑ GS ↓ Social inequalities ↑ Social cohesion ↓ Air pollution ↓ Heat stress		↑ Physical and mental health
			3.25-5.01 m2/ inhabitant	Fang, 2017	Studying GS accessibility using two thresholds and exploring changes over time	↑ GS ↑ Social interaction		↑ Physical and mental health
			10m2/ inhabitant m2/census block area	Padilla et al, 2016	Studying the relationship between child and neonatal mortality and indicators of environmental inequalities: environmental exposure, access to healthcare and deprivation	↓ Inequalities ↓ Environmental exposures ↓ Air pollution ↑ Healthcare access	↓Child and neonatal mortality	↑ Physical and mental health
			10m2/ inhabitant	Akpinar, 2016	Studying users' perceptions and preferences in urban greenways	↑ GS ↑ PA ↑ Restoration effect		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			m2/ inhabitant 9.5 m2/ inhabitant (WHO)	Senanayake et al, 2013	Analyzing the environmental quality based on GS	↑ GS ↓ Air pollution ↑ Economic benefits ↓ Population density ↓Vehicles density		↑ Physical and mental health
			m2/ inhabitant	WHO, 2012	Expert consultation on health indicators of sustainable cities	↑ GS ↑ Social cohesion ↑ PA ↑ Healthy nutrition		↑ Physical and mental health
			52 m2/ inhabitant	Hino et al, 2011	Studying the relationship between measures of built environment and recreational PA	↑PA		↑ Physical and mental health
			Mexico (Baja California): 10 m2/ inhabitant WHO: 9 m2/ inhabitant	Peña-Salmon & Rojas-Caldelas, 2009	Studying a methodological proposal for planning urban GS based on a sustainability perspective	↑ GS ↑ Social contact	↓ Stress	↑ Physical and mental health
		Accessibility, Availability & Quality	% of GS (availability)	Huang et al, 2017	Studying the health benefits provided by GS in 28 megacities, through indicators of availability and accessibility	↑ GS ↑ Restoration effect ↓ Air pollution ↓Noise ↓Heat effect (UHI) ↑ PA ↑ Social contact	↑ Mental health ↑ Self-reported health ↑ Recovery from surgery ↓ Stress ↓ CVD	↑ Physical and mental health
			# facilities (fitness zones)	Bostrom et al, 2017	Studying the implementation and measurement of fitness zones in GS to increase PA	↑ GS ↑ PA	↓ CVD ↓ Obesity ↓ Type 2 diabetes ↓ Stress	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Usability = PA, rest and relaxation opportunities (#features)	Liu et al, 2017	Studying the association between socio-demographic, environ- mental, and individual factors with regards to their impact on GS visitation	↑ GS ↑ Restoration effect ↑ PA	↑ Relaxation	↑ Physical and mental health
			Number of park amenities/ facilities (bathrooms, water fountains, lights) + Number of Aesthetic features + Number of Concerns (graffiti)	Kaczynski et al, 2016	Developing a Park index to explore the potential for GS use	↑ GS		↑ Physical and mental health
			Percentage of GS area Number of inhabitants with a garden Number of inhabitants with view of GS Number of inhabitants visiting GS	Ward Thompson et al, 2016	Studying the effect of GS access in people's stress levels	↑ GS ↓ Social isolation ↓ Sense of belonging ↑ PA	↓ Self-rated stress ↑ Mental health	↑ Physical and mental health
			↑ Easy to reach percentage of youth accessing the GS ↑ Characteristics supporting accessibility Number of amenities offered	Aytur et al, 2014	Studying measures of PA in outdoor community recreational environments, to enhance their usability, focused on people with mobility limitations	↑ GS ↑ PA	↓ CVD	↑ Physical and mental health
