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Review

Walking Behavior of Older Adults and Air Pollution: The Contribution of the Built Environment

Mohammad Paydar [1], Asal Kamani Fard [2,*] and Soheil Sabri [3]

[1] Escuela de Arquitectura Temuco, Facultad de Ciencias Sociales y Artes, Universidad Mayor, Av. Alemania 0281, Temuco 4780000, Chile; mohammad.paydar@umayor.cl
[2] Departamento de Planificación y Ordenamiento Territorial, Facultad de Ciencias de la Construcción y Ordenamiento Territorial, Universidad Tecnológica Metropolitana, Dieciocho 390, Santiago 8330526, Chile
[3] Urban Digital Twin Lab, School of Modeling Simulation and Training, University of Central Florida, 3100 Technology Parkway, Orlando, FL 32826, USA; soheil.sabri@ucf.edu
* Correspondence: akamani@utem.cl

Abstract: Although an increase in walking is recommended to improve physical activity and public health, especially among older adults, the frequency of outdoor pedestrian activities, including walking, should be reduced when there is increased air pollution. There is limited understanding of the inter-relationships between two research fields, namely, older adults walking behavior and air pollution. This study investigates these factors and identifies their relationships with associated built environment factors. More than 200 peer-reviewed journal articles that met the selection criteria were analyzed. The factors pertaining to air pollution in the built environment were classified based on the scale of the urban environment. Comparing the built environment factors related to both fields of study, several common features such as the type of street enclosure (urban spatial), sky view factor (urban spatial), percentage of front gardens (urban design), and land use patterns were identified. Furthermore, we found that it is important to understand how the subjective/objective measures of the urban-design-related factors identified on the street are linked to air pollution at both street and neighborhood scales. A wide range of urban vegetation factors (pattern, size, and density) in both fields of study at a street scale were also identified. These inter-relationships need to be examined by future studies to get a clearer picture of the factors which might improve walking behavior among older adults while reducing the air pollution in urban environments.

Keywords: air pollution; walking behavior; older adults; built environment; urban design

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1. Introduction

Obesity has been increasing in many countries worldwide, and obesity-related health conditions are the number one risk factor for death and disability, especially among older adults [1,2]. At the same time, regular physical activity improves health conditions and, accordingly, the quality of life among older adults [3]; therefore, there needs to be an increase in physical activity, especially among this special age cohort [4]. For instance, over the last decade, the percentage of elderly people (over the age of 65) who did not attain the recommended 150 min of physical activity per week increased by 9% from 2010 to 2017 in Chile [5,6]. As one kind of regular moderate physical activity that people of all ages worldwide practice, walking is also an easily accessible physical activity [7] that contributes to maintaining the minimum level of physical exercise and improving physical health [8]. Therefore, increasing the amount of walking among older adults can make an important contribution toward meeting their recommended level of physical activity and improving their general health.

According to ecological models, the built environment is important for improving walking behavior, walking, and the propensity to walk [9,10]. The built environment plays a vital role in enhancing walking behavior among older adults, since they are more sensitive than other groups to the built environment's suitability for walking [11]. Previous studies showed the contribution of several built environment features toward improving the walking behavior of older adults, including population/housing density, access to parks, green spaces, different facilities, mixed land use, infrastructure, and the functional aspects of walking environments, such as walking facilities, traffic safety, personal security, and the aesthetic attributes of the walking environment [12–16]. These built environment features have been examined in terms of their association with walking behavior as well as the tendency for older adults to walk at different urban scales.

In addition, many cities worldwide encounter medium-to-high air pollution, especially during certain seasons, which strongly affects the public health of their inhabitants [17–20]. Although increased walking is recommended to improve physical activity and public health, especially among older adults, the frequency of outdoor pedestrian activities, such as walking, should be reduced with increased air pollution. This is due to the severe effects of air pollution on their health, since older adults are counted among the most vulnerable groups. Thus, while the walking frequency of older adults should generally be increased to raise the minimum level of physical activity and general health, such physical activity also needs to be reduced in cities/seasons with medium-to-high air pollution. This is a problem that needs addressing in such cities to protect the general health of older adults.

Furthermore, it should be mentioned that pedestrians' awareness of air pollution may deter them from stepping outside. Nonetheless, for the reasons listed below, people's regular outdoor walking is rarely affected by this awareness. First, the relationship between ambient air pollution exposure and perception of air quality is still being determined [21]. Some studies observed associations between public perceptions of air quality and pollution exposure [22,23], while others did not [21,24]. Second, it was demonstrated that not everyone has the same perception of air pollution and that only specific individuals—such as those with respiratory issues—perceive air pollution to be worsening considerably more [21]. Third, even though it is possible that the awareness of air pollution could prevent people from walking outdoors, this awareness usually works well when air pollution reaches the warning level for all groups (151 < air quality index < 200), as this is typically when the media begins seriously warning the public [23]. Put another way, many people may carry on with their regular daily activities, including strolling outdoors, as long as air pollution has not reached serious alert conditions for all individuals (151 < air quality index < 200). The health of those more vulnerable to air pollution, such as older adults, could experience serious effects from this, as their health may still be significantly impacted by an air pollution index below 150 while walking outdoors (e.g., 101 < air quality index < 150).

The mentioned problem regarding the conflict between the improvements from outdoor walking gained by older adults and the need to reduce their outdoor walking at the same time—which air pollution enhances—is especially important when considering the built environment's impact on these relationships. There are several built environment features (e.g., housing density, street connectivity, mixed land use, and aesthetic-related factors including vegetation patterns) that contribute to an improvement in the walking behavior of older adults in different environments. Thus, these features should be improved based on the findings of relevant studies [13,14,25]. However, the built environmental factors that positively correlate with the walking frequency of older adults in normal situations (e.g., aesthetic-related factors and mixed land use) should not be applied by urban and transport policymakers in cities/seasons with medium-to-high air pollution because of the need to reduce the outside walking frequency of older adults, which air pollution enhances. This means the same environmental factors that help older adults walk more often should be applied in the opposite way to prevent them from walking and protect their health as air pollution increases. This is a significant problem that needs to be addressed in such cities and seasons. Otherwise, the results of studies on the relationships between walking behavior and the built environment do not make sense in such cities, especially about seasons when there is higher air pollution. Therefore, we argue that relationships between the walking behavior of older adults and the built environment must be concurrently examined with the relationships between these same built environmental factors and air pollution to achieve more realistic results. To the best of our knowledge, these relationships, taking into account both subjects, have yet to be concurrently considered. It is also vital to consider how different urban scales may play a significant role in these interactions.

This review study aims to highlight the inter-relationships between two lines of study, including the walking behavior of older adults (over the age of 65) and air pollution in terms of their connection with built environment features. This can help design and redesign the built environment to enhance the walking behavior of older adults and simultaneously reduce air pollution in cities/seasons with medium-to-high air pollution. In this regard, this review offers future research directions by clarifying the links between the two disciplines of walking behavior and air pollution in terms of the jointly built environmental factors at different urban scales and in different urban contexts with medium-to-high air pollution conditions. These outcomes will eventually help balance enhancing older adults' walking habits and lowering air pollution, based on new arrangements of built environmental factors.

The second section presents the literature review methods, followed by the section on the results. The first subsection of the results reviews the relationships between the walking behavior of older adults and the built environment. Then, the paper focuses on the relationship between air pollution and the built environment. This subsection is itself classified into four sub-subsections, based on the scale of the urban environments. In the next section, the findings are discussed in terms of the built environment's contribution to the walking behavior of older adults and air pollution at different urban scales. Finally, the section on the conclusions highlights the main findings and provides an agenda for future directions. Figure 1 shows the conceptual framework of this study.

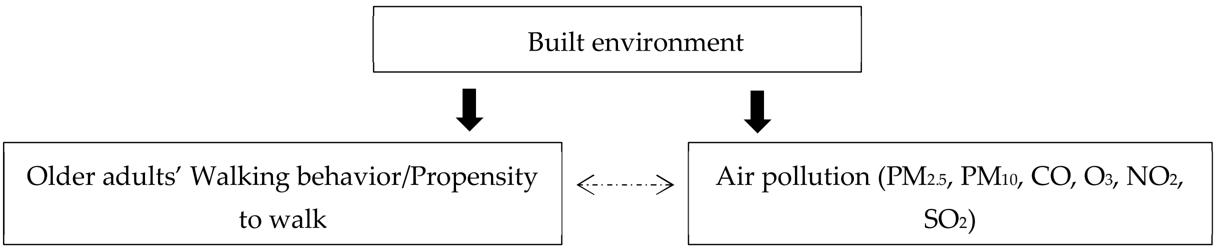

Figure 1. The conceptual framework regarding the associations among walking behavior, air pollution, and the built environment.

2. Literature Review Methods

We systematically searched English language journals in databases including the Web of Science Core Collection, PubMed, Avery, the Environment Index, Medline, and Academic Search Complete. And just the articles from peer-reviewed journals were selected. This study only reviewed articles between 2000 and 2023 with quantitative research methods combining cross-sectional and longitudinal studies. For the first subsection, the combined keywords were walking, propensity to walk, pedestrians, seniors, older adults, the elderly, neighborhood, and the built or physical environment. Studies were included if the minimum age of the research participants was 60 years. Regarding different types of walking, studies, including transport/utilitarian walking, recreational walking, and total walking of older adults, were selected. Then, articles were chosen regardless of whether the built environment is measured using subjective, objective, or combined methods. Such studies were excluded if the dependent variables were related to physical activity rather than walking.

It should be noted that earlier studies also assessed the relationship between the built environment features and microscale walking behavior among older adults because this group of people usually participates in interesting or pleasurable activities at the street scale. While considering older adults walking at a street scale, previous studies evaluated older adults' walking behavior (mostly measured by the number of pedestrians at each street link), path choice, and perceived attractiveness for walking along the pathways. In this regard, the combination of keywords of walking, older adults, street, path choice, the propensity to walk, and perceived attractiveness for walking was used to search for new articles at this urban scale. These new articles are included in Section 3.1. The final paragraph of Section 3.1 is devoted to studies that examined the relationships between older adults' street-level walking behavior and built environmental features.

