Systematic Review

Duration as the Sixth Dimension of the Built Environment Travel Behaviour Framework

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Abstract

The built environment (BE) plays a central role in shaping everyday mobility patterns and determining how physical activity (PA) is integrated into daily life. Foundational BE frameworks such as the 5Ds (density, diversity, design, distance to transit, and destination accessibility) have shaped policy and planning worldwide. However, these frameworks remain predominantly spatial and overlook temporal dynamics. This review addresses this omission by introducing *Duration* as the sixth dimension (6th D) of the BE framework, reframing accessibility in terms of the lived temporal experience of movement rather than static spatial distance. Travel conditions vary across the day. Routes that are safe and efficient at one time often become congested, stressful, and prohibitive at another. Such variability undermines PA and active transport (AT) and diminishes the health benefits of supportive BE. Methodologically, the review synthesises evidence from 1991 to 2025 across public health, transport planning, BE, and environmental psychology. Pertinent literature (102 shortlisted articles) published in English was retrieved from Scopus, Web of Science (WoS), and PubMed, which collectively provide comprehensive coverage of multidisciplinary research spanning transport planning, public health, and behavioural sciences. The PRISMA 2020 approach and VOSviewer (version 1.6.20), were used, together with a structured, Excel-based integrative synthesis, to analyse publication trends, conceptual evolution, and integrative patterns in the retrieved literature. The synthesis shows that accessibility, mobility stress, and travel behaviour are strongly time-dependent. This time dependence is systematic rather than incidental across contexts. Globally, commute durations beyond 45 min are associated with lower life satisfaction and poorer health outcomes. Embedding *Duration* within BE frameworks establishes a time-responsive and equity-sensitive paradigm for healthier and more resilient urban systems.

Keywords: active transport; built environment; duration; physical activity; temporal variability; traffic stress

1. Introduction

The 21st century has brought rapid urban densification, technological advancement, and global connectivity, reshaping how people move, connect, and engage with their environments [1–3]. Accordingly, modern lifestyles have become increasingly sedentary, displacing many forms of incidental physical activity (PA) that were once part of daily routines [4]. PA, defined as any skeletal muscle movement that expends energy, whether undertaken in leisure, work, household, educational, or transport settings [5], has long

been linked to the built environment (BE) [6]. The World Health Organization (WHO) recommends at least 150 min of moderate-intensity or 75 min of vigorous-intensity PA per week, or an equivalent combination [7]. A recent study established that thirty minutes of daily exposure to supportive BE conditions increases walking by 20–70 steps per minute, whereas weather stressors such as heat or rain reduce it by 25–50 steps per minute [8]. Built and social environments collectively enable or constrain mobility [3], with factors such as density, connectivity, and access to services systematically shaping opportunities for PA [6,9,10].

Despite such evidence, global levels of PA continue to decline [11–14]. A pooled analysis covering 507 surveys from 163 countries shows that the global age-standardised prevalence of insufficient PA increased from 23.4% in 2000 to 26.4% in 2010, reaching 31.3% in 2022 [15]. Prevalence remains higher among women (33.8%) than men (28.7%), rising particularly among adults aged 60 years and older [15]. Given these trends, the global target of a 15% relative reduction in physical inactivity (PIA) by 2030 is unlikely to be achieved without transformative interventions [15].

PIA contributes substantially to global disease burden, accounting for approximately 9% of premature mortality worldwide [16,17]. It remains a major behavioural risk factor associated with preventable morbidity and reduced health expectancy across populations [18]. PIA increases the risk of life-threatening diseases such as cardiovascular disease, type 2 diabetes, and several cancers [19]. Conversely, PA supports a healthy weight [19], reduces obesity [20], and lowers all-cause mortality [21,22], including cardiovascular disease, diabetes, and cancers [23], as well as improving mental health [24]. Despite clear evidence of benefit, PIA remains entrenched worldwide, underscoring the limits of individual action in the absence of supportive BE and policy contexts. This highlights the need to examine how the BE structures opportunities for PA.

Classic BE frameworks, such as the 5Ds (density, diversity, design, distance to transit, and destination accessibility) [25,26], have long shaped research. However, these frameworks remain largely spatially focused. The extant literature has relied on cross-sectional designs [27–29], generating valuable evidence on how density, diversity, and design influence PA. Yet these approaches implicitly assume that environmental exposures are constant across the day. In practice, the functionality of the same infrastructure can change within hours, a limitation highlighted by Arif and Ullah [8]. For instance, a route that is safe and accessible at 6 AM may become congested, stressful, and time-consuming by 8 AM [30,31]. Fluctuations in traffic volume, speed, perceived safety, and exposure to noise or pollution shape travel choices; however, current frameworks fail to capture this intra-day variability. Such instability challenges static conceptualisations of accessibility and mobility equity.

Empirical evidence confirms this temporal sensitivity. Using large-scale camera-based pedestrian counts across Manhattan, Dobler et al. [32] identified a characteristic three-peak weekday structure with increased foot traffic around 9 AM, 12 PM to 1 PM, and 5 PM, corresponding to morning, midday, and evening commute cycles. A similar observation was made by Arif and Ullah [8], who reported pronounced fluctuations in traffic stress and accessibility across comparable time periods, confirming intra-day variability in mobility patterns. Evidence of such temporal adaptations is observed along York Avenue in New York City, where pedestrian flows shift from the east to the west sidewalk between noon and 6 PM as direct sunlight intensifies [33]. This behavioural adjustment illustrates how exposure and comfort conditions vary across the day, prompting time-specific route selection even within the same street environment.

Traffic safety research shows that peak-hour periods exhibit unique and heterogeneous risk characteristics that are often overlooked in conventional analyses [34]. Myhrmann and Mabit [35] reported that cycling during the early morning (7–8 AM) and afternoon

peak hours (3–6 PM) in Copenhagen was associated with a higher likelihood of bicycle crashes. Similarly, Mokhtarimousavi et al. [36] found that pedestrian crash severity in California varied significantly by time of day and day of the week, with higher risks during morning and evening peaks under poor lighting and surface conditions. Safety, therefore, is not static but temporally contingent. Supporting this evidence, the Daily Traffic Stress (DTS) framework [8] quantifies temporal fluctuations in traffic exposure by integrating hourly and daily variations in congestion, flow, and perceived stress. The DTS framework demonstrates that traffic stress (TS) is cyclic, intensifying during peak hours and easing during off-peak periods.

These studies reveal a fundamental methodological gap. While spatial determinants of active transport (AT) have been extensively modelled, their temporal variability remains largely unquantified. Addressing this gap is the novelty of this review, which motivates the proposal of *Duration* as the Sixth D. Duration is conceptualised as a structural temporal property of urban systems, rather than as a trip-level mobility outcome, an exposure metric, or a behavioural moderator. This study aims to answer the following research question: How can temporal variability be integrated within BE frameworks to improve accessibility, health, and mobility equity? To address this question, the study pursues the following objectives:

1. To review the extant literature on the BE, PA, and AT to identify how temporal variability, including traffic fluctuations and commuting duration, remains unaccounted for in conventional 5D frameworks of the BE.
2. To synthesise published evidence from multidisciplinary studies spanning BE, transport planning, and public health domains, together with real-world traffic datasets (Queensland (QLD), Australia, the United Kingdom (UK), and New Zealand), to justify the introduction of *Duration* as the 6th dimension of the BE framework.