			Number of amenities, Safety (↑lighting) and environmental qualities (shades and paths)	Dzhambov & Dimitrova, 2015	Studying the effect of GS on noise sensitivity and noise annoyance	↓ Noise	↓ Noise annoyance ↑ Noise sensitivity	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			50–55 dB LAeq,16 55 dB Lnight interim target (WHO) Noise ≤60 dB	Jabben et al, 2014	Proposing , indicators to characterize the intrinsic environmental properties and external value of GS	↓ Noise ↑ Restoration effect		↑ Physical and mental health
			Place factor: Serene, spacious, wild, culture and lush	Annerstedt Van Den Bosch et al, 2012	Studying the effect of GS qualities on mental health	↑ GS ↑ PA ↑ Stress relief	↑ Mental health	↑ Physical and mental health
		Size	>800 m2	Graça et al, 2018	Studying how different types of urban green spaces influence ES delivery	↑ GS ↑ ES: ↑Air quality ↑ ES: ↓Water runoff ↑ ES: ↑Climate regulation		↑ Physical and mental health
			≤ 0.25ha ≤ 0.5ha ≤ 0.25ha	Smith et al, 2017	Studying quantitative indicators of natural environment exposure in different cities of Europe	↑ GS ↑ Restoration effect ↑ PA ↑ Social contact	↓ Stress*	↑ Physical and mental health
			Min. size 1ha	Ekkel & De Vries, 2017	Reviewing GS accessibility measures	↑ GS ↑ PA ↑ Social cohesion ↑ Restoration effect		↑ Physical and mental health
			Min. size 1ha	Huang et al, 2017	Studying the health benefits provided by GS in 28 megacities, through indicators of availability and accessibility	↑ GS ↑ Restoration effect ↓ Air pollution ↓Noise ↓Heat effect (UHI) ↑ PA ↑ Social contact	↑ Mental health ↑ Self-reported health ↑ Recovery from surgery ↓ Stress ↓ CVD	↑ Physical and mental health
			Min. size 1ha	Annerstedt Van Den Bosch et al, 2016	Developing and testing a GS indicator for public health	↑ GS ↑ PA ↑ Stress relief	↓ Stress	↑ Physical and mental health
			≤ 0.5ha	WHO Regional office Europe, 2016	Studying the indicator of GS and its mechanisms to provide health benefits	↑ GS ↑ PA ↑ Air quality ↓ Stress relief ↑ Restoration effect ↑ Social cohesion	↓ NCDs ↓ Stress ↑ Immune system response ↑ Restoration	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Min. size 2ha	Kabisch et al, 2016	Studying GS availability in 299 European cities, and the development of a GS availability indicator	↑ GS ↑ PA	↓ CVD ↓ Mortality ↑ Mental health	↑ Physical and mental health
			> 2.5 m2 ≤ 720 km2	Ngom et al, 2016	Studying the effects of type and proximity to GS in cardiovascular and diabetes morbidity	↑ GS ↓ Air pollution ↑ PA	↓ CVD* ↓ Diabetes ↓ Hypertension	↑ Physical and mental health
		Ecosystem Services & Biodiversity	NDVI > 0	Smith et al, 2017	Studying quantitative indicators of natural environment exposure in different cities of Europe	↑ GS ↑ Restoration effect ↑ PA ↑ Social contact	↓ Stress*	↑ Physical and mental health
			NDVI > 0	Huang et al, 2017	Studying the health benefits provided by GS in 28 megacities, through indicators of availability and accessibility	↑ GS ↑ Restoration effect ↓ Air pollution ↓Noise ↓Heat effect (UHI) ↑ PA ↑ Social contact	↑ Mental health ↑ Self-reported health ↑ Recovery from surgery ↓ Stress ↓ CVD	↑ Physical and mental health
			NDVI > 0	Ekkel & De Vries, 2017	Reviewing GS accessibility measures	↑ GS ↑ PA ↑ Social cohesion ↑ Restoration effect		↑ Physical and mental health
			NDVI > 0	WHO Regional office Europe, 2016	Studying the indicator of GS and its mechanisms to provide health benefits	↑ GS ↑ PA ↑ Air quality ↓ Stress relief ↑ Restoration effect ↑ Social cohesion	↓ NCDs ↓ Stress ↑ Immune system response ↑ Restoration	↑ Physical and mental health
			NDVI > 0 (0.3-0.8)	Senanayake et al, 2013	Analyzing the environmental quality based on GS	↑ GS ↓ Air pollution ↑ Economic benefits ↓ Population density ↓Vehicles density		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			CO_2 absorption capacity	Peña-Salmon & Rojas-Caldelas, 2009	Studying a methodological proposal for planning urban GS based on a sustainability perspective	↑ GS ↑ Social contact	↓ Stress	↑ Physical and mental health