In Section 3.2, a combination of the keywords including "urban form", "built environment", "sprawl", "compact form", and "air pollution" was used. Then, we excluded papers that did not directly address our main topic (the relationships between the built environment and air pollution), such as those that dealt with environmental justice, environmental equality, and SES at the level of the neighborhood. In addition, studies that examined various urban pollutants (as opposed to studies that just examined wind speed or wind direction) but did not include $PM_{2.5}$ in their investigations were not considered, due to the special role that $PM_{2.5}$ plays in transport-related air pollution. Later, articles were divided into three categories based on the scale of the urban environments: macroscale (city scale), mesoscale (neighborhood scale or scales of buffer zones between 100 and 1000 m radius), and street scale (street canyon). This classification was used to review the relationships between various types of pollutants and the urban form and the built environment. Finally, one subsection is devoted to the relationships between urban vegetation and air pollution at different urban scales due to the significant impact of urban vegetation on air pollution at different urban scales. To arrange the former subsection, all the articles from the previous three subsections—that considered the relationships between green spaces and air pollution—were selected. However, deposition/absorption and aerodynamic impacts are two main ways urban vegetation affects air pollution dispersion. As a result, the search continued using the keywords "street canyon", "greenery", "deposition", and "aerodynamic impact" in combination to find new articles. These new articles were also used to form the last subsection.

To analyze the selected articles (more than 200 remaining articles from both fields of research), summaries of each article were recorded, including the author, year, study objectives, methodology, sample, location, independent and dependent variables, and a summary of the statistical results regarding the significant and non-significant variables. Particular attention was paid to the validity and reliability of the data collection tools. The synthesis concentrated on the Results section that contained the extracted dependent and independent variables from each article (paying particular attention to the built environmental factors), the rationale behind selecting the built environmental factors, and the relationships between the dependent and independent variables. The most common threshold was $p = 0.05$, which determines the significant or non-significant relationship between the endogenous and exogenous variables. Regardless of the degree of correlation, attributes with positive and negative values across the selected studies were combined and marked with an asterisk (*). Three main types of associations, including "No association", "Positive significant association", and "Negative significant association", were categorized through different codes. For instance, (+) was used for positive association, and (-) was used for negative association. The moderation effects were excluded from the association calculation. We also disregarded other kinds of data and conclusions that had nothing to do with how the built environment affects walking behavior and air pollution. However, the control variables from each article were also extracted because of the potential importance of confounders or additional factors that could have affected the study's results.

3. Results

3.1. Impacts of the Built Environment on the Walking Behavior/Tendency to Walk of Older Adults

The walking measurements (such as walking minutes weekly, daily walking minutes, weekly walking frequency, the percentage of individuals reaching 150 min or more per week, the percentage of no walking, and the number of walking days per week) were highly diverse. However, the most commonly measured walking behavior outcomes were walking minutes per week and the ratio of certain walking minutes or above per week (i.e., percentage of older adults walking 150 min/week or not walking).

According to studies on the built environment and walking behavior [12,26–28], increased population and housing density help older individuals to walk more. According to Lamquiz and Lopez-Domnguez [29], the percentage of walking trips positively correlates with resident density, retail food density, and job density. Dovey and Pafka [30] discovered that density promotes vibrant street life and easy access to various amenities on foot. Elderly people's walking behavior is improved by having access to various facilities like shops and restaurants [31–33]. Similarly, having access to parks and playgrounds improves elderly people's propensity to walk [12,34–36]. However, several researchers did not discover a connection between park access and senior citizens' walking behavior [37]. Elderly people's walking behavior improves when more bus stops are present [33,38]. Additionally, mixed land use is favorably connected with senior people's walking behavior in terms of both diversity and accessibility [39–41]. However, Thornton et al.'s [14] research discovered a negative association between mixed land use and senior citizens' recreational walking. Finally, the type of house, whether a villa or apartment, influences older adults' walking level [42].

Furthermore, how elderly individuals walk is tied to the environment's infrastructure or functional features. For instance, according to Thornton et al. [14], Todd et al. [36], Troped et al. [43], and Van Holle et al. [44], a more connected walking network improves the walking behavior of senior persons. Infrastructure as a whole helps older individuals walk more comfortably [39,45]. Other functional elements of pedestrian networks that have a favorable impact on senior citizens' walking behavior include the existence of sidewalks and the condition of the pavement [12,41,46,47]. Seniors are more likely to desire to walk when the sector is longer and the routes are wider [48]. According to Cerin et al. [49], Cerin et al. [50], and Barnett et al. [39], "amenities along the sidewalks"—including places for resting or sitting—are another element that improves elderly people's walking behavior. "Physical barriers along the sidewalks" are another practical element that adversely impacts how elderly people walk [51,52]. Less sloping along walkways improves senior people's propensity to walk [53,54]. In addition, the availability of bicycle lanes is linked to an increase in senior individuals' walking [55].

Additionally, walking by senior individuals is favorably connected with perceived traffic safety [25,54–56]. Seniors' propensity to walk is negatively impacted by traffic volume [12,51,56]. Older adults walk more frequently when more crosswalks and curb cuts are present [12,57]. Similar to this, more traffic control systems and crossing aids, including traffic lights and pedestrian signals, improve elderly people's propensity to walk [57,58]. More perceived personal security (protection from crime) and a lower crime rate also improve older individuals' propensity to walk [12,55,58,59]. The presence of street lighting improves elderly people's walking behavior, as one of the connected environmental elements to personal security [12,53]. The presence of other individuals improves older people's security, which is another environmental aspect related to personal security [55,60–62]. Elderly persons who exhibit more symptoms of illnesses, physical infirmities, and stray animals tend to walk less [53,63,64]. Finally, the increased degree of surveillance from neighboring buildings and a lower percentage of blind walls also improve senior people's walking behavior [31,65].

Finally, according to several studies [26,35,66–68], the aesthetic qualities of the walking environment and the design elements of the path context are crucial in improving older adults' walking behavior. However, they have a stronger connection to leisure walking than to walking for transportation [69]. Numerous factors, including visual attraction, the visibility of landmarks along the pathways, the vistas of public gardens, the transparency of fronting structures, visible activity, street trees, and illumination, were discovered to be associated with the surrounding environment of the pathway [70–75]. The scale of the street space, the presence of street trees, visible activity, transparency, and the coherence of the built form are likely to contribute to the quality of the path surroundings. However, as stated by Southworth [74], there is no universal spatial design theory for the pedestrian environment. Elderly people's walking behavior is favorably influenced by the presence of natural views [53], but there is a negative link with litter on the sidewalks [57]. According to several studies [16,31,66,67,76,77], parks and green spaces also improve older persons' walking behavior. Elderly individuals are more likely to walk when there are more trees along the walkways, front gardens, and levels of greenery [31,78]. In addition, the types of buildings' facades and how well they are maintained match senior people's walking desire [58,65]. Older people's walking behavior was also influenced by off-street parking lot spaces, building height, architectural articulation, and the degree of enclosure [13,78].

The aesthetic and design-related factors along walkways are more related to the dimension of "want to", when taking into account the three dimensions of "need, can, and want to", concerning the walking of older adults. According to Krogstad et al. [9], these factors may contribute to generating a more enjoyable experience of walking, rather than other aspects like walking to meet the daily needs. Older individuals typically engage in exciting or delightful experiences at a street level, as part of their aesthetic experiences along the streets. In this regard, numerous studies concentrated on the characteristics of pathways and their connections to the walking behavior of older adults at the street scale. Table 1 shows the urban-design-related variables and landscape elements that contributed to older adults' walking at the street scale.

Table 1. Street characteristics and landscape elements that contributed to the walking of older adults at the street scale.

Authors (Year)	Street Characteristics and Landscape Elements	Main Findings
Borst et al. [31] (path choice and street characteristics)	Pavement with curb, the presence of the sidewalk, ramps on/off the pavement, slopes and/or stairs, quality of pavement, width of the sidewalk, obstacles, zebra crossings, vegetation and trees along the route, waste terrain, green strips, front gardens, blind walls, fences, benches, bus or tram stops, litter on the street, dog droppings, trees along the route, graffiti, high-rise (>3 stories), vacant buildings, linked to park, street vendors, pedestrian density, traffic volume, crime, number of others, and type of land uses along the streets including dwellings, shops, business buildings, catering establishments.	Positive correlation with path choice: - Pavement with curb - Front gardens - Shops Negative correlation with path choice: - Slopes and/or stairs - Blind wall - Litter on the street
Borst et al. [78] (perceived attractiveness for walking and street characteristics)	Pavement with curb, the presence of the sidewalk, ramps on/off the pavement, slopes and/or stairs, quality of pavement, width of the sidewalk, obstacles, zebra crossings, vegetation and trees along the route, waste terrain, green strips, front gardens, blind walls, fences, benches, bus or tram stops, litter on the street, dog droppings, trees along the route, graffiti, High-rise (>3 stories), vacant buildings, linked to park, street vendors, pedestrian density, traffic volume, crime, number of others, and type of land uses along the streets including dwellings, shops, business buildings, catering establishments.	Positive correlation with attractiveness for walking: - Zebra crossings - Trees along the route - Height of the buildings - Front gardens - Shops and business buildings Negative correlation with attractiveness for walking: - Litter on the street - Vacant buildings - Traffic volume
Hajrasouliha and Yin [79] (pedestrian volume and built environment variables in 302 street segments in Buffalo, US)	Integration, intersection density, land use mix, job density, population density.	Positive correlation with walking behavior: - Job density - Integration - Intersection density

Table 1. *Cont.*

Authors (Year)	Street Characteristics and Landscape Elements	Main Findings
Foltête et al. [80] (walking behavior and landscape elements)	*Vegetation:* bushes, trees, green spaces, squares; *built forms:* small buildings, tall buildings; *visual obstacles:* walls; shrub hedges, lawns, flowers; *empty spaces:* parking lots, rivers; *other variables:* presence of sidewalks, width of sidewalks, residential, commercial.	Positive correlation with walking behavior: - Trees - Squares Negative correlation with attractiveness for walking: - Residential
Zhai and Korca, [48] (walking behavior and pathway design characteristics)	Pathway pavement: pathway form (straight or curving), presence of benches, presence of flowers, presence of steps, degree of shade, presence of light fixtures, pathway width, pathway length, enclosure type (presence of tall objects along pathway), degree of enclosure (lateral visibility), water on side, visual connection with water, visual connection with landmarks, pathway connection with activity zones.	Positive correlation with walking behavior: - Pavement of plastic track and brick - The presence of benches - The presence of light fixtures - Pathway length - Pathways with flowers - Pathways without steps Negative correlation with attractiveness for walking: - Connection with activity zones
Joseph and Zimring [81] (path choice and path design characteristics)	Path type, path segments, path material, path slope, path condition, street crossing, path obstruction, steps, path continuity, amenities, types of destinations, number of destinations, types of views.	Positive correlation with Path choice: - Path segments - The presence of a destination along a path - Path continuity Negative correlation with Path choice: - Path with steps
Isaacs, [82] (walking experience and aesthetic-related factors)	A variety of open spaces are connected by narrow and bending streets, controlled view of the spaces, physical and visual connectivity, sense of enclosure, landmark objects as visual focal points, complexity in the surfaces, details.	Positive features for daily walking: - Vegetation - The furnishings within the space - The presence of people - The absence of cars - The presence of interesting shops - The negative features:
Van Cauwenberg et al. [83] (propensity to walk and the physical environmental factors)	Benches, sidewalk type, sidewalk width, sidewalk evenness, separated sidewalk from cycling path, presence of green strip, obstacles on the sidewalk, presence of historic elements, presence of driveways, number of traffic lanes, traffic calming devices, safety to cross, safety from crime, pleasantness	Positive correlation with propensity to walk: - Presence of vegetation - Benches - Surveillance - Presence of historic elements - Sidewalk separated from cycling path - Safety from crime - Pleasantness Negative correlation with propensity to walk: - The presence of green strips