The remainder of this paper is structured as follows: Section 2 outlines the methodology; Section 3 presents the results; Section 4 discusses key findings; and Section 5 concludes with practical implications and limitations.
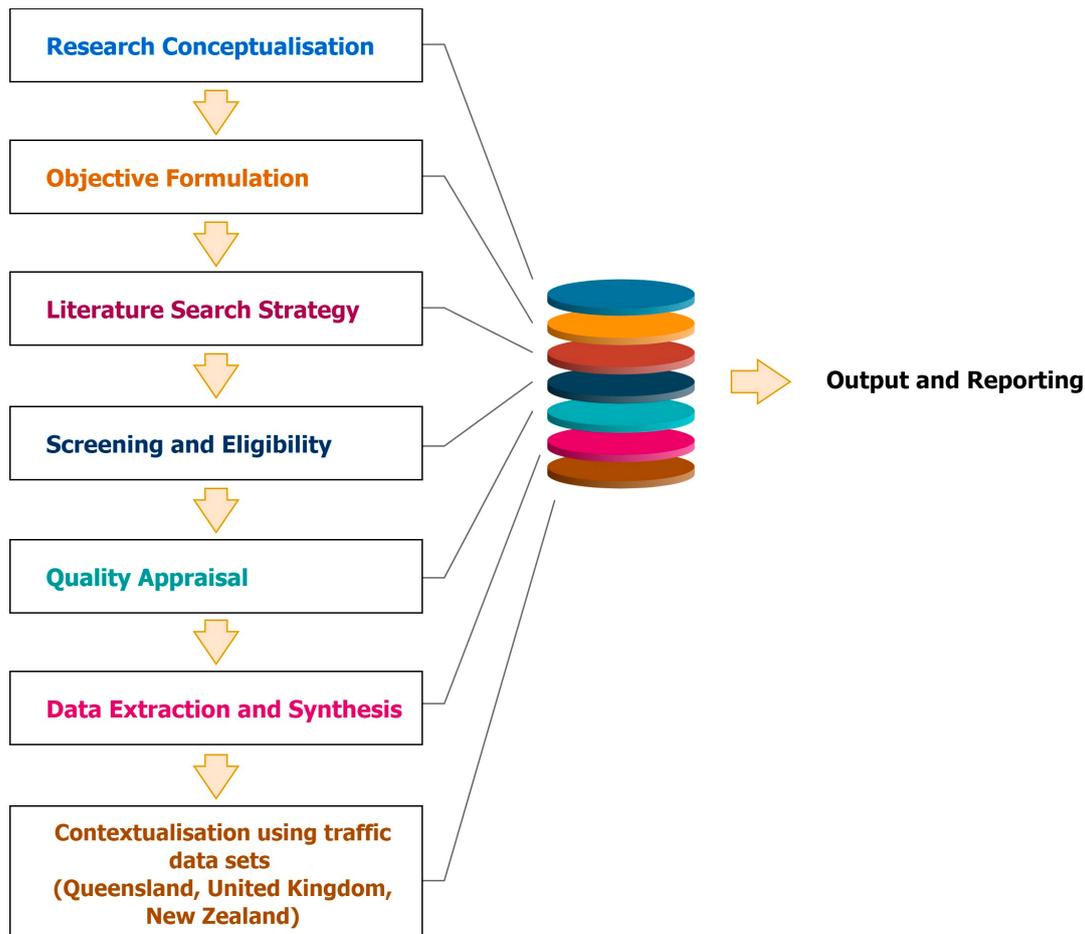
2. Methodology

The study followed a structured multi-step process, as illustrated in Figure 1. Literature was retrieved from Scopus, Web of Science, and PubMed, which are widely recognised as core databases for interdisciplinary systematic reviews [37,38]. This combination ensured comprehensive coverage of peer-reviewed journal articles while minimising duplication across overlapping sources. The search targeted peer-reviewed articles and reviews published between 1991 and 2025.

Data were extracted and verified in Microsoft Excel using a structured template documenting author(s), year, study design, region, and thematic focus [39,40]. The VOSviewer software (version 1.6.20) was used for bibliometric visualisation to identify keyword co-occurrence and conceptual linkages. Methodological quality of peer-reviewed studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal tools [41], and studies were classified as high, moderate, or low quality according to design-specific checklists. The review process adhered to PRISMA 2020 standards [42], ensuring transparency, reproducibility, and methodological consistency across databases.

2.1. Search Strategy and Database Coverage

A comprehensive search was conducted across the selected databases using Boolean logic and truncations to ensure inclusive coverage of interdisciplinary literature, following established practices [8,43]. Search terms integrated domains of the BE, PA, stress, and travel behaviour with data-driven and geospatial approaches central to contemporary

transport and mobility research, including geographic information systems, GPS tracking, sensor-based monitoring, large-scale mobility datasets, artificial intelligence, machine learning, and related analytical techniques. This interdisciplinary scope reflects the methodological diversity required to capture temporal variation in accessibility, congestion, and mobility exposure. To maintain conceptual focus, inclusion was restricted to studies that explicitly examined temporal variability in mobility or accessibility in relation to urban form, transport systems, or health-relevant outcomes. This approach aligns with guidance for evidence synthesis in complex systems research, which recognises that phenomena spanning multiple interacting domains necessitate broader evidence bases rather than narrow, single-discipline samples [44–46].

Figure 1. Methodological Workflow of the Narrative Review. Diagram developed by the authors.

Table 1 presents the databases, search strings, filters, coverage, and counts of retrieved articles for the current study.

The literature examining temporal aspects of travel, commuting, and accessibility employs diverse terminology, including congestion exposure, commuting burden, transport fatigue, travel time unreliability, and time pressure. These terms were not used as standalone primary search keywords, as their usage varies substantially across disciplines and often refers to specific or partial aspects of the travel experience rather than to a consistent conceptual construct. The search strategy prioritised established and commonly used terms within built-environment, transport, and public-health research, including traffic stress, daily traffic stress, mobility stress, temporal variability, travel time, and duration. Studies employing alternative terminology were not excluded a priori. Such studies were retained during title, abstract, and full-text screening when their analytical focus, measures,

or definitions addressed temporal variability, commuting-related stress, or time-sensitive accessibility within built-environment and mobility contexts. This approach ensured comprehensive coverage of relevant evidence while maintaining conceptual consistency across the final set of included studies.

Table 1. Databases, strings, filters, coverage, and record counts.