			Tree density, tree species density, diameter of breast height, tree leaf area, tree leaf biomass, Simpson's diversity index on species dominance	Graça et al, 2018	Studying how different types of urban green spaces influence ES delivery	↑ GS ↑ ES: ↑Air quality ↑ ES: ↓Water runoff ↑ ES: ↑Climate regulation		↑ Physical and mental health
	Blue Space	Distance	300m*; 500m; 1km	Smith et al, 2017	Studying quantitative indicators of natural environment exposure in different cities of Europe	↑ GS ↑ Restoration effect ↑ PA ↑ Social contact	↓ Stress*	↑ Physical and mental health
			≤ 1600m	Christian et al, 2017	Studying the relationship between neighborhood environment attributes and walkability	↑ BS ↑ PA (walking)	↓ NCDs	↑ Physical and mental health
			Buffers: ≤1km*; 1 to 5km; 5 to 20km; 20 to 50km; 50km	Wheeler et al, 2012	Studying the effects of coastal proximity (BS) on health	↑ BS	↑ Self-rated health	↑ Physical and mental health
			Buffers: <300m*; 300m to 1km; 1 to 5km; > 5km	Schipperijn et al, 2010	Studying the factors that influence the use of GS	↑ GS ↑ BS		↑ Physical and mental health
		Type	Fresh inland water (standing or linear), coastal water	Smith et al, 2017	Studying quantitative indicators of natural environment exposure in different cities of Europe	↑ GS ↑ Restoration effect ↑ PA ↑ Social contact	↓ Stress*	↑ Physical and mental health
Built environment	Public Open Space POS	Distance	≤ 400m	Hooper et al, 2018	Studying POS standards and their relationship to PA	↑ Service provision ↑ PA		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			≤ 400m	Bahadure & Kotharkar, 2018	Studying measures of sustainability at the neighborhood level based on composite indicators	↑ Mixed-land use ↑Sustainability		↑ Physical and mental health
			≤ 400m	Hooper et al, 2015	Studying specific design features that showed the strongest associations with PA behaviors	↑ Service provision ↑ GS ↑ PA		↑ Physical and mental health
			≤ 1 km	Koohsari et al, 2013	Studying proximity measures to examine associations with amount of PA and POS	↑ Air quality ↑ PA ↑ Quality of life ↑ Social cohesion		↑ Physical and mental health
			≤ 500 m	Hino et al, 2011	Studying the relationship between measures of built environment and recreational PA	↑ PA		↑ Physical and mental health
			≤10min walk ≤700m elderly	Sugiyama et al, 2009	Studying aspects of neighborhood open space associated with health, life satisfaction, and PA for elderly people	↑ Liveability/life satisfaction ↑ Social cohesion ↑ PA elderly	↓ CDV ↓ Diabetes type 2 ↓ Cancer ↓ Depression ↓ Anxiety	↑ Physical and mental health
		Proportion	40 m2/inhabitant 20 m2/inhabitant	Bahadure & Kotharkar, 2018	Studying measures of sustainability at the neighborhood level based on composite indicators	↑ Mixed-land use ↑Sustainability		↑ Physical and mental health
		Accessibility, Availability & Quality	Number of POS	Koohsari et al, 2013	Studying proximity measures to examine associations with amount of PA and POS	↑ Air quality ↑ PA ↑ Quality of life ↑ Social cohesion		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Good quality paths: easy to walk, enjoyable no obstacles (0) Pleasantness (adequacy to engage in activities, quality of trees and number of facilities)	Sugiyama et al, 2009	Studying aspects of neighborhood open space associated with health, life satisfaction, and PA for elderly people	↑ Liveability/life satisfaction ↑ Social cohesion ↑ PA elderly	↓ CDV ↓ Diabetes type 2 ↓ Cancer ↓ Depression ↓ Anxiety	↑ Physical and mental health