3.2. Impacts of the Built Environment on Air Pollution

This subsection reviews the studies that examined relationships between the built environment and air pollution. Variables like PMx, NOx, and COx were typically used to characterize the air pollution characterization indices [84,85]. Other significant sources of air pollution include nitrogen oxide emission from vehicle exhaust and sulfur dioxide emission from industrial dust [86]. The urban form or urban spatial structure was extensively investigated concerning air pollution in these studies. The complexity of urban settlements was frequently reduced in early studies to two-dimensional (2D) topologies of urban and non-urban areas. This approach makes it easier to analyze urban dynamics and compare cities [87]. Li et al. [88] noted that city-scale analyses failed to distinguish between the pollution levels in various city neighborhoods. In this respect, other studies examined the impacts of urban form on air quality at a finer scale (e.g., neighborhood and street) inside specific cities [89].

This subsection is categorized into four sub-subsections based on the scale of the studies: macroscale, mesoscale, and microscale urban environments. The first subsection recognizes the built environmental factors and urban form that contribute to air pollution in macroscale urban environments such as cities. The second subsection reviews the studies on mesoscale urban environments. The mesoscale urban environments in these studies are referred to as the buffer zones between a 100 and 1000 m radius. The third subsection reviews the microscale urban environments (street canyons) studies. The next subsection focuses on urban vegetation and its relationship with air pollution at different urban scales. The reason for dedicating one subsection to urban vegetation is due to its importance concerning air pollution at all urban scales and the need to make comparisons of its impact on air pollution at different urban scales. The final subsection summarizes the findings from all the subsections.

3.2.1. Association between Air Pollution and the Built Environment Based on the City Scale

Regarding city-scale research, some studies measured the impact of the urban form on air pollution in large cities and metropolitan areas, and others divided the samples into urban and rural areas and cities of various sizes [90,91]. One difference based on city size is that the air pollution in big cities is mostly due to non-point source emissions (transport-related emissions), while the role of point source pollution emissions (due to various factors such as wood burning heater) is more highlighted in small-to-medium cities. Transport-related emission is the main non-point source of $PM_{2.5}$ in big cities [92]. According to these studies, the size of the city affects how the urban form influences the air quality [93].

The extent to which the urban form is fragmented/sprawled or unified/dense has been one of the most important factors contributing to changes in the emission and distribution of different urban pollutants. Urban sprawl was measured through different factors in different contexts, such as using three key factors of density, scatter, and land-use composition [94]; six primary aspects [95]; three indicators of the total size, density, and clustering of EU cities [96]; and the Smart Growth America (SGA) index, as a composite indicator of urban sprawl that integrates four urban form elements including residential density, street connectivity, regional centeredness, and land use mix [97,98]. In addition, many studies used satellite-derived measures of the urban form and urban landscape patterns to measure the disorderly expansion, fragmentation, and complexity of cities [99,100]. The examples of these landscape metrics and their relevant indices—used in different studies—are urban extension (measured by the total urban area and proportion of urban buildup in a given area), urban fragmentation (measured by the number of urban patches and patch density), urban patch size (measured by the mean patch area and largest patch index), and the layout of urban patches (measured by the patch cohesion index and aggregation index) [100–104]. It is to be noted that a patch is an area having relatively homogeneous conditions relative to other patches. Less fragmented urban regions are anticipated to have higher urban continuity with more continuous and less "leapfrog" development.

To some extent, low density (lower urban continuity), scattered development, higher shape complexity, and more segregated land use contribute to increasing long-distance commuting and driving more to reach daily destinations [98,105]. This results in the heightening numbers of Vehicle Kilometers of Travel (VKT) and larger non-point source emissions, especially $PM_{2.5}$ [98]. Contrarily, compact urban forms with high densities may result in increased walking and transit use as well as decreased vehicle travel distances [106,107], which contribute to improving urban air quality [89]. Numerous studies conducted in the USA, Europe, and China revealed that urban sprawl and fragmentation are strongly related to high $PM_{2.5}$ concentrations [88,90,108]. In EU cities with more than 100,000 people, Cárdenas Rodríguez et al. [109] discovered a positive correlation between the number of fragments and the yearly mean PM10 concentration. According to Bereitschaft and Debbage [98], metropolitan regions in the USA with higher levels of urban sprawl or sprawl-like urban morphologies (measured by residential density and street network connectivity) contribute to increased $PM_{2.5}$, O_3, and CO_2 emissions. According to Yuan et al. [110], urban continuity (as one of the indicators of urban sprawl) is linked to a considerable rise in $PM_{2.5}$ and PM_{10} concentrations in China's cities. PM_{10} and $PM_{2.5}$ were two significant pollutants that are substantially positively related to scattered/fragmented patterns measured by the number of urban patches in 25 Chinese cities [104]. Cities in northern China have significantly reduced non-point source emissions thanks to a less fragmented and complex urban shape, as evaluated by compact ratio, largest patch index, and population density [86]. McCarty and Kaza [90] discovered that cities with more urban patches have significantly contributed to lower air quality in the United States. An empirical study of 287 cities in China suggested that an urban compactness ratio is negatively associated with NO_2 and SO_2 density [111]. Cappelli et al. [112], discovered the negative impact of urban sprawl on PM_{10} concentration in European Union cities. As one of the indicators of a compact city, mixed land use is linked to an increased usage of public transportation, which can reduce emissions [98,113]. Stone [114] discovered that large U.S. cities with higher levels of urban sprawl or more sprawl-like urban morphologies, measured by SGA, have much higher O_3 concentrations.

In contrast, Cho and Choi [115] found no evidence to support the claim that a compact urban design lowers PM_{10} concentration in South Korea, and dense development can result in even higher pollution levels in certain parts of China [93]. By placing more people in dense urban areas, where some air pollutants, including PM, are frequently present in the highest concentrations, compact development may increase exposure to air pollution [116–118]. Higher mixed land uses (as one of the indicators of a compact city) can worsen air quality by fostering conditions that encourage increased traffic and population density [119,120]. Tao et al. [92] found that more fragmented or sprawled cities in China have lower $PM_{2.5}$ concentrations than their more spatially compact counterparts. According to Clark et al. [121], more centralized populations were linked to significantly higher population-weighted $PM_{2.5}$ concentrations among 111 U.S. urban areas. In contrast, more population density was linked to significantly lower population-weighted $PM_{2.5}$ and O_3 concentrations. Therefore, although the compact form mostly contributes to decreasing air pollution on the city scale, the effect of a compact urban form on air pollution at the city scale is not conclusive.

Some research on the association between urban form and air pollution used the polycentricity and dispersion indices as the representative indices of the urban spatial form [84,122,123]. This could be considered as another indicator of the complexity of the urban form and urban density/sprawl. In 25 Chinese cities, the polycentric urban form was linked to high air quality [99]. Tao et al. [92] suggested that moderately distributed and polycentric urban development is preferable to compact and monocentric growth for lowering $PM_{2.5}$ levels in Chinese cities. However, as urban economic production increases, and the per capita GDP reaches a certain point, the beneficial effect of polycentricity on lowering $PM_{2.5}$ concentration begins to wane [124]. As a result, when it comes to the interactions between urban form and air pollution, economic issues play a role. For instance, Du et al. [125] discovered that economic urbanization—as determined by GDP per unit area—has a much greater impact on air quality than either population urbanization or land urbanization in the Beijing–Tianjin–Hebei region. Likewise, in the cities of South Korea, NOX, PM_{10}, and $PM_{2.5}$ exhibited a substantial positive association with the gross regional domestic product per person [126].

Additionally, it was discovered that various forms of urban land play a significant role in the urban spatial structure. According to Legras and Cavailhès [127], urban land use patterns determine the distribution of air pollution and polluting activities. In the Yangtze River Delta (YRD) in China, Lu et al. [128] investigated the relationship between various land uses and $PM_{2.5}$ concentrations and discovered a negative association between $PM_{2.5}$ and forest land and a positive association between $PM_{2.5}$ and urban land over the past decade. Residential, transit, and industrial land ratios among all types of urban land have a considerable effect on air pollution [84]. According to Yuan et al. [129], there was a correlation between residential and transportation land proportions and $PM_{2.5}$ concentration. Higher pollution levels were associated with residential use [130–132]. Residential density is the major predictor of O_3 and $PM_{2.5}$ concentrations and CO_2 on-road emissions [98]. A growing body of studies shows that industrial land use and air pollution positively correlate [131,133–135]. In the cities of South Korea, greater NOX, PM_{10}, and $PM_{2.5}$ levels resulted from more industrial land use [126]. There is conflicting evidence regarding how commercial land use affects air pollution. According to some researchers [136,137], commercial land use can hurt air quality; nevertheless, a different study, in Seoul, South Korea, discovered that $PM_{2.5}$ and PM_{10} concentration levels tend to be lower in regions with significant commercial land use [138].

Finally, geographical variables like elevation may have an impact on atmospheric circulation or pressure, which may have an impact on air quality. Lower altitude regions have worse air quality, which indicates a negative relationship between altitude and PM concentrations [139,140]. Also, it should be mentioned that numerous studies discovered a high correlation between air pollution concentrations and climatic factors such as wind speed and direction [141,142]. $PM_{2.5}$ and PM_{10} are positively correlated with temperature [131,143]. These meteorological variables were primarily employed as the control variables in this research.