Database	Search String Used	Coverage	Filters	Count
Scopus	(((("built environment" OR "urban form" OR "urban design" OR neighbourhood * OR walkabil * OR "land use" OR densit * OR diversit * OR "destination accessibility" OR "distance to transit" OR "street connectivity" OR "transport planning" OR "sustainable mobility" OR accessibility) AND ("physical activity" OR "active transport" OR "active travel" OR walking OR cycling OR commuting) AND ("traffic stress" OR "daily traffic stress" OR "commuting stress" OR "travel stress" OR "psychological stress" OR "travel anxiety" OR "commute time" OR "commuting burden" OR "temporal variability" OR "travel time" OR duration) AND (("machine learning" OR "artificial intelligence" OR "big data" OR microsimulation OR GIS) AND (transport * OR mobility OR "built environment" OR "physical activity"))))	1991–2025	English, peer-reviewed journal articles only	8943
PubMed	((("built environment" [Title/Abstract] OR "urban form" [Title/Abstract] OR "urban design " [Title/Abstract] OR neighborhood * [Title/Abstract] OR walkabil * [Title/Abstract] OR "land use " [Title/Abstract] OR densit * [Title/Abstract] OR diversit * [Title/Abstract] OR "destination accessibility" [Title/Abstract] OR "distance to transit" [Title/Abstract] OR "street connectivity" [Title/Abstract]) AND ("physical activity" [Title/Abstract] OR "active transport" [Title/Abstract] OR "active travel" [Title/Abstract] OR walking [Title/Abstract] OR cycling [Title/Abstract] OR commuting [Title/Abstract] OR "machine learning" [Title/Abstract] OR "artificial intelligence" [Title/Abstract]) AND (stress [Title/Abstract] OR anxiety [Title/Abstract] OR "commute time" [Title/Abstract] OR "travel time" [Title/Abstract] OR "transport planning" [Title/Abstract] OR "sustainable mobility" [Title/Abstract]))	1991–2025	English, peer-reviewed journal articles only	1923
Web of Science	Topic ["built environment" OR "urban design" OR "urban form" OR neighborhood * OR neighbourhood * OR walkabil * OR "land use" OR densit * OR diversit * OR "street connectivity" OR "destination accessibility" OR "distance to transit"] AND Topic ["physical activity" OR "active transport" OR "active travel" OR walking OR cycling OR commuting OR "sustainable mobility"] AND Topic ["traffic stress" OR "commuting stress" OR "travel stress" OR "psychological stress" OR "commute time" OR "travel time" OR "temporal variability" OR "daily traffic"] AND Topic ["machine learning" OR "artificial intelligence" OR "big data" OR microsimulation OR GIS OR "geographic information systems" OR "transport planning" OR "mobility planning"]	1991–2025	English, peer-reviewed journal articles only	107
Subtotal				10,973

Table 1. *Cont.*

Database	Search String Used	Coverage	Filters	Count
Irrelevant records excluded	Unrelated articles identified through title and abstract screening, removal of duplicates, and methodological quality appraisal			10,871
Final records included	Studies conceptually aligned with BE, PA, AT, Stress, Behaviour, and Commuting.			102

Note: The complete list of included studies and detailed bibliographic information is provided in Appendix A. Also, * is used to include all possible variants of the keyword.

2.2. Study Selection and Eligibility Criteria

Titles and abstracts were screened independently by the authors, followed by full-text eligibility checks. Duplicate records were removed using EndNote. Discrepancies were resolved through consensus among reviewers. All eligible empirical and review studies underwent critical appraisal using JBI design-specific checklists [41]. Detailed inclusion and exclusion criteria were developed and applied in the current study, as listed in Table 2.

Table 2. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Peer-reviewed journal articles published between 1991 and 2025.	Non–peer–reviewed publications.
Studies examining BE, PA, AT, TS, SEM, or related determinants of mobility behaviour.	Studies unrelated to BE, PA, AT, TS, or SEM (e.g., laboratory psychology, animal studies, or stress research unrelated to transport or mobility).
Research exploring Temporal Variability, Commuting Behaviour, or Travel-Time and Accessibility Metrics within the context of active or sustainable mobility.	Studies focusing solely on clinical, occupational, or cognitive stress without transport, temporal, or built-environment relevance.
Articles applying Machine Learning, Artificial Intelligence, GIS, or Big Data Analytics to mobility, accessibility, transport planning, or AT analysis.	Modelling or simulation studies unrelated to transport, accessibility, or PA outcomes.
Studies addressing Urban Design, Transport Planning, Mobility Planning, Accessibility, or Sustainable Mobility transitions.	Papers limited to land-use economics, logistics, or freight-transport research without behavioural, accessibility, or public-health relevance.
Studies examining Psychological Stress or Travel Stress in relation to daily travel, commuting, or BE conditions.	Studies on psychological or physiological stress unconnected to mobility or travel context.
Articles written in English and accessible through Scopus, Web of Science, or PubMed.	Non-English publications or inaccessible sources.
Publications providing complete methodological and analytical detail suitable for bibliometric or systematic synthesis.	Grey literature (e.g., reports, working papers, theses, and conference proceedings).

Figure 2 outlines the number of records retrieved, screened, excluded, and retained across all databases in accordance with PRISMA 2020 guidelines.

2.3. Supplementary Open Data Sources

The literature synthesis was first used to identify recurring temporal constructs, thresholds, and patterns related to accessibility, commuting duration, and mobility stress. These conceptual findings were then contextualised and illustrated using supplementary datasets drawn from open-access governmental and institutional sources. The primary datasets included the QLD Government Traffic Data (2023) [30], UK Department for Transport