	Urban Environment	Environmental exposures	Lden= 61-65 dB [Polish standards]	Koprowska et al, 2018	Studying objective and subjective noise exposures in relation to urban GS availability	↑ GS ↓ Noise	↓ CVD ↓ Annoyance ↓ Sleep disturbance ↓ Cognitive impairment	↑ Physical and mental health
			45-55 dB residential noise/ 55-65 dB commercial noise	Bahadure & Kotharkar, 2018	Studying measures of sustainability at the neighborhood level based on composite indicators	↑ Mixed-land use ↑Sustainability		↑ Physical and mental health
			≤ 55 dB Lden ≤ 50dB Lnight	D'Alessandro & Schiavoni , 2015	Reviewing European priority indices for noise action plans	↓ Noise	↓ CVD ↓ Annoyance ↓ Sleep disturbance	↑ Physical and mental health
			Air pollution (NO and SO)	Senanayake et al, 2013	Analyzing the environmental quality based on GS	↑ GS ↓ Air pollution ↑ Economic benefits ↓ Population density ↓Vehicles density		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Biological effects: L Amax, inside ≤32 to 35 dB Sleep quality: L Amax inside ≤42 dB L night, outside ≤42 dB Well-being: L night, outside ≤40 to 42 dB Medical conditions: L night, outside ≤42 dB	WHO Regional office Europe, 2009	Night noise guidelines for Europe	↓ Noise ↑ Sleep ↓ Self-reported disturbance ↓ Sedative drugs use	↑ Restoration ↓ Insomnia ↓ Anxiety ↓ Psychiatric disorders ↓ Noise ↑ Cognition and SWS	↑ Physical and mental health
			Respiratory hazard index (EPA); PM<2.5 µm & PM2.5. Values >1 in NATA's hazard index Ozone: ≥85 ppb Nitrate level: 2mg/L (EPA) Lead: Percentage of houses with higher lead risk, Percentage of children with (+) lead poisoning (10 µg/dL) Radon risk (4 pCi/L)	Athens et al, 2008	Studying the methods used to develop a summary measure of the environmental health	↓ Air pollution ↓ Water pollution ↓ Metal pollution	↓ Cancer ↓ Respiratory diseases ↓ Cognitive and behavioral problems in children ↓ Fertility in adults ↓ Lung cancer	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Particulate Matter: PM2.5≤ 10 µg/m3 annual mean 25 µg/m3 24-hour mean PM10≤ 20 µg/m3 annual mean 50 µg/m3 24-h mean Ozone: O3: daily max. 8h mean (µg/m3) ≤100 Nitrogen dioxide: NO2≤ 40 µg/m3 annual mean NO2≤ 200 µg/m3 1-h mean Sulfur dioxide: SO2≤ 20 µg/m3 24-h mean 500 µg/m3 10-min mean	WHO, 2005	Air quality guidelines for particulate matter, ozone, nitrogen	↓ Air pollution	↑ Cardio-pulmonary function ↓ Lung cancer ↓ Mortality	↑ Physical and mental health
			Noise ≤55 dB day time (7:00-23:00h) LAeq,24h ≤70 dB(A) Speech intelligibility: 300 to 3000 Hz Sleep: ≤30 dB(A) Annoyance: ≤80 dB(A)	WHO, 1999	Guidelines for community noise	↓ Noise ↑ Sleep	↓ Hearing impairment ↓ Interference with speech communication ↓ Anxiety ↓ Annoyance ↓ Stress	↑ Physical and mental health
		Safety	# Fatal accidents/annum/unit area #Crimes/ 1000 persons	Bahadure & Kotharkar, 2018	Studying measures of sustainability at the neighborhood level based on composite indicators	↑ Mixed-land use ↑Sustainability		↑ Physical and mental health
			Number of traffic lights	Hino et al, 2011	Studying the relationship between measures of built environment and recreational PA	↓ Accidents ↑ PA		↑ Physical and mental health
			Safety scale from traffic, satisfaction with sidewalks quality	Gómez et al, 2010	Studying the association between built environment and walking patterns of elderly people	↑ GS ↑ PA ↓ Accidents	↓ NCDs ↓ Bone fracture	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			Night safety Number of crime=0	Sugiyama et al, 2009	Studying aspects of neighborhood open space associated with health, life satisfaction, and PA for elderly people	↑ Liveability/life satisfaction ↑ Social cohesion ↑ PA elderly	↓ CDV ↓ Diabetes type 2 ↓ Cancer ↓ Depression ↓ Anxiety	↑ Physical and mental health