3.2.2. Association between Air Pollution and the Built Environment in Mesoscale Urban Environments

The air pollutant concentration varies within a city as well [88]. The shape, size, and structure of urban areas on a flat surface are referred to as the two-dimensional (2D) features of the urban fabric in studies at the city scale [144]. Three-dimensional (3D) urban datasets have become more widely available in recent years, allowing spatial analysts to record the fine-grained characteristics of urban form elements such as buildings, plots, roadways, and facilities [89]. In this regard, numerous studies examined the effects of the urban form on air pollution at a finer scale, such as neighborhoods and streets. According to several studies [108,145], the three-dimensional (3D) urban form, including horizontal and vertical characteristics, can directly affect urban ventilation and the dispersion of pollutants. The impacts of the urban form on air pollution dispersion in meso- to microscale urban environments was measured through the field monitoring of air pollution, simulations using computational fluid dynamics (CFD) and other techniques, or a combination of these two methods.

Zhang et al. [87] discovered that the formation and dispersion of $PM_{2.5}$ in urban settings are influenced by street accessibility, the length of road segments, topography, urban vegetation, nearby green spaces, and transportation infrastructure (Table 2) [87]. In a different study, Zhang et al. [89] discovered that accessibility, intersection densities, adjacent block patterns, building arrangement, building density, and land use function, including small urban parks, significantly impact air pollution (Table 2). According to Ahn et al. [146], various dimensions of the urban form, including density (population, housing, and business density), spatial morphology including building coverage ratios, floor area ratios, mean/median building heights, land use, and geographical characteristics such as altitude are related to the emission and dispersion of air pollution (Table 2). Jia et al. [147] looked into the connection between housing morphology and air quality in three residential sectors in Shenzhen. They discovered that the high-density housing development is not a barrier to enhancing wind flows and air quality, and surface roughness has a favorable impact on wind regimes (Table 2). Hassan et al. [148] found that occlusivity and plot area ratio were mainly related to dispersion at the pedestrian level and that volume area ratio promoted PM_{10} dispersion (Table 2). Jiang et al. [149] investigated the relationship between urban morphology and air quality (wind speed, CO, and $PM_{2.5}$) in two residential neighborhoods in Beijing, China. The parameters significantly affecting the PM 2.5 concentration included the standard deviation of the building height, mean building volume, and average building height (Table 2).

Building density (BD) and floor area ratio (FAR) are the most important criteria according to Yuan et al.'s [129] study of the urban morphological characteristics affecting PM 2.5 concentrations in Wuhan. They discovered that high-rise and high-density building areas had the biggest impact on PM 2.5 (Table 2). In another study, Yuan et al. [123] found that building density and floor area ratio were positively correlated with $PM_{2.5}$ and PM_{10} exposures. And Edussuriya et al. [150] investigated the link between urban morphology and air quality in 20 urban residential areas in five major districts of Hong Kong (Table 2). They could not find any significant relationship based on the scale of the districts. Still, for the scale of the selected urban residential areas, they found correlations between PM and five morphological variables [151] (Table 2). Li et al. [152] analyzed the spatial variations in eight air pollutants among 18 ambient air monitoring stations across Shanghai. They found that the distance to the primary road, the standard deviation of building floors, building density, and transport facilities were the top urban form features influencing the spatial variations of most of the pollutants (Table 2). Yang et al. [153] used the CFD model and simulated 80 blocks of the city center of Nanjing, the capital of Jiangsu Province in China. They discovered that the primary indicators influencing the flow of near-surface air pollutants are site coverage, average height, and the degree of enclosure, with an average height showing the greatest impact (Table 2). Finally, Shi et al. [154] found that $PM_{2.5}$ is positively correlated with building volume density, building coverage ratio, and frontal area index; it is negatively correlated with variability in building heights (Table 2).

Table 2. The findings of studies that examined the relationships between urban form and air pollution in mesoscale urban environments.

Study Area, Scale and Author	Outcomes	Methods	BE Variables (Urban Form Factors)	Main Findings
Street block level using evidence from 15 megacities in China (Zhang et al. [87]	CO, NO_2, $PM_{2.5}$, and PM_{10}	Using existing monitoring site data and geospatial open data.	*City plan:* street system; block pattern; building layout; *Building form patterns:* building 3D forms; building 2D forms; *Land use pattern:* land use function; land use intensity	Positive correlation with $PM_{2.5}$: - Road intersection separation distance (RISD) - Population density (PD) - Normalized Different Vegetation Index (NDVI) Negative correlation with $PM_{2.5}$: - Average slope (BRD) - Land use diversity (LUD) - Eccentricity degree of building distribution (BDE) - Adjacent block number per unit length (ULABN) - Near-block green spaces (NGS) - Density of restaurants (RD)
Street block level using evidence from 15 megacities in China (Zhang et al. [89]	$PM_{2.5}$	Easily accessible data sources were used in this study, including satellite derived $PM_{2.5}$ data and geographical open data.	Twenty-one urban-form- and land-use-related factors	Positive correlation with $PM_{2.5}$: - Average greening rate of adjacent blocks (NGS) - Ratio of business land uses (SA_PUB) - Ratio of business land uses (SA_BUS) - Ratio of industrial land uses (SA_IND) Negative correlation with $PM_{2.5}$: - Block's average building area (MBA) - Area-weighted spatial compactness ratio (AWBSCR) - Ratio of cultural land uses (SA_CUL)

Table 2. *Cont.*

Study Area, Scale and Author	Outcomes	Methods	BE Variables (Urban Form Factors)	Main Findings
Eight hundred forty-nine sampling microscale locations in Seoul, South Korea [146]	$PM_{2.5}$ and PM_{10}	$PM_{2.5}$ and PM_{10} were collected from 849 sampling locations. Urban form factors were measured in the selected buffer zones, 100, 300, 500, and 1000 m from each environmental sensor.	*Density:* population, number of businesses, number of housings; *Transportation*: predicted traffic volume, global integration, road density, road width, length of the highway, length of the major road, distance to highway road, distance to major road, number of subway stations, number of bus stops, number of nodes; *Spatial morphology*: building coverage ratio, floor area ratio, building height (mean/ median); *Land use*: commercial area, mixed-use area, industrial area, transportation facilities area, green area (park area), water area, NDVI; *Geographical characteristics*: elevation	Positive correlation with $PM_{2.5}$ and PM_{10}: - High transportation density (bus stop density) - Building density (building height (100 M.) and floor area ratio (100 M.). - Industrial land use (density) - Elevation Negative correlation with $PM_{2.5}$ and PM_{10}: - Highway accessibility (distance to highway and length of highway) - Mixed land use - Residential density (number of housing and population density)
Three residential sites in a district located in Shenzhen [147]	$PM_{2.5}$ and NAIs; wind pattern and flow regimes	CFD and using field monitoring of air pollution using nine sampling points; configuration variables of the urban form.	*Land utilized and building density*: plan area density, compactness factor (Cf), frontal area density (*lf*), rugosity; *Urban friction:* urban roughness length (Z0); *Permeability parameters:* open space aspect ratio, distance between buildings; *Basic 3D morphological parameters*: mean built volume, mean building height, standard deviation of the building height, plot ratio; *Air velocity simulation*: meteorological data	Positive correlation with velocity performance based on the CFD model (which has the reverse relationship with air pollution): - Urban roughness length - Mean building height Negative correlation with velocity performance based on the CFD model (which has the reverse relationship with air pollution): - Plan area density - Open space aspect ratio - Distance between buildings
Mubarak residential blocks in Port Said city [148]	Wind pattern and PM_{10} dispersion	CFD model and field measurement of PM_{10}.	Absolute rugosity (Hm); occlusivity factor (Oc); *Urban density indicators:* plot area ratio (PAR), volume area ratio (VAR), (λP), (λF)	Negative correlation with PM_{10}: - VAR - λF - Oc - PAR - λP
Two residential neighborhoods located in Beijing [149]	Wind speed, CO, and $PM_{2.5}$	Computational fluid dynamics (CFD); intelligent environmental monitoring equipment was used to monitor the temperature, wind speed, wind direction, CO concentration, and $PM_{2.5}$ concentration.	Building density (BD); floor area ratio (FAR); average building height (AH); space openness (SO); standard deviation of building height (SDH); mean building volume (MBV); degree of enclosure (DE)	Positive correlation with wind speed (and consequently dispersion of air pollution) based on the CFD model: - AH - SDH - MBV Negative correlation with wind speed (and consequently dispersion of air pollution) based on the CFD model: - BD - DE Negative correlation with $PM_{2.5}$: - AH - SDH - MBV
Grid of 1 km × 1 km in downtown Wuhan, China [129]	$PM_{2.5}$	$PM_{2.5}$ concentration in January 2016 using remote sensing data (taken from satellites). The built environment was measured in each grid area.	*Land cover:* sum of forest and grassland, high-rise building area, low-rise building area, high-rise separate building, low-rise separate building, high-rise high-density building area, High-rise low-density building area, construction site; *Land use*: residential land, administration land, business land, industrial land, green land, land use mix; *Urban form building*: mean floor, building density; *Street network*: road density for all types, arterial road density, sub-arterial road density, branch road density, road density for all types, road junction	Positive correlation with $PM_{2.5}$: - High-rise high-density building areas - Floor area ratio (FAR) - Building density - Road density for all types - Densities of arterial roads and sub-arterial roads - Road junction density - Residential land - Administrative land Negative correlation with $PM_{2.5}$: - Bus station density - Proportion of grasslands
Five hundred nineteen zones in downtown Wuhan, China [123]	PM_{10} and $PM_{2.5}$	Air pollution was measured through existing air monitors; population density was measured through smartphone data.	- Residential density - Employment density - Building density - Floor area ratio	Positive correlation with $PM_{2.5}$ and PM_{10}: - Floor area ratio (FAR) - Building density