Dataset (2000–2024) [47], and New Zealand Transport Data (2022) [31]. Strategic planning references were drawn from the Singapore Land Transport Master Plan 2040 [48] and the Northshore Hamilton Priority Development Area (PDA) Infrastructure Reports (Economic Development Queensland) [49]. Additional international benchmarks were obtained from the U.S. Census Bureau [50], the European Union Commuting Time Statistics [51], and the Australian Department of Infrastructure and Regional Development [52]. These datasets were not used to derive new causal estimates; instead, they were used to illustrate and support the review's central argument that accessibility and mobility conditions vary systematically over time. This integrated methodological workflow is summarised in Figure 1.
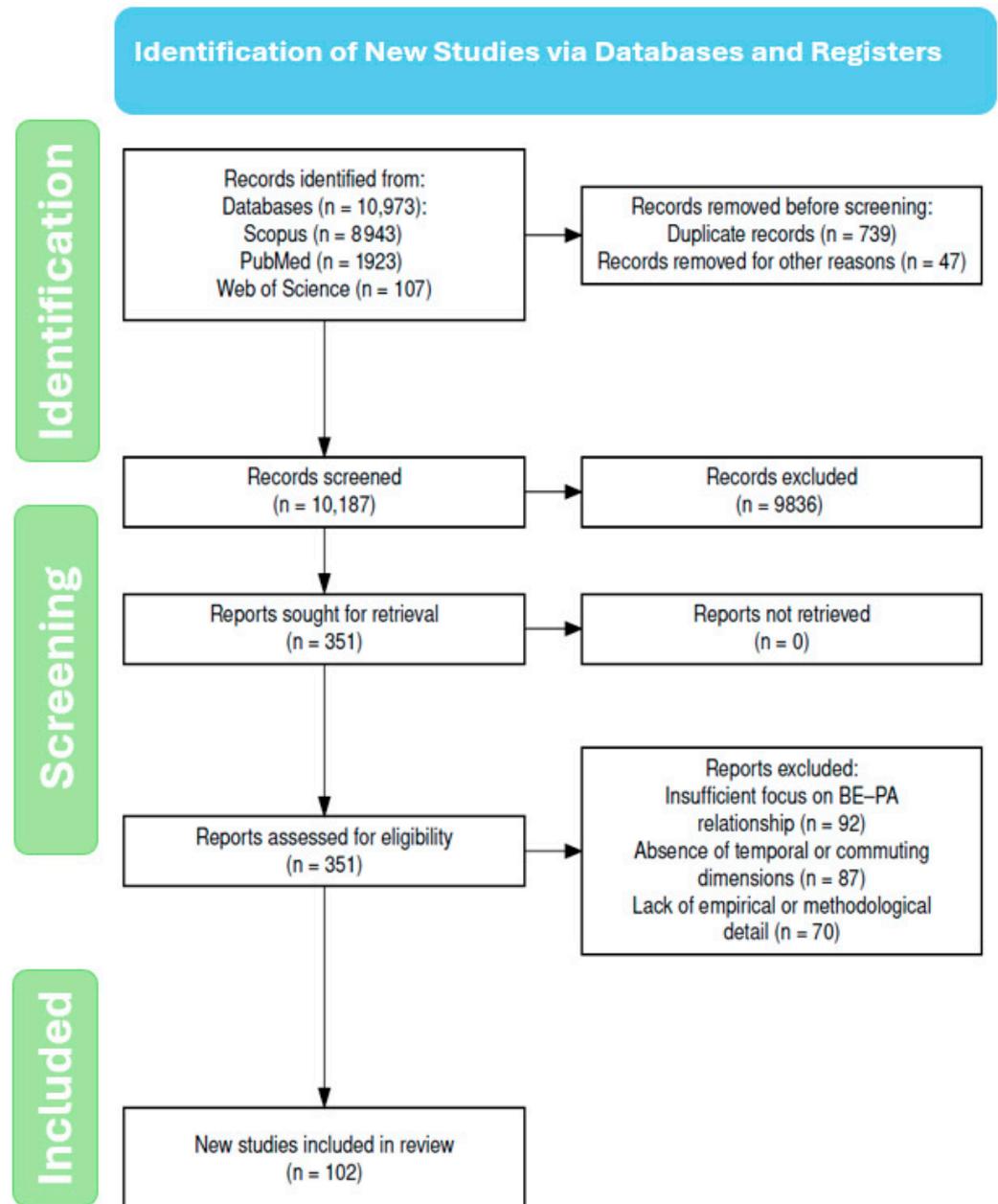
Figure 2. PRISMA 2020 Flow Diagram of Study Identification and Selection Process.

2.4. Data Synthesis and Analysis

Given the heterogeneity of study designs and outcomes, a systematic narrative synthesis was applied. Extracted data were first organised in Microsoft Excel, where studies

were coded by thematic focus, methodological design, and geographic context. Evidence was then integrated thematically across four domains: global trends in physical activity and health risks; the evolution of transport and built-environment frameworks (3Ds, 5Ds, and extensions); behavioural and commuting-related stressors influencing travel mode and wellbeing; and the intersection of technological and policy innovations, including Geographic Information Systems (GIS), Global Positioning Systems (GPS), wearable sensors, big data analytics, bus rapid transit systems, congestion charging, superblocks, and transit-oriented developments. Findings were synthesised narratively, and where applicable, associations were categorised as positive (+), negative (−), or mixed (0).

2.5. Characteristics of Included Studies

The final dataset comprised 102 peer-reviewed publications representing a broad methodological spectrum. These studies primarily comprised empirical investigations (including cross-sectional, longitudinal, cohort, and experimental designs), as well as systematic, meta-analytic, scoping, and bibliometric reviews, and conceptual and methodological framework articles, as shown in Table 3. The emergent focus areas include global trends in PA and health risks, the evolution of transport and BE frameworks, behavioural and commuting-related stressors influencing travel mode and wellbeing, and technological and policy innovations.

Table 3. Focus areas of included studies.

Focus Area	Brief Description	Count
Global Trends in PA and Health Risks	Examines global surveillance of PA, sedentary behaviour, and their links to chronic disease, mortality, and psychosocial determinants of health across populations.	26
Evolution of Transport and BE Frameworks (3Ds, 5Ds, and Extensions)	Focuses on the development and application of BE frameworks. Such as density, diversity, design, destination, and distance frameworks to explain mobility, accessibility, and AT behaviours.	23
Behavioural and Commuting-Related Stressors Influencing Travel Mode and Wellbeing	Investigates psychological, temporal, and experiential stressors associated with commuting; explores relationships between travel mode, satisfaction, wellbeing, and behavioural intention.	24
Technological and Policy Innovations (GIS, GPS, Sensors, Big Data, bus rapid transit systems, Congestion Charging, transit-oriented developments)	Encompasses technological and governance-driven advances, including AI, ML, GIS, and big data analytics, as well as infrastructure and policy innovations that support sustainable, low-stress mobility.	29
Total		102

Geographically, the evidence base spanned high-income regions and low- and middle-income countries, ensuring diversity across urban contexts. Classification of study types was verified through each article's methodological description and journal indexing rather than the authors' subjective interpretation. This approach ensured consistency with PRISMA 2020 [42] and JBI [41] appraisal standards, while recognising the diversity of research designs employed across the included literature. Studies overlapped across BE, transport, health, and behavioural subfields, illustrating the interdisciplinary scope of the evidence base.

3. Results and Analysis

The results are presented in four sections, corresponding to the bibliometric, conceptual, developmental, and empirical dimensions of this review.

3.1. Bibliometric Network Analysis Across Databases

The bibliometric analysis was conducted using VOSviewer (version 1.6.20). Keyword co-occurrence data were extracted from the three repositories: Scopus (Figure 3a), Web of Science (Figure 3b), and PubMed (Figure 3c), and were standardised through cleaning procedures, such as merging synonyms. The resulting maps identified thematic linkages and conceptual clusters across disciplines.

Bibliometric mapping revealed overlapping domains encompassing the BE, travel behaviour, and public health. The most frequently co-occurring keywords were related to accessibility, travel time, and BE design, alongside behavioural and psychosocial constructs such as walking and physical activity. Clusters centred on mental health, anxiety, obesity, sedentary behaviour, and cardiovascular disease indicated a strong emphasis on psychosocial and chronic disease outcomes within the mobility literature. Environmental and public health concepts, including urban health, sustainability, and social determinants, further reflected the multidisciplinary scope of this research domain. The observed clustering demonstrates that mobility research increasingly integrates spatial characteristics of urban form with behavioural and psychological dimensions, providing a foundation for examining how built environments shape movement patterns and associated health outcomes.