	City fabric	Street connectivity	Median block length	Satariano et al, 2016	Studying the relationship between neighborhood characteristics and PA of elderly with mobility disability	↑ PA ↑ Body function	↑ Mobility ↓ Premature death	↑ Physical and mental health
			Number of junctions/ street km	Hooper et al, 2015	Studying specific design features that showed the strongest associations with PA behaviors	↑ Service provision ↑ GS ↑ PA		↑ Physical and mental health
			Percentage of urban streets with sidewalks (walkability) Km cycle lanes constructed/ year (cyclability)	WHO, 2012	Expert consultation on health indicators of sustainable cities	↑ GS ↑ Social cohesion ↑ PA ↑ Healthy nutrition		↑ Physical and mental health
			Number of street links/ Number of street nodes	Gómez et al, 2010	Studying the association between built environment and walking patterns of elderly people	↑ GS ↑ PA	↓ NCDs ↓ Bone fracture	↑ Physical and mental health
			Number of junctions/ street km Street density/ street length	Coombes et al, 2010	Studying the association between access to GS, PA and the odds of being overweight or obese	↑ GS ↑ PA	↓ Overweight ↓ Obesity	↑ Physical and mental health
		Distance to services and facilities	150 - 300 m; 200m*	Bahadure & Kotharkar, 2018	Studying measures of sustainability at the neighborhood level based on composite indicators	↑ Mixed-land use ↑Sustainability		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
			≤ 150m to high traffic road Distance (m or min) to healthcare services (mother, child) Number healthcare services (medical density)	Padilla et al, 2016	Studying the relationship between child and neonatal mortality and indicators of environmental inequalities: environmental exposure, access to healthcare and deprivation	↓ Inequalities ↓ Environmental exposures ↓ Air pollution ↑ Healthcare access	↓Child and neonatal mortality	↑ Physical and mental health
			400m bus stop 800m rail stop	Giles-Corti et al, 2016	Studying the health impact of city planning in creating healthier and more sustainable compact cities, through changing transport mode choices	↑Street connectivity ↓Traffic hazards ↑Availability ↓Crime ↑Social and physical activities ↑Commercial and recreational opportunities ↑Local business opportunities ↑Mixed-land use ↓ Traffic incidents ↓ Air pollution ↓ Risk factors	↓ CVD ↓ Road trauma ↓ Respiratory diseases ↓ Mental illness ↓ Diabetes type 2 ↓ Cancer	↑ Physical and mental health
			Number of services within 2-3 blocks	Satariano et al, 2016	Studying the relationship between neighborhood characteristics and PA of elderly with mobility disability	↑ PA ↑ Body function	↑ Mobility ↓ Premature death	↑ Physical and mental health
			≤ 1600m ≤ 400m bus stop ≤ 800m train station ≤ 1600m to primary school	Hooper et al, 2015	Studying specific design features that showed the strongest associations with PA behaviors	↑ Service provision ↑ GS ↑ PA		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
	Land use	Density & Sprawl	People/ unit area (80 - 150 inhabitants/ ha) % Working population (33%)	Bahadure & Kotharkar, 2018	Studying measures of sustainability at the neighborhood level based on composite indicators	↑ Mixed-land use ↑Sustainability		↑ Physical and mental health
			1000 people/ km2	Fang, 2017	Studying GS accessibility using two thresholds and exploring changes over time	↑ GS ↑ Social interaction		↑ Physical and mental health
			Degree of dispersion of a geographical area	Mosammam et al, 2016	Studying land use land cover and urban sprawl	↑ Density ↓ Car dependence ↑ Fertile land to plant ↑ Air quality		↑ Physical and mental health