Table 2. *Cont.*

Study Area, Scale and Author	Outcomes	Methods	BE Variables (Urban Form Factors)	Main Findings
Neighborhood scale (2 km × 2 km) in Shanghai, China [155]	$PM_{2.5}$	$PM_{2.5}$ was measured through mobile equipment. Urban form factors were measured in the buffer zones of 25, 50, 100, and 300 m around each reference test point.	- Land cover (16 variables) - Intersection density - Public transportation stop density - Traffic volume - Road network type within each buffer - Number of parking lots - Number of restaurants - Height of the buildings - Meteorological parameters	Positive correlation with $PM_{2.5}$: - Traffic volume - Major roads - Secondary roads - Building height - Commercial land Negative correlation with $PM_{2.5}$: - Green spaces
Twenty urban residential areas in five major districts of Hong Kong [150,151]	$PM_{2.5}$, nitrogen dioxide, ozone, and carbon monoxide	Urban morphology variables were measured through manual calculations of the scales of each neighborhood based on digital maps and GIS data. Mobile monitors were employed to measure air pollution and meteorological data.	Topography/urban terrain altitude; distance from water body; urban layout; city size; proximity to pollution sources and sinks; population density; urban density; urban land use; frontal area density; mean built volume; traffic load; location; plot ratio or plan area density; mineralization factor; capacity factor; complete aspect ratio; mean contiguity factor; roughness height; zero-plane displacement height; urban porosity (Po); sinuosity (Si); occlusivity (Oc); canyon/building orientation; canyon aspect ratio; street aspect ratio; street block ratio; mean building height; mean canyon width; canyon height ratio	No significant correlations between air pollution and urban form factors based on the scale of the district.But at the scale of each residential site, a positive correlation with $PM_{2.5}$: - Plan area density - Near field traffic - Compactness factor - Rugosity or floor area ratio (FAR) - Distance between buildings Positive correlation with NOX: - Plan area density - Compactness factor - Mean contiguity factor - Occlusivity *Negative correlation with NOX:* - Mean building height - Std. dev. of bldg. height
Buffer zone of 1 km around the existing air pollution stations of Shanghai, China [152]	$PM_{2.5}$, PM_{10}, SO_2, $PM_{2.5}$, O_3, CO, NOx, NO, and NO_2	Urban air pollutants were measured through existing data of current air pollution stations. Urban form variables were measured in a buffer of 1 km around the existing air stations.	*Points of interest (POI):* leisure facility (LF), transport facility (TF), corporation (CORP), hygiene, facility (GF), government agency (GA), catering facility (CF), road crossing (RC), parking lot (PL), gas station (GS); *Distance-based features:* distance to water (DW), distance to primary road (DPR), total length of subway lines (SL), primary road length (PRL), secondary road length (SRL); *Building density (BD):* average building floors (ABF), max building floors (MBF), standard deviation of building floors (SDBF)	Negative correlation with $PM_{2.5}$: - CORP - TF Negative correlation with PM_{10}: - SDBF Negative correlation with O_3 - DPR Negative correlation with CO and NO - BD
Eighty blocks of Nanjing, China [152]	Wind speed using CFD	CFD simulation.	Site coverage; average height; plot ratio or floor area ratio (FAR); degree of enclosure; average height; height difference	Positive correlation with airflow, which reduces air pollution: - Average height. Negative correlation with airflow, which enhances air pollution: - Site coverage - Degrees of enclosure
Street-level measurement of air pollution in Hong Kong. The mobile equipment was installed in a bus [154].	$PM_{2.5}$	Mobile monitoring of street-level $PM_{2.5}$ dataset; A series of buffers (with radii of 50 m, 100 m, 200 m, 300 m, 400 m, and 500 m) was created around each data aggregation point. GIS was also used to measure urban form factors.	- Mean and standard deviation of building height (h)/ - Variability in building heights - Ground coverage ratio (λP), - Building volume density (BVD), - Sky view factor (of the entire hemispherical sky view and its eight - Sectors, Ψ - Frontal area index (three layers) (λF)	Positive correlation with $PM_{2.5}$: - Building volume density - Building coverage ratio - Frontal area index of the podium layer Negative correlation with $PM_{2.5}$: - Variability in building heights

According to the reviewed studies in this subsection, the street layout and traffic-related characteristics are two of the most crucial elements influencing air pollution's emission and dispersion. Several transport-related factors were found to influence air pollution, including road intersection distance, transport density, highway accessibility, road density, density of arterial roads, road intersection density, traffic volume, presence of major roads, and bus stop density [87,129,146,155].

Additionally, the previously mentioned disagreement over how to relate a compact urban form to air pollution persists among the research that looked at these associations in mesoscale urban environments. From a regional viewpoint, a compact spatial structure might result in better air quality due to lower overall car emissions. Still, it could also result in higher local $PM_{2.5}$ concentrations and greater exposure to $PM_{2.5}$ in local areas [156,157]. The positive correlation between air pollution, notably $PM_{2.5}$, and the compact urban form—at a finer scale in large cities—is supported by numerous studies. According to Guo et al. [137], high building density was linked to increased traffic; this, in turn, caused more emissions and less dispersion and resulted in poor air quality. Building density also positively correlated with air pollution, especially $PM_{2.5}$, in several more studies [123,129,149,154]. According to Zhang et al. [87], building density positively affected CO and NO_2 in 15 megacities in China. Other indicators of building density also showed a positive correlation with air pollution and $PM_{2.5}$; they include floor area ratio [123,129,146,150], plan area density [147,150,151], compactness [150,151], building coverage ratio [154], and building volume density [154]. As another indicator of high-density urban growth, air pollution increased along with population density [87,93]. Furthermore, several studies showed a positive correlation between air pollution and $PM_{2.5}$ and the height of the buildings, which might be considered as another sign of a compact urban form [146,155]. According to Yang et al. [153], high-rise buildings had a significant impact on urban ventilation and the spread of air pollution, which was supported by Li et al. [152] as well. Shi et al. [154] also found a positive correlation between variability in urban height and $PM_{2.5}$ in Hong Kong.

There are also studies on mesoscale urban environments that support the negative correlation between urban density and air pollution. In Seoul, South Korea, Ahn et al. [146] discovered a negative association between residential density with $PM_{2.5}$ and PM_{10} levels. Mixed land use, as another measure of urban density, also showed a negative correlation between $PM_{2.5}$ and PM_{10} [146]. Hassan et al. [148] discovered a negative association between PM_{10} and "plot area ratio" as well as "volume area ratio" in Port Said, Egypt. Jiang et al. [149] found a negative correlation between building volume and $PM_{2.5}$ in Beijing, China. Another metric of building density—known as the height of the buildings—also revealed a negative relationship with air pollution [153]. Various studies on mesoscale urban environments discovered that building height was adversely correlated with air pollutants, including NOX and $PM_{2.5}$ [147,149–151]. Therefore, although the compact urban form mostly contributes to enhancing air pollution in mesoscale urban environments, the relationship between compact urban forms (and its different indicators such as building density) and air pollution in mesoscale urban environments—similar to the studies on macroscale urban environments—is not conclusive.

Additionally, there are plenty of morphological features that—despite not being directly connected to urban density—affect how buildings are organized and are strongly associated with air pollution. In Shenzhen, China, and Hong Kong, the distance between buildings is positively correlated with air pollution and $PM_{2.5}$ [147,150,151]. In Shenzhen, China, the "open space aspect ratio" positively correlates with air pollution [147]. In Beijing and Nanjing, China, the degree of enclosure is negatively correlated with air pollution [149,153]. In Hong Kong, occulusivity and NOX are inversely associated [150,151]. In Hong Kong, the frontal area index also negatively correlates with $PM_{2.5}$.

The air pollution in a mesoscale urban environment also exhibited significance for the aspects connected to land use. According to Zhang et al. [89] and Ahn et al. [146], there was a positive association between industrial land use and air pollution. The number of restaurants displayed a negative association with $PM_{2.5}$ in 15 Chinese megacities [87]. Residential and administrative land uses were linked to an increase in $PM_{2.5}$ in downtown Wuhan, China [129]. According to Gao et al. [155], commercial land increased $PM_{2.5}$ in two neighborhoods in Shanghai, China.

Finally, climatic factors were also shown to considerably impact urban air quality in mesoscale urban environments [158,159]. The maximum and minimum air temperature, ground surface temperature, air pressure, wind speed, daily mean sunshine duration, and daytime mean and nighttime mean of precipitation are some of the meteorological factors that are related to air pollution dispersion in mesoscale urban environments.

3.2.3. Association between Air Pollution and the Built Environment in Microscale Urban Environments (Street Canyon)

Numerous variables, including street canyon characteristics, weather, traffic, and green infrastructure, affect the ventilation and pollutant removal in a street canyon [160]. Shen et al. [161] discovered that the aspect ratio, street width, street continuity ratio, lateral openings, and crossings significantly affected the air flows and pollutant dispersion on six streets worldwide. The aspect ratio (AR)—which is the ratio of building height (H) to street width (W)—is a key factor in determining the characteristics of street canyons [161]. Deeper canyons, which have bigger H/W, typically have less ventilation and pollutant removal, since airflows within a street canyon become separated from the surrounding ones [160]. Certain design aspects may enhance ventilation in street canyons with a high aspect ratio. According to Chew and Norford [162,163], adding void decks might increase pedestrian-level wind speeds, and the benefit becomes more apparent with a rise in void deck height.

Additionally, the construction of high-rise buildings would change the thermal equilibrium in street canyons and cause an urban heat island (UHI) impact. Urban air pollution and UHI are two interconnected issues [164]. Another crucial factor influencing the clearance of pollutants from a roadway canyon is the building length to street width ratio (L/W) (160). Intersections are significant locations for air exchange and emission re-distribution. Building height variations (symmetric/asymmetric) and roof types (flat/triangular/slant) are additional significant factors. According to Llaguno-Munitxa and Bou-Zeid [165], buildings with round roofs had the best street canyon ventilation, while those with balconies had the worst. Huang et al. [166,167] discovered that downward wedged roofs led to the best pollutant removal for canyons with the same roof shape on both sides. According to Takano and Moonen [168], as the roof slope increased, pollution levels fell. Additionally, Fu et al. [169] found that highly symmetric or asymmetric street canyons reduce pollution concentration at the pedestrian level. Previous studies showed that street canyons with non-uniform heights better encouraged dispersion than those with uniform heights [170,171].

Furthermore, the geometry of the street canyon is altered by the presence of in-street barriers including trees, viaducts, noise barriers, and curbside parked cars [160]. In-street barriers could significantly reduce air pollution in the pedestrian breathing zone, since they only affect the airflows in the bottom of a street canyon, unlike H/W, L/W, and building layouts that determine the overall airflow [160]. Urban vegetation is the most important in-street barrier, and the next subsection is devoted to this topic. To improve the roadside air quality in urban street canyons, other in-street barriers like curbside parking spaces, low boundary walls along the walkways, viaducts, and noise barriers can also be used as solid barriers [172]. When compared to the no-parking condition, parked cars could reduce pollution concentrations over footpaths [173]. However, the effect of parked cars on the dispersion of air pollution depends on the wind direction, whether perpendicular or parallel winds [173]. According to Gallagher et al. [174], the footpath air quality significantly improved with the car–wall combined barrier. According to research by Hagler et al. [175] and Lee et al. [176], road sections with noise barriers could have pollutant concentrations up to 50% lower than those in areas without them. Viaducts also have an impact on how air pollution is dispersed in street canyons [177].