3.2. Foundational and Integrative Perspectives on Stress Frameworks

3.2.1. Classical Frameworks: Emergence of the 3Ds and 5Ds

Initial research on the BE and mobility relied on simple measures of neighbourhood form [53]. It highlighted how spatial design shapes PA and travel choices. The 3Ds (density, diversity, design) were introduced by Cervero and Kockelman (1997) [54], later expanded to the 5Ds with the addition of distance to transit and destination accessibility [25,26]. Table 4 presents the 5Ds of BE along with their definitions.

Table 4. The 5Ds of the BE.

| Dimension (D)	Conceptual Definition	References
Density	Concentration of population, employment, or dwellings within a given area; higher density generally supports walking, cycling, and public transport.	[54]
Diversity	Mix of land uses (e.g., residential, commercial, recreational) within a neighbourhood; greater diversity reduces travel distances and promotes PA and AT.	[54]
Design	Street network characteristics such as connectivity, intersection density, and pedestrian infrastructure influence route choice and walkability.	[54]
Destination Accessibility	Ease of reaching desired destinations (e.g., jobs, shops, schools) within a region; often measured by proximity or travel time to key activity centres.	[25,26]
Distance to Transit	Proximity to public transport stops or stations; shorter distances increase the likelihood of walking or cycling to transit.	[25,26]
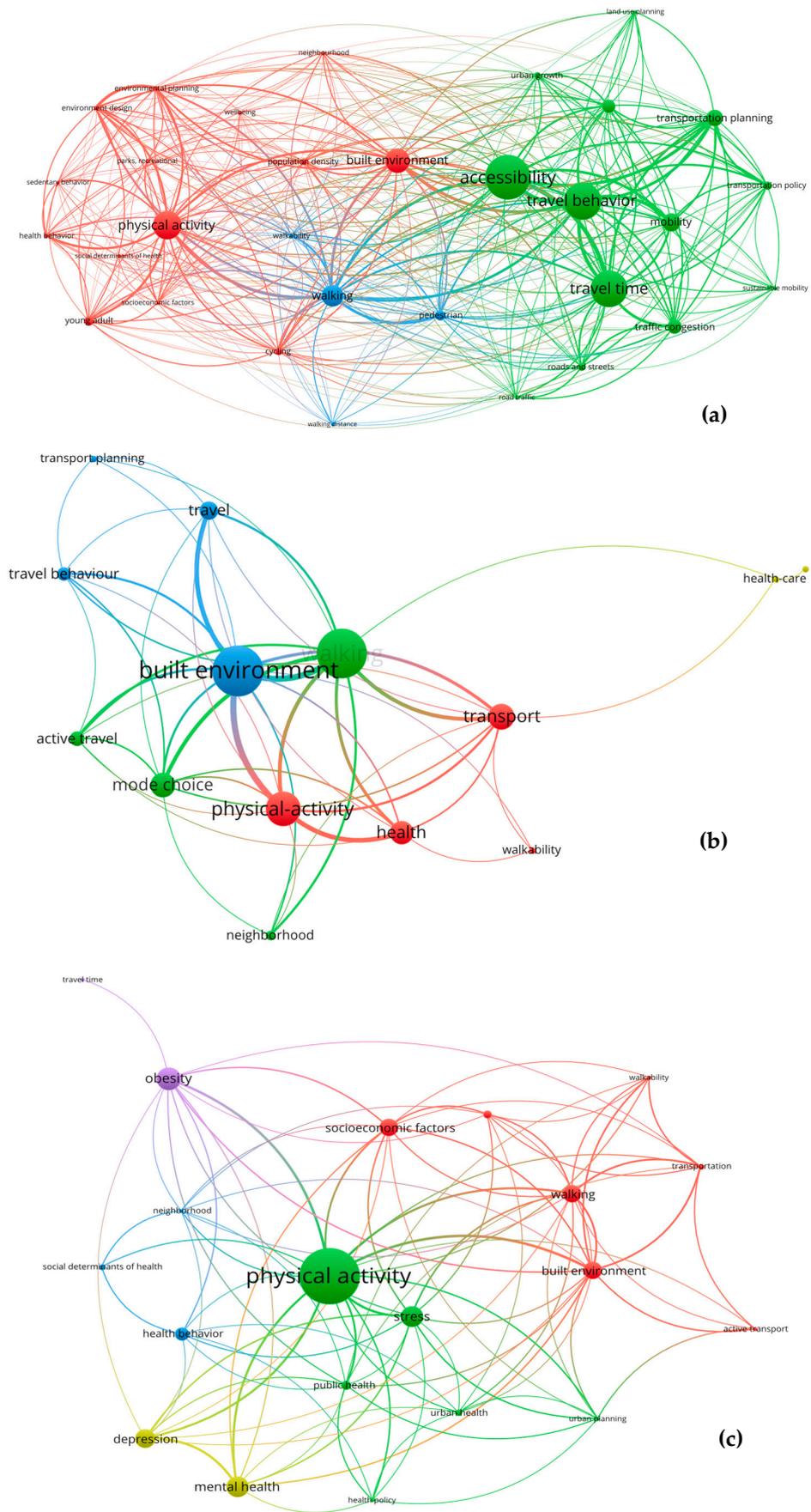
Figure 3. VOSviewer clustering of the retrieved papers: (**a**) Scopus, (**b**) Web of Science, (**c**) PubMed.

The 5Ds framework has been foundational in transport, urban planning, and PA research, shaping decades of evidence on how the BE influences mobility and AT. Extensions such as demand management (e.g., parking supply and cost) and demographics have occasionally been introduced as sixth and seventh Ds, yet these remain ancillary attributes rather than core spatial dimensions [25]. As clarified by Ewing and Cervero [25], these elements are not integral components of the BE but contextual modifiers. Recent studies continue to operationalise the BE through the original five spatial dimensions, namely density, diversity, design, destination accessibility, and distance to transit, as shown by Chen et al. [55] and reaffirmed by Schukei and Rowangould [56]. Together, these findings consolidate the 5Ds as the central framework for analysing the influences of BE on travel behaviour.

The Level of Traffic Stress (LTS) framework [57] classifies road segments by the degree of stress or comfort experienced by cyclists and other active-transport users. It categorises networks from LTS 1 (very low stress, suitable for children) to LTS 4 (high stress, suitable only for highly confident cyclists). The classification is primarily based on infrastructure design features, including traffic volume, vehicle speed, lane width, and the presence or absence of dedicated cycling facilities. The Pedestrian Quality of Service Framework [58] has been used to evaluate pedestrian environments, though it does not directly quantify stress using a Likert or categorical scale. Broader determinants of behaviour are interpreted through the Socio-Ecological Model (SEM), which explains behaviour through multilevel influences spanning from individual to policy contexts [59–61], while the Theory of Planned Behaviour (TPB) links behavioural intention to attitudes, subjective norms, and perceived control [62]. These frameworks collectively address aspects of safety, comfort, and behavioural intention, yet overlook how stress fluctuates with time, congestion, and contextual change.