			Dwellings within 1·2 km of activity centers and public transport hubs. Higher density in central areas.	Giles-Corti et al, 2016	Studying the health impact of city planning in creating healthier and more sustainable compact cities, through changing transport mode choices	↑Local business opportunities ↑Mixed-land use	↓ CVD ↓ Road trauma ↓ Respiratory diseases ↓ Mental illness ↓ Diabetes type 2 ↓ Cancer	↑ Physical and mental health
			Number of inhabitants /km2	Senanayake et al, 2013	Analyzing the environmental quality based on GS	↑ GS ↓ Air pollution ↑ Economic benefits ↓ Population density ↓Vehicles density		↑ Physical and mental health
			Number of inhabitants/ m2	Hino et al, 2011	Studying the relationship between measures of built environment and recreational PA	↑ PA		↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
		Land composition & desirability	Ped-sheds2 ≥0·6 within 0·8–1·2 km Crime prevention principles, reduced traffic exposure and greenness Mix of housing types and local destination	Giles-Corti et al, 2016	Studying the health impact of city planning in creating healthier and more sustainable compact cities, through changing transport mode choices	↑Street connectivity ↓Traffic hazards ↑Availability ↓Crime ↑Social and physical activities ↑Commercial and recreational opportunities ↑Local business opportunities ↑Mixed-land use ↓ Traffic incidents ↓ Air pollution ↓ Risk factors	↓ CVD ↓ Road trauma ↓ Respiratory diseases ↓ Mental illness ↓ Diabetes type 2 ↓ Cancer	↑ Physical and mental health
			Number of food shops, number of alcohol shops, number of general services	Hooper et al, 2015	Studying specific design features that showed the strongest associations with PA behaviours	↑ Service provision ↑ GS ↑ PA		↑ Physical and mental health
			Number of fresh food markets/ km2	WHO, 2012	Expert consultation on health indicators of sustainable cities	↑ GS ↑ Social cohesion ↑ PA ↑ Healthy nutrition		↑ Physical and mental health
			Number of recreational infrastructures ≤ 500 m Access within shortest distance to recreational facilities	Hino et al, 2011	Studying the relationship between measures of built environment and recreational PA	↑ PA		↑ Physical and mental health
			Number of land uses Percentage buildings in area (commercial or residential)	Coombes et al, 2010	Studying the association between access to GS, PA and the odds of being overweight or obese	↑ GS ↑ PA	↓ Overweight ↓ Obesity	↑ Physical and mental health

Environment	Policy	Indicator	Benchmarks	Authors	Study objective	Health pathway	Health endpoint	General outcome
		Housing	Number of different housing types	Hooper et al, 2015	Studying specific design features that showed the strongest associations with PA behaviors	↑ Service provision ↑ GS ↑ PA		↑ Physical and mental health
			Percentage of urban slum	WHO, 2012	Expert consultation on health indicators of sustainable cities	↑ GS ↑ Social cohesion ↑ PA ↑ Healthy nutrition		↑ Physical and mental health

Table 6. Identified quantitative indicators and orientative benchmarks

Policy	Indicator	Benchmark
Green space	Distance	≤ 300 m to GS
	Proportion	10 m^2/inhabitant
	Size	≤ 0.5ha
Blue space	Distance	≤ m to BS
POS	Distance	≤ 400 m to POS
	Proportion	m^2/inhabitant
Urban environment	Environmental exposures	**Noise:** ≤ 55 dB day time and ≤ 40 dB night time **Air:** Particulate Matter: $PM_{2.5}$≤ 10 µg/m^3 annual mean 25 µg/m^3 24-hour mean PM_{10}≤ 20 µg/m^3 annual mean 50 µg/m^3 24-h mean Ozone: O_3: daily max. 8h mean (µg/m^3) ≤100 Nitrogen dioxide: NO2≤ 40 µg/m^3 annual mean NO2≤ 200 µg/m^3 1-h mean Sulfur dioxide: SO_2≤ 20 µg/m^3 24-h mean 500 µg/m3 10-min mean

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