Finally, while considering the climatic factors, wind speed and direction mostly influence street canyon emission dispersion. When it comes to wind direction, winds parallel to the street are beneficial for emission removal [160]. Higher wind speeds generally help to quickly eliminate air pollution. The heating of building facades and ground surfaces—caused by sunlight's impact on roadside air quality—results in buoyancy, which drives airflows and emission dispersion in street canyons [178,179].

3.2.4. Effects of Urban Vegetation on Air Quality in Urban Environments with Different Scales

Urban vegetation is counted as one of the in-street barriers concerning air pollution in street canyons, but it is separately considered in this subsection due to its special influence on air pollution in urban environments at different scales, such as its link to the temperature–humidity system that contributes to the formation of urban heat islands [180]. In city-scale studies about the effects of the urban form on air quality, urban vegetation or urban green spaces were frequently considered as a sort of land use. Urban forestry contributed to the reduction in air pollution [181]. According to Bottalico et al. [181], Florence's urban forest could remove up to 5% of O_3 and 13% of PM_{10} from the air. Greenery and parks were regularly linked to improved air quality [182–184]. According to research by Sun et al. [185] and Tian et al. [186], vegetation, measured by the Normalized Difference Vegetation Index (NDVI), has the potential to reduce air pollution in densely populated metropolitan areas. In Seoul, South Korea, areas with fewer green spaces showed higher levels of air pollution [146]. However, according to Jung et al. [126], a park area did not exhibit a significant link with any sort of air pollution in the cities of South Korea. Furthermore, it was found that different species of trees had varying levels of efficiency in eliminating air pollutants compared to other types of vegetation, such as grass [187,188].

Urban vegetation was also investigated in mesoscale urban environments, including the scale of neighborhoods and urban blocks. Generally, although vegetation density helps to reduce urban air pollution, urban vegetation alone may not be enough to deal with $PM_{2.5}$ pollution. Nearby small urban parks and green spaces may only have a very small impact on $PM_{2.5}$ and urban heat island mitigation [87]. In contrast, among the 15 cities in China evaluated by Zhang et al. [87], the NDVI indicated positive effects in almost half of the cities. In a different study, lower levels of O_3 concentration were found in regions with trees, but lower levels of NO_2 concentration were not [189]. Gao et al. [155] discovered a negative correlation between $PM_{2.5}$ and green spaces in two neighborhoods in Shanghai, China. However, Yuan et al. [129] discovered that the percentage of grasslands—and not the amount of green land—contributes to reducing $PM_{2.5}$. This demonstrates how different types of greenery, such as grass or trees, can help to lower air pollution. According to studies on the effects of urban vegetation on air pollution in mesoscale urban environments, local climates can significantly impact the ability of urban greenery to remove air pollutants.

Depending on the vegetation's design and the quantity of air pollution in the area, vegetation can positively or negatively impact urban air quality in microscale urban contexts like urban canyons [190]. Urban vegetation primarily influences the dispersion of air pollution through two mechanisms, deposition/absorption and aerodynamic impacts. Plant-based barriers must be dense enough to offer a sizable surface area for deposition and porous enough to allow the penetration rather than deflection of the air stream above the barrier [190]. In general, it was discovered that the aerodynamic effects are even up to several times more substantial than the deposition effects [191,192]. For instance, in low wind circumstances, the aerodynamic effect of trees is more important than the deposition effect in particular [191,193].

Concerning the effects of urban vegetation on air pollution through deposition, numerous elements such as leaf structure, tree height and canopy geometry, source location, and meteorological conditions affect plants' capacity to absorb, deposit, or retain pollutants [194,195]. According to Sgrigna et al. [196] and Vos et al. [193], placing plants close to the source of the pollution increases the deposition. Hedges and other low-level plants typically increase deposition, which improves the air quality in street canyons [197]. Thick tree barriers without gaps were more effective than trees with gaps on air pollution [198]. It is also likely that thick and thin leaves differ in terms of particle size [190]. Grass with hairy leaves had greater deposition than other herbaceous plants [199–201]. Conifers were found to have faster deposition rates than deciduous trees in several studies [202,203].

According to studies on the aerodynamic impacts of urban vegetation, the shape, height, crown size, and porosity of vegetation all help to limit the spread of air pollution [204,205]. The height of trees' trunks is the crucial element that affects air movement and pollution dispersion [206]. Another relevant metric is leaf area density (LAD), particularly for vegetation barriers next to roads that help to decrease air pollution [207]. According to numerous studies [197,208–210], street canyons with trees have lower airflows and higher pollutant concentrations than those without trees. Vegetation barriers should be permeable enough to allow air to pass through to lessen the detrimental impacts of dense vegetation areas on the dispersion of air pollution [172,190]. Gromke and Ruck [211] proposed that (1) tree crowns should not occupy huge canyon volumes, (2) appropriate free space should be reserved between crowns and nearby building walls, and (3) trees should be lower than building roofs to reduce the detrimental influence on air ventilation. Therefore, to control the air quality in urban street canyons, careful vegetation selection is essential, taking into account planting density, crown size, leaf area density, and height [190].

Furthermore, the effects of urban vegetation on air pollution dispersion depend on the aspect ratio and wind direction/speed. For shallow canyons, trees have a greater effect on air quality [153]. According to Ng and Chau [212], deeper roadway canyons were more susceptible to more tree coverage than shallower ones. In addition, trees were found to improve air quality under parallel winds, but they were found to damage it in perpendicular winds [191,213]. According to Li et al. [214], the ideal height of vegetation barriers along highways to influence air pollution depended on the aspect ratio, but it was mainly unaffected by the perpendicular wind speeds. In street canyons with perpendicular winds, Gromke et al. [215] discovered that continuous hedges could improve air quality.

Finally, green roofs, walls, and screens may lessen some of the drawbacks of using tree-based solutions [216]. With little impact on canyon airflows, this green infrastructure can efficiently absorb pollutants from neighboring emission sources via pollutant deposition to leaf surfaces [160]. For instance, green walls and roofs in street canyons were found to improve the air quality for pedestrians in terms of PM pollution [217]. The effects of urban vegetation on air pollution dispersion may also vary depending on the time of year and season because of the effects of the season on the plant type [190,218].

3.2.5. Classification of the Built Environmental Factors Relevant to Air Pollution

Reviewing the studies that examined the relationships between the built environment and air pollution shows that these studies could be classified based on the scale of the urban environments. The studies at the macroscale (the scale of the cities) mostly focused on the relationships within the urban form, with special attention to urban density versus urban sprawl and air pollution. Four categories comprised the built environment factors associated with air pollution in macroscale urban environments or at the scale of cities: transportation-related factors, the urban form (sprawled versus unified/dense), patterns of urban land use, and geographic variables. A wider range of the built environmental variables was used in the studies that examined the relationships between air pollution and the built environment in mesoscale and microscale urban environments. There were five categories in which the built environment factors associated with air pollution in mesoscale urban environments fall. These categories are urban density-related factors, transport-related factors, land use patterns, building-height-related factors, and factors related to the building spatial arrangement. Finally, the built environmental factors related to air pollution in microscale urban environments were classified into two main categories: related factors to the spatial arrangement of the street and in-street barriers. In-street barriers were further divided into two subcategories, including non-vegetation barriers and vegetation-related barriers (vegetation density and vegetation design). Table 3 shows the classification of the built environmental factors and the subfactors in each category concerning air pollution at the three scales of macroscale (cities), mesoscale (usually the buffer zones between a 100 and 1000 m radius), and microscale (street canyon) urban environments.

Table 3. The classification of the built environmental factors related to air pollution in macroscale urban environments (scale of cities), mesoscale urban environments (from neighborhood scale to block scale), and microscale urban environments (scale of street canyons).

Built Environmental Factors Related to Air Pollution in Macroscale Urban Environments (Scale of the Cities)	Built Environmental Factors Related to Air Pollution in Mesoscale Urban Environments (Scale of Buffer Zones with a Radius of 100 to 1000 m)	Built Environmental Factors Related to Air Pollution in Microscale Urban Environments (Scale of the Street Canyon)
1. Transport-related factors: road density **2. Urban form (fragmented/sprawled or unified/dense):** urban extension, urban fragmentation, urban patch size, urban patch shape, the layout of urban patches, urban continuity, urban shape complexity, and polycentric urban structure [98,100–104,123,126]. **3. Urban land use pattern:** residential, industrial, commercial, green spaces, etc. [84,98,127,128,130,136–138] **4. Geographical variables:** elevation [139,140]	**1. Transport-related factors:** road intersection distance, transport density, highway accessibility, road density, the density of arterial roads, road intersection density, traffic volume, the presence of major roads, and bus stop density [87,129,146,155]. **2. Factors related to urban density:** residential density [146], mixed land use [146], industrial land use [89], building density [89,123,129,137,149,152], floor area ratio [123,129,146,150,151], plot area ratio [148], plan area density [147,150,151], plot area ratio [149], compactness (spatial compactness ratio) [89,150,151], building coverage ratio [154], building volume density [149,154]. **3. Factors related to the spatial arrangement of the buildings:** the distance between buildings [147,150,151], open space aspect ratio [147], degree of enclosure [149,153], occlusivity [150,151], frontal area index [147], physical and visual connectivity (using space syntax and isovist). **4. Factors related to height of the buildings:** the height of the buildings [146,147,149–153,155], variability in urban height [146,154], sky view factor [154]. **5. Land use pattern:** commercial land use [155], number of restaurants [87], residential and administrative land uses [129].	**1. Related factors to the spatial arrangement of the street:** aspect ratio (height to the width of the street), street width, street continuity ratio, lateral openings [161], building void decks [162,163,219], high-rise buildings [164], varying heights of the buildings (symmetric/asymmetric), the ratio of building length to street width (L/W) and road intersections [160], roof shapes (flat roof, pitched roof, or other types) [165–167]. **2. In-street barriers:** ***2.1. Non-vegetation barriers:*** curbside parked cars (parallel parking/ perpendicular parking/no parking) [160,173], low boundary walls along the sidewalks [174], noise barriers, usually along urban highways [175,176]. ***2.2. Vegetation-related barriers (vegetation density and design):*** vegetation density, the type of greeneries, whether trees, bushes, or grass [197], the proportion of grasslands versus green lands [129], the arrangement of the greeneries concerning the road (the distance to the road and the type such as uniform type or others [220]), the presence of green walls or green roofs, tree density (number of trees and other indicators) [193,221], free space between crowns and adjacent building walls and buildings, roadside barriers consisting of trees with gaps/thick tree barriers with no gaps [198], the ratio of the average height of the trees to the average height of the building, the type of trees in terms of leaf area density (LAD) (conifers versus deciduous trees) [201,202,207], hairiness and possibly wax content [190,199], crown morphology [205], canopy porosity [222,223], trees' trunk height [206].