3.2.2. Established Stress Constructs

Alongside the spatial and behavioural models, transport and health research have developed parallel constructs to describe stress associated with mobility. TS refers to the discomfort and perceived danger individuals experience when navigating environments with high traffic density, poor design, and inadequate pedestrian or cycling infrastructure [63]. Commuting stress, by contrast, focuses on the strain associated with daily home-work travel, emphasising the psychological and physiological effects of unpredictability, delays, and lack of control [64]. Later research extended commuting stress into travel stress, capturing strain across broader contexts, including leisure trips, intercity journeys, and air travel (where crowding, delays, and uncertainty are prevalent) [65]. A related but distinct construct is travel anxiety, a risk-based anticipatory state tied to perceived threats, sociocultural risks, or safety concerns that strongly influence willingness and intentions to travel [66]. These constructs confirm stress as a central dimension of mobility, yet it remains context-specific rather than cumulative.

Research further highlights this fragmentation across modes and disciplines. A large-scale commuter survey comparing walking, driving, and public transit users found that driving was the most stressful mode, though specific stressors differed by mode (e.g., congestion for drivers, crowding for transit users) [67]. A quasi-longitudinal analysis using the China Health and Nutrition Survey (2006–2015) reported that long-duration motorised commutes increased psychological stress, while long-duration active commutes were associated with lower stress, highlighting the moderating role of urbanicity and commute time [68]. A systematic review of 45 studies on commuting, subjective well-being, and mental health found that commute *Duration* and mode significantly influence both experiential indicators (commute satisfaction, stress, and emotional response) and general

mental states (life satisfaction, depression, and cognitive well-being) [69]. The review also noted that results remain inconclusive, mainly due to variations in study design, measurement, and temporal scope. It further showed that exceeding certain duration thresholds consistently reduces well-being, whereas active travel modes enhance both the commuting experience and mental health. These findings indicate that mobility stress arises from interacting spatial, behavioural, and temporal factors, underscoring the need for integrated frameworks to capture these dynamics.

3.2.3. Integrating Perspectives Across Disciplines

Mobility stress spans transport planning, environmental psychology, public health, and wider BE fields. Table 5 presents the conceptual focus of mobility-related stress across various disciplines. In transport planning, stress is framed as congestion, time loss, and reduced utility [70,71]. Environmental psychology emphasises perception, safety, self-efficacy, and control [72–74], while public health research focuses on exposure, dose–response effects, and inequities in vulnerability [75–77]. The integration of these perspectives is essential.

Table 5. Conceptualisation of mobility-related stress across disciplines.

Field/ Discipline	Construct or Variable	Conceptual Focus/Explanation	References
Transport Planning	Congestion	Traffic volume exceeding road capacity, leading to delays and frustration.	[70,71]
	Time loss	Reduced travel-time reliability and perceived inefficiency of the network.	[70,71]
	Reduced utility	Decrease in perceived trip satisfaction and overall mobility benefit.	[70,71]
Environmental Psychology	Perception	Individual appraisal of safety, comfort, and environmental cues during travel.	[72–74]
	Safety	A sense of physical and social security while moving through environments.	[72–74]
	Self-efficacy	Confidence in one's ability to navigate or overcome travel-related barriers.	[72–74]
	Control	The degree to which individuals feel they can manage or predict travel conditions.	[72–74]
Public Health	Exposure	*Duration* and intensity of contact with physical or psychosocial stressors during mobility.	[75–77]
	Dose–response	Relationship between level of exposure and health outcome (e.g., cardiovascular or mental health effects).	[75–77]
	Vulnerability/Inequity	Differential susceptibility to stress based on socioeconomic or demographic factors.	[75–77]

A cycling corridor may be judged supportive of PA in transport models. Yet, it is often avoided during peak hours because users perceive it as unsafe, undermining its potential to promote health.

3.3. Developmental Phases of Built Environment and Physical Activity Research

3.3.1. Early Developments: Descriptive and Correlational Studies

Early research on the BE and PA was primarily descriptive, identifying correlations between neighbourhood form and walking behaviour without establishing causality. Foun-

dational studies demonstrated that compact, mixed-use, and well-connected environments were associated with higher rates of walking and cycling, but these relationships were primarily cross-sectional and vulnerable to residential self-selection bias [78,79]. Handy et al. (2007) [78] provided early quasi-longitudinal evidence that neighbourhood design influences walking behaviour even after controlling for individual travel attitudes and preferences, suggesting a partial causal pathway. Similarly, Frank et al. (2007) [79] integrated data on neighbourhood selection and community preferences, showing that residents who both preferred and lived in walkable areas walked significantly more and drove less than those in car-dependent settings, with corresponding reductions in obesity prevalence. Earlier syntheses by Handy (2002) [80] further consolidated the empirical foundations linking land-use mix, density, and street design to mobility and health outcomes, establishing BE as a key determinant of AT. However, these studies rarely captured time-of-day variation.

3.3.2. Global Growth and Diversification (2000–2010)

Between 2000 and 2010, research on BE–PA associations expanded globally, diversifying the empirical base across multiple regions (USA, Australia, Denmark, UK, The Netherlands) [81,82]. The period also saw the introduction of walkability indices that combined GIS measures of land use, density, and street connectivity [83–85]. Evidence consistently linked mixed land use, shorter travel distances, and greater connectivity with higher levels of PA [86,87]. However, critiques emerged around self-selection bias (residents choosing neighbourhoods aligned with their preferences) [88] and the limits of cross-sectional designs [81], which could not capture temporal fluctuations.

3.3.3. Consolidation and Policy Alignment (2010–2020)

During this period, policy developments did not follow a single uniform trajectory across regions; instead, international frameworks, such as those of the WHO and UN initiatives, provided a shared normative direction, while implementation and translation into planning practice remained highly context-specific. The decade witnessed growth in research output, as evidenced by numerous systematic reviews and meta-analyses examining associations between the BE-PA [89–91]. Advances in GIS technology enabled more refined spatial measures of the BE and their associations with PA [92]. Global health initiatives, including the United Nations Sustainable Development Goals (SDGs) [93] and the WHO Global Action Plan on PA 2018–2030: More Active People for a Healthier World [94], reinforced the importance of PA for disease prevention and population health. The WHO plan reaffirmed the target to reduce global inactivity by 15% by 2030 [94], emphasising the creation of active societies, environments, and systems. It marks a major policy shift toward integrating PA into transport, urban design, and health promotion. This policy direction aligns with the BE dimensions of accessibility and design. It also highlights the relevance of *Duration*, which represents the temporal reliability of mobility as a determinant of sustained activity levels. These initiatives positioned PA as a global public health priority and aligned urban design with the broader agenda of reducing non-communicable diseases (NCDs).

3.3.4. Transformative Trends and Temporal Turn (2020–2025)

Human mobility and transport research has expanded rapidly, with recent bibliometric reviews confirming steady growth in interdisciplinary, data-driven, and technology-integrated studies [95,96]. Advances in wearable sensors, GPS tracking, and GIS-linked big data have enabled the capture of real-time data in mobility and exposure [97,98]. These innovations signal a clear temporal shift in mobility studies, highlighting how accessibility and stress fluctuate dynamically throughout the day. In health research, a recent meta-analysis reported non-linear associations between steps per day and health, with

inflection points at around 7000 steps per day [99]. Similarly, QLD traffic monitoring data (2023) [30] shows that traffic volumes on urban corridors can vary up to threefold between early morning and peak commuting hours, illustrating how static measures obscure critical temporal fluctuations. A newly published study further identifies distinct daily patterns in traffic stress, characterised by morning peak traffic stress (MPTS), midday traffic stress (MDTS), and evening peak traffic stress (EPTS), which reflect how stress levels fluctuate across the day [8].

Advances in travel demand forecasting reveal that progress on the supply and demand sides of modelling has primarily developed independently, with limited attention to temporal consistency between individual travel behaviour and network dynamics [100]. This gap underscores the need for frameworks that capture time-sensitive reliability and dynamic accessibility. Emerging applications of artificial intelligence (AI) and machine learning (ML) approaches have enhanced the ability to model real-time congestion and dynamic exposure [101]. Such tools remain supportive rather than substitutive of theoretical innovation. Moreover, ongoing efforts to unify sustainable mobility paradigms, such as the CalmMobility framework [102], underscore the necessity of integrated perspectives that connect temporal reliability with human-centred mobility planning.

3.4. Evidence Necessitating Duration as the Sixth Dimension

In Australia, commutes of ≥45 min are classified as lengthy [52]. In the United States, the average one-way commute is 27.6 min [50]. Across the European Union, the average is 25 min, with Latvia reporting the longest (33 min), followed by Hungary and Luxembourg (29 min each) [51]. The UK is at 30 min. Notably, commuting satisfaction declines sharply once trips exceed 30–45 min, after which dissatisfaction dominates [103].

Beyond averages, time reliability holds nearly equal importance to mean travel time in user valuation [104]. For example, accessibility measured using real-time Automatic Vehicle Monitoring (AVM) data is significantly lower than estimates from scheduled General Transit Feed Specification (GTFS) feeds, particularly in peripheral areas where variability and disruptions are common [105]. Hence, planned accessibility systematically overestimates lived accessibility.

Duration varies across the day. A daily diary study of 90 UK employees found that the average morning commute was 34.25 min (SD = 22.40), while the evening commute extended to 41.96 min (SD = 28.95) [106]. Similar patterns of temporal asymmetry have been identified across multiple countries using the Multinational Time Use Study, where morning commutes were found to last longer than evening return trips [107]. This asymmetry shows that commute duration is time-sensitive, shaped by traffic dynamics, environmental, and contextual conditions. Recognising such systematic differences is vital, as longer evening commutes amplify TS and recovery demands, whereas shorter morning commutes may serve distinct preparatory functions. The evidence confirms that *Duration* is a dynamic condition influencing satisfaction and health. Recognising it as the sixth 'D' strengthens BE models by embedding temporal reliability. Figure 4 presents the proposed expanded 6D BE framework. It positions *Duration* as the 6th dimension of the framework, with equal conceptual weight to the other 5Ds. The rationale is subsequently presented.

3.4.1. Theoretical Justification of Sixth D of BE

Duration is proposed as the sixth D to capture the temporal efficiency and reliability of accessibility in the BE framework. While the traditional dimensions describe what exists spatially, *Duration* defines how accessibility and mobility evolve across time. A neighbourhood may exhibit high density, mixed land uses, and proximity to transit, yet if commuting time doubles across the day, its functional value is reduced. *Duration*,

therefore, reflects lived accessibility rather than planned design. Temporal reliability is critical because temporal mobility stress (TMS) arises not only from distance but also from delays, unpredictability, and prolonged exposure. Even a commute that appears short on paper can become a source of stress when congestion, unsafe crossings, or unreliable transit intervene.
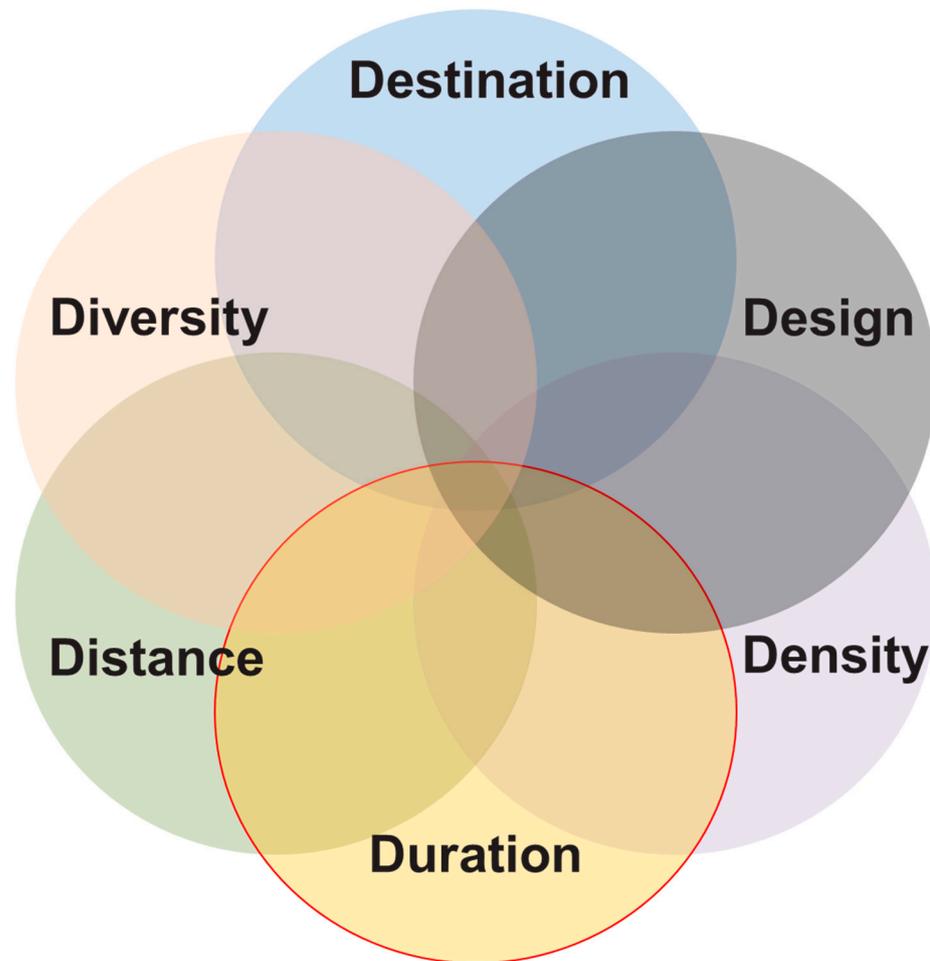
Figure 4. The proposed (expanded) 6Ds framework of the BE. Diagram developed by the authors.