4. Discussion

Urban density/sprawl is one of the most important built environment features that influences air pollution in macroscale urban environments (the size of cities). Urban sprawl usually contributes to increased air pollution (especially $PM_{2.5}$) in cities, leading to more vehicle displacements [88,90,108]. Although the impact of urban density on mesoscale urban environments is controversial, it mainly shows a positive correlation with different types of pollutants in these urban environments due to the higher local pollutant concentrations and greater exposure to air pollution in local areas [123,129,137,149,154]. For instance, different indicators of urban density, measured in mesoscale urban environments, such as building density and floor area ratio, mostly show a positive correlation with different types of pollutants in these studies [87,146,150,151]. At the same time, urban density is mostly measured by population density or housing density in studies on the walking behavior of older adults, mostly showing a positive correlation with the level of walking at both regional and neighborhood scales in different environments [29,30]. This is the first finding that juxtaposes the two fields of research in which, while urban density mostly positively functions in improving the walking behavior of older adults, it appears as one of the factors that contributes the most to increasing air pollution in mesoscale urban environments such as neighborhoods. A similar conflict with urban density exists regarding the relationships between mixed land use and air pollution, as well as the walking behavior of older adults. As an indicator of urban density, mixed land use has a special place in both research fields. Mixed land uses may help reduce air pollution by encouraging residents to use fewer means of transport that emit pollutants. For instance, mixed land use at the scale of cities is linked to increased public transport usage, which can reduce air pollution [98,113]. However, the contribution of mixed land use to air pollution in mesoscale urban environments such as neighborhoods is inconclusive. Concerning the walking behavior of older adults, mixed land use, in terms of diversity and accessibility, is positively correlated with the walking behavior of elderly people [39–41]. These relationships between urban density and mixed land use need to be examined with both the walking behavior of older adults and air pollution in environments with medium-to-high air pollution.

Furthermore, when considering macroscale urban environments (at the scale of cities), there are a variety of indicators used to measure the complexity of the urban form/shape and urban density/sprawl in studies on air pollution. Some of these indicators are urban extension, urban fragmentation, urban patch size, and the layout of urban patches [100–104]. This is while urban density is simplified by certain indicators such as housing density or population density in studies on the walking behavior of older adults. One possibility is to employ a variety of urban-form-related factors (used in studies on air pollution with respect to urban density) in studies on the walking behavior of older adults. This could help to better understand the role of these urban-form-related factors in both fields of study. Urban polycentricity is another example of these urban-form-related factors concerning the walking behavior of older adults that could be examined.

Studies on microscale–mesoscale urban environments concerning air pollution are more compatible (than macroscale-related studies) with studies on the walking behavior and preferences of older adults, because the daily walking experience of older adults usually occurs on microscale walking pathways within their neighborhoods. A wider range of built environment features that affect air pollution could be observed in mesoscale urban environments (at the scale of neighborhoods) and microscale urban environments (at the scale of street canyons). By considering all the built environment features measured by the previous studies regarding air pollution in meso–micro urban environments, these features could be classified into four categories: transport-related factors, spatial and form-related factors, in-street barriers with respect to street canyons (including vegetation-related barriers and non-vegetation-related barriers), and the land use pattern. Table 4 shows the selected built environment features from the presented classifications, which are most closely related to air pollution in each category, according to previous studies.

Some of the presented urban-form-related factors in Table 4 (relating to mesoscale urban environments) include open space aspect ratio, mean building height, building density, floor area ratio (the ratio of a buildings total gross floor area to its site area), degree of enclosure, and occlusivity. In addition, vegetation density is measured by the NDVI [87].

The features presented in Table 4 could be measured for air pollution in microscale urban environments (street scale) and/or mesoscale urban environments (such as at the neighborhood scale, but more precisely at the scale of buffer zones with a 100–1000 m radius) [146,154,155] depending on the clarified type of measurement with respect to each factor, as is shown in Table 4 ("zone" is used in this table for a mesoscale urban environment such as a neighborhood). In addition, some of the features presented in Table 4 could be measured at both street and neighborhood scales, and the link between these two urban scales could help to better understand the relationships between microscale and mesoscale urban environments and the association of the built environment with air pollution at both urban scales. The physical and visual connectivity, degree of enclosure, mean building height, and variability of the height of the buildings are examples of these factors. These factors are highlighted (in italics) in Table 4.

Table 4. Built environment features and their relation to air pollution (all of these features could be measured concerning both air pollution and walking behavior/tendency to walk at both street and neighborhood scales) (highlighted features are the features that showed correlations to both walking of older adults and air pollution at a street scale according to previous studies).

Transport-Related Factors	Spatial and Urban Form-Related Factors	In-Street Barriers		Land Use Pattern
		Non-Vegetation Barriers	Vegetation-Related Barriers	
• The type of street whether arterial road or other type (street scale, zone) • Perception of boundary walls along the walkways in each street scale (street scale) • **Number of bus stops (street scale/zone)** • **Traffic volume (street scale/zone)** • **Intersection density (zone)**	• **Number of routes connected with each street scale (street scale)** • Residential density (zone) • Population density (zone) • Floor areas ratio (zone) • Building density (zone) • Compactness (zone) • Open space aspect ratio (zone) • Percentage of first floor porous façade along each street (street scale) • **Enclosure type of the street (street scale)** • ***Degree of enclosure (street scale, zone)*** • Aspect ratio (Height to width of the street) (street scale) • Street width (street scale) • **The length of the street (street scale)** • **Landmark objects and Visual connection with landmark (street scale)** • Occlusivity (zone) • ***The level of physical and visual connectivity*** **(street scale/ zone) (Using spaces syntax indices such as Isovist)** • ***Mean building height (street scale/zone),*** • ***Variability in building height (street scale [in terms of being symmetry or asymmetry], zone)*** • **Sky view factor (proportion sky across) (street scale)** • **The degree of openness of the facade along the route (street scale)**	• **Number and type of parked cars (street scale)** • **Perception of boundary walls along the walkways in each street scale (street scale)** • Average height of boundary walls along the walkways (street scale) • Presence of noise barriers (street scale)	• **Street connected to parks (street scale)** • **Percentage of front gardens (street scale)** • Vegetation density (NDVI) (zone) • **The type of greeneries whether trees, bushes or grass (street scale)** • The proportion of grasslands versus green lands (zone) • **Green strips (street scale)** • The presence of green walls (street scale) • **Tree density (number of trees) (street scale)** • Free space between crowns and adjacent building walls and buildings (street scale) • The length of the trees which seems connected along the street (street scale) • The ratio of the average height of the trees to the average height of the building along the street (street scale) • Trees' trunk height (average along each street) (street scale) • Number and percentage of types of trees whether deciduous and coniferous plants (street scale) • Percentage of each type of trees along each street (street scale) • The volume of the leaves of the crown of total trees along each street (street scale) • Percentage of each type of coniferous plants along each street (This functions in winter) (street scale) • Percentage of trees without leaves along each street (street scale) • The percentage of trees located far from streets in each street (street scale)	• ***Mixed land use (street scale/zone)*** • **Type of land uses including Dwellings, Shops, Business buildings, Catering establishments (street scale/zone)** • **Water on side in each street (street scale)** • **Visual connection with water along each street (street scale)**

Comparing Table 4 with the built environment features that contribute to the walking preferences of older adults at a street scale (Table 1), several common built environment features could be observed. These features (as highlighted in Table 4) are certain urban-design-related factors (such as vegetation density, vegetation type, and boundary walls along the sidewalks), several spatial-related factors (such as building height, building density, physical and visual connectivity, and degree of enclosure), and the land use pattern (such as residential and commercial land use) [31,48,78,80]. Thus, recognizing the relationships between these built environment features and the walking preferences of older adults, as well as air pollution at both street and neighborhood scales, would help us to understand how they can be applied with respect to both subjects in medium-to-high air pollution environments. In addition, one possibility would be to adjust the buffer zones (mesoscale urban environments) to the scale of each street section to measure the built environment features presented in this table at both urban scales. This could result in the greatest possibility for comparisons between the built environment factors that influence the walking behavior of older adults as well as air pollution in both microscale (street scale) and mesoscale (the scale of the buffer zones) urban environments (Figure 2). Figure 2 shows how the built environmental factors—related to both air pollution and the walking behavior of older adults—in sections A and B could be measured at both the street scale (along links A and B) and by the adjusted buffer zones to links A and B depending on the length of each link.

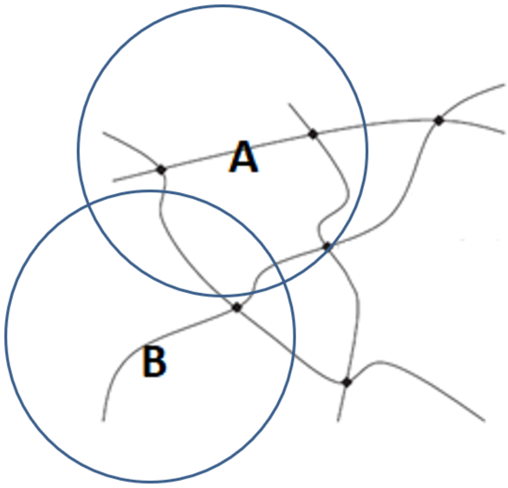

Figure 2. Schematic diagram of buffer zones adjusted to each street link.

The other factors presented in Table 4 (non-highlighted) are built environment features that only relate to air pollution. However, certain similarities could be found between these features and the features that influence the walking preference of older adults. For instance, vegetation density—used in studies on air pollution—and the number of trees—used in studies on the walking of older adults—are very similar. Another similarity is the similarity between "the proportion of grasslands versus green lands" used in studies on air pollution and "the type of vegetation, whether trees, bush, or grass" in studies on walking preference. Such similarities show that all the features related to air pollution, recognized by previous studies, as shown in Table 4, could be potentially related to the walking behavior of older adults. In this regard, all the features presented in Table 4 could also be examined regarding the walking preferences of older adults. Recognizing the relationships between these built environment features and both subjects (walking behavior and air pollution) would provide a precise picture regarding the influence of different features on air pollution and the walking behavior of older adults at both the street and neighborhood scale. This could help to better answer the problem raised in this study.

One of the important issues regarding urban-design-related features is how older adults perceive those elements along the streets and how the subjective/objective measures of these street features are linked to air pollution at both a street and neighborhood scale. These urban–design-related features could be spatial-related, such as the degree of enclosure or certain on-street barriers (e.g., the type of vegetation along the streets). For instance, it is important to understand how the degree of enclosure on the streets, as perceived by older adults, and its related physical features are related to their tendency to walk and how the same features contribute to air pollution at both a street and neighborhood scale. Another example in this regard is how the subjective/objective "variety of building height" along the street contributes to the walking behavior of older adults at different urban scales and how the same feature contributes to air pollution. The results of such examinations would provide a more precise picture of the relationships between urban-design-related street features and the walking behavior of older adults as well as air pollution. Another important issue is how certain urban-form-related features at a neighborhood scale are linked to their associated urban-design-related features, which may influence the enjoyability of older adults' walking experiences at a street scale. For instance, how is the open space aspect ratio (measured at a neighborhood scale) linked to visual connectivity (measured at a street scale)? Another example is how the degree of enclosure (the ratio of the total outer perimeter of the building to the total perimeter of the base; measured at a neighborhood scale) is linked to the degree of enclosure, measured subjectively/objectively at a street scale. Future studies could consider all these relationships to draw a clearer picture in terms of the contribution of urban-design-related features at a street scale to the walking frequency of older adults and air pollution in environments with medium-to-high air pollution.

Of the built environment features that contribute to air pollution, in-street barriers could be more important for urban/transport policymakers due to more possibilities for rearranging these factors along the streets compared to other relevant factors such as spatial-related factors [160]. Thus, recognizing the relationships between these in-street barriers and air pollution is important for future urban policies. Concerning in-street barriers, boundary walls along the walkways and the number and type of parked cars are considered to be two important factors that contribute to both the aesthetic walking experience of older adults [78,224] and air pollution at the street scale [160,173]. These factors are, therefore, of special importance for both the walking behavior of older adults and air pollution. As a result, they should be a focus for future studies in such environments.

Likewise, vegetation-related factors play an important role in the absorption/dispersion of air pollution among types of in-street barriers. The impact of vegetation density and vegetation type on air pollution in mesoscale urban environments is disputed. While urban vegetation or green spaces mostly contribute to decreasing air pollution in mesoscale urban environments [155,189], some studies found no relationship [189]. The vegetation-related features also have a primary role in the aesthetic walking experience of older adults; thus, they significantly impact walking behavior among older adults at the street scale [31,78]. According to the "Psycho-physiological stress reduction theory" and the "Attention Restoration Theory", vegetation-related features also contribute to improving mental health among older adults [225,226]. Some vegetation-related features, such as neighboring small urban parks and greens, also play an important role in enhancing urban vitality along the streets [227]. However, a wider range of vegetation-related features (compared to those examined in studies on the walking preferences of older adults) was used in studies on air pollution in street canyons. Examples of these vegetation-related features at a street scale are vegetation density, the types of greenery, the presence of green walls, crown morphology, hairiness, canopy porosity, and tree trunk height. Therefore, finding the associations between this wide range of vegetation-related features, as presented in Table 4, and air pollution, as well as the walking behavior of older adults at both a street and neighborhood scale, will clarify the influence of these features on both subjects. This could be a central point for future studies in cities/seasons with medium-to-high air pollution.

Another important issue with respect to vegetation-related features at a street scale is that the impact of in-street barriers, especially trees and vegetation-related features, on wind environment and air pollution dispersion depends on certain spatial and urban-form-related features such as the aspect ratio of the street, height of the surrounding buildings, and building density [220,228]. This shows that the inter-relationships between the vegetation-related features at a street scale and these spatial and form-related features are to be recognized while examining their relationship with air pollution. This needs to be examined by future studies as well.

Furthermore, several features, as presented in Table 4, which could be measured at a street scale, are potentially related to several urban design qualities. For instance, landmark objects and the visual connection with landmarks along the pathways, the variability of the buildings' height along the street, and the land use pattern (for instance, if a street section is known by its commercial land uses) influence the level of legibility of that street [229]. The height of the building and the aspect ratio (H/W) of the street are closely related to two urban design qualities called human scale and enclosure. "The degree of openness of the facade along the route" is closely related to enclosure and coherence. The question raised in this regard is do these features along the pathways imply that there is a relationship between these urban design qualities and air pollution in such environments? Future studies could investigate this.

It is also important to underline the significance of physical and visual connectivity to both fields of study. Physical and visual connectivity are important features for the walking experiences of older adults and for enhancing urban vitality along the streets [29,79,230,231]. Street connectivity (that influences walking behavior and air pollution) is directly related to physical and visual connectivity. Visual connectivity is connected to personal security as one of the important features related to the walking experiences of older adults [13]. Physical and visual connectivity are also important features in wind situations and the dispersion of air pollution along the streets [161]. Studies on walkability used space syntax and its different indices, such as closeness centrality, betweenness centrality, global and local integration, isovist, and other indices, to measure physical and visual connectivity [232]. These indices could be applied to measure physical and visual connectivity. Examining the relationships between physical and visual connectivity and the walking experiences of older adults and air pollution at both a street and neighborhood scale would provide a clearer picture regarding the simultaneous influence of these features on both subjects.

In addition, most existing experimental studies used wind tunnels or highly simplified CFD models concerning the relationship between the built environment and air pollution in street canyons. Despite the apparent advantages of these simulating models, previous studies on air pollution along street canyons recommended more sophisticated CFD modeling or real-world experiments [160]. Furthermore, the impact of the presented built environment factors at both street and neighborhood scales is highly dependent on certain meteorological factors such as the sunshine intensity level, wind direction, and wind speed. Thus, these factors need to be controlled while examining these relationships. Finally, it should be emphasized that results from one context regarding the effects of the features presented in Table 3 (especially vegetation-related factors) on air pollution cannot simply be applied in another context, unless a new investigation is conducted in a specific environment [220,233].

5. Conclusions

Although increased walking is recommended to improve physical activity and public health, especially for older adults, the level of outdoor pedestrian activities, including older adults' walking, should be reduced when there is increased air pollution. In this regard, recognizing the built environment features that influence the walking behavior of older adults and air pollution is an important issue to be addressed in environments with medium-to-high air pollution. This review study aimed to recognize the inter-relationships between two fields of research, namely, the walking tendencies of older adults and air pollution, in terms of the associated built environment features.

In this regard, the relevant built environment features were identified and classified. Studies on the relationships between built environment features and air pollution were categorized based on the scales of urban environments, including macroscale (the scale of cities), mesoscale (the scales of buffer zones from a 100 to 1000 m radius), and microscale urban environments (the scale of streets). While studies at the city scale concerning air pollution usually investigated urban-form-related features by focusing on urban density versus urban sprawl, a wider range of built environment variables was found in studies on micro—mesoscale urban environments. The built environment features related to air pollution in micro—mesoscale urban environments (which are more compatible with the walking experiences of older adults than macroscale-related studies) were classified into four categories: transport-related features, spatial and form-related features, in-street barriers along streets canyons (including vegetation-related barriers and non-vegetation-related barriers), and the land use pattern. In addition, how each feature was measured (whether at a street scale or neighborhood scale) was presented.

Several common features were recognized when comparing the built environment features related to the walking behavior of older adults and the built environment features related to air pollution in micro—mesoscale urban environments. They include certain urban-design-related features (such as vegetation density, vegetation type, and boundary walls along the sidewalks), several spatial-related factors (such as building height, building density, physical and visual connectivity, and degree of enclosure), and the land use pattern (such as residential or commercial land use). Examining how these common built environment features simultaneously influence the walking behavior of older adults and air pollution at both a street and neighborhood scale (in cities/seasons with medium-to-high air pollution) could address the research gap raised in this study. However, to achieve the clearest picture, it is recommendable that all the built environment features related to air pollution in micro—mesoscale urban environments be examined regarding their influence on the walking behavior of older adults at both street and neighborhood scales.

This review study, in addition to recognizing the common built environment features that contribute to both air pollution and the walking behavior of older adults, introduced several lines of research for future studies. First, it is important to understand how the presented urban-design-related features are perceived by older adults and how the subjective/objective measurements of these street features are linked to air pollution. These urban-design-related features could be examined to understand to what extent they are related to the spatial dimensions, such as the degree of enclosure or the type of vegetation along the streets. Secondly, in-street barriers are of special importance for both air pollution and the walking behavior of older adults due to the possibility for the easy rearrangement of these features along the streets by urban/transport policymakers compared to spatial-related features. Within the category of in-street barriers, vegetation-related features have a specific role due to their influence on both air pollution and the walking behavior older adults. Therefore, finding associations between the wide range of vegetation-related features presented in this article and air pollution and older adults' walking behavior appears to be a significant issue. Third, certain aspects of the urban form, like building density, influence how much vegetation-related features contribute to air pollution. Future research must look into these relationships as well. Fourth, several built environment features at a street scale are related to various urban design qualities such as legibility and enclosure. The question raised in this regard is whether there is any relationship between these urban design qualities and air pollution. Fifth, special attention should be paid to the role of physical and visual connectivity at both street and neighborhood scales due to their role in both fields of study. Finally, the impact of certain meteorological features such as wind direction and wind speed is critical in the aforementioned inter-relationships. Thus, these factors must be controlled while examining the relationships between the built environment and air pollution at street and neighborhood scales. These inter-relationships should be examined by future studies in environments with medium-to-high air pollution. The findings of such studies would be highly applicable for urban and transport policymakers to adopt policies regarding the rearrangement of built environment features, which could lead to an improvement in the walking behavior of older adults together with reducing microscale and mesoscale air pollution.

Finally, it is also to be noted that to avoid any deviation from the conceptual framework of the study and the possibility of summarizing the extensive contents of this study in one article, only the direct effect of independent variables on the dependent variables was focused on by this study, while other mechanisms of the effect of variables on each other, such as the existence of mediators, were not investigated. This limitation will need to be addressed in future studies.

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