Evidence from observed commuting behaviour across multiple national contexts shows that daily commute durations differ significantly by time of day [107]. Using time-use diary data from seven countries included in the Multinational Time Use Study (MTUS), a large-scale study found that commuting to work, concentrated during morning peak periods, is typically longer and more temporally constrained than commuting from work [107]. Further, static schedule-based accessibility measures overestimate lived accessibility because they ignore real-time delay and reliability issues [108]. Temporal variation in mobility patterns has also been confirmed through public transport use, where distinct urban rhythms emerge between weekdays and weekends, showing that accessibility and travel behaviour fluctuate over time [109]. A study by Bimpou and Ferguson (2020) demonstrated that when day-to-day travel-time reliability is integrated into accessibility

modelling, measured accessibility declines significantly, particularly during peak hours, providing a more realistic representation of actual network performance [110].

The expanded 6Ds framework, presented in Figure 4, reconceptualises the BE as a dynamic system where spatial and temporal dimensions operate jointly. Duration complements the five traditional spatial components by capturing how accessibility and mobility reliability fluctuate over time. Its inclusion shifts the analytical focus from static proximity to lived experience, revealing how congestion, scheduling, and exposure shape daily mobility outcomes. The framework thus positions time as an intrinsic property of urban accessibility, essential for evaluating equity, efficiency, and health resilience within contemporary transport systems.

3.4.2. Transport and Health Integration

By foregrounding time, *Duration* directly links BE to public health outcomes. Prolonged travel erodes the feasibility of walking and cycling, reducing PA and increasing reliance on motor vehicles. Moreover, extended exposure to heavy traffic, noise, and air pollution intensifies TS and discourages AT. Longer and less predictable commute durations are associated with lower levels of PA and poorer health behaviours [111]. In this sense, *Duration* operates as a time-exposure variable. Hence, the longer individuals remain in unsafe or congested environments, the lower the probability of engaging in healthy mobility behaviours such as AT.

Descriptive traffic datasets from Queensland, New Zealand, and the UK demonstrate pronounced peak-hour variability and associated increases in observed travel times that constrain accessibility [30,31,47]. For instance, conditions in many cities are highly favourable for cycling or walking at 6 AM when roads are clear. Yet, the same routes become functionally unsafe or inaccessible by 3 PM due to higher traffic density [30,31]. Capturing such intra-day variability is essential to explain discrepancies in transport mode choice, particularly among young adults. Travel behaviour changes among this group often occur in response to life events such as entering the workforce or relocating, which impose fixed schedules and increase exposure to peak-hour travel [112].

3.4.3. Policy and Planning Implications

Integrating *Duration* redefines how planners and policymakers evaluate infrastructure performance and equity. A system that appears efficient under average conditions may fail when judged against peak-time realities or unforeseen disruptions. Karner et al. [113] show that low-income and marginalised populations are disproportionately exposed to long and unpredictable travel times, which exacerbate transportation inequities and reduce access to opportunities. *Duration* makes visible the inequities that emerge when low-income or marginalised populations are disproportionately exposed to prolonged, unpredictable commutes. This framing aligns transport policy with broader goals of equity, sustainability, and health promotion in line with the United Nations Sustainable Development Goals (SDGs) [93].

Duration allows BE research to move beyond static assessments toward future-oriented dynamic planning. As populations grow and vehicle ownership increases, current travel times will not hold over the next decade. Embedding temporal analysis, such as forecasting travel durations under different growth scenarios, helps ensure that interventions remain relevant in dynamic urban conditions.

3.4.4. Temporal Variability in Accessibility Across Different Countries

The graphs in Figures 5 and 6 illustrate how temporal dynamics reshape mobility within the same BE context. These are developed based on hourly traffic volume data from the QLD Government's open data portal (2023) [30], which captures weekday and weekend

variations across the state road network. On weekdays (Figure 5), accessibility collapses sharply during AM and PM peaks. Thus, identical streets that appear walkable at 6 AM and 7 PM can become congested and stressful by 8 AM and 3 PM. In contrast, weekends (Figure 6) show smoother midday peaks with lower volatility, with the same networks remaining broadly accessible for AT (walking, cycling) and transit. This comparison across multiple time windows shows that access is not a fixed dimension of infrastructure, but a dynamic condition shaped by temporal rhythms. By capturing these fluctuations, the graphs show why *Duration* is a decisive dimension. As such, it reveals that the accessibility of the BE is governed less by its physical form than by the time at which it is experienced. Peak-hour fluctuations restrain mobility by increasing congestion and delay, thereby reducing travel speed, reliability, and the usability of active and motorised transport relative to off-peak periods [30].
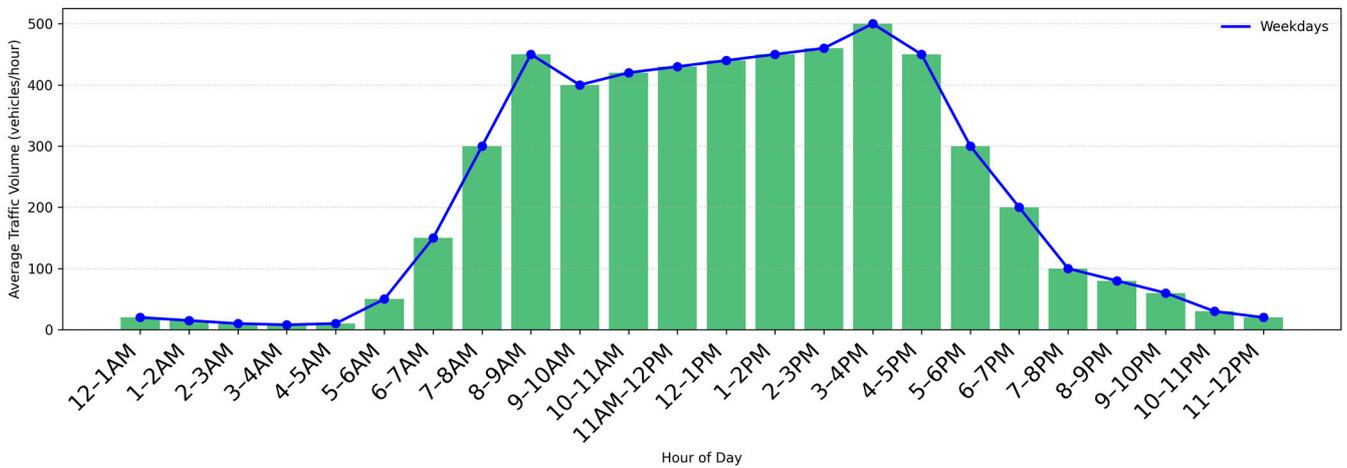
Figure 5. Temporal distribution of average weekday traffic volumes on Queensland state-controlled roads (2023). The *x*-axis represents hours of the day, while the *y*-axis represents the average traffic volume (vehicles per hour) [30]. (Diagram developed by the authors.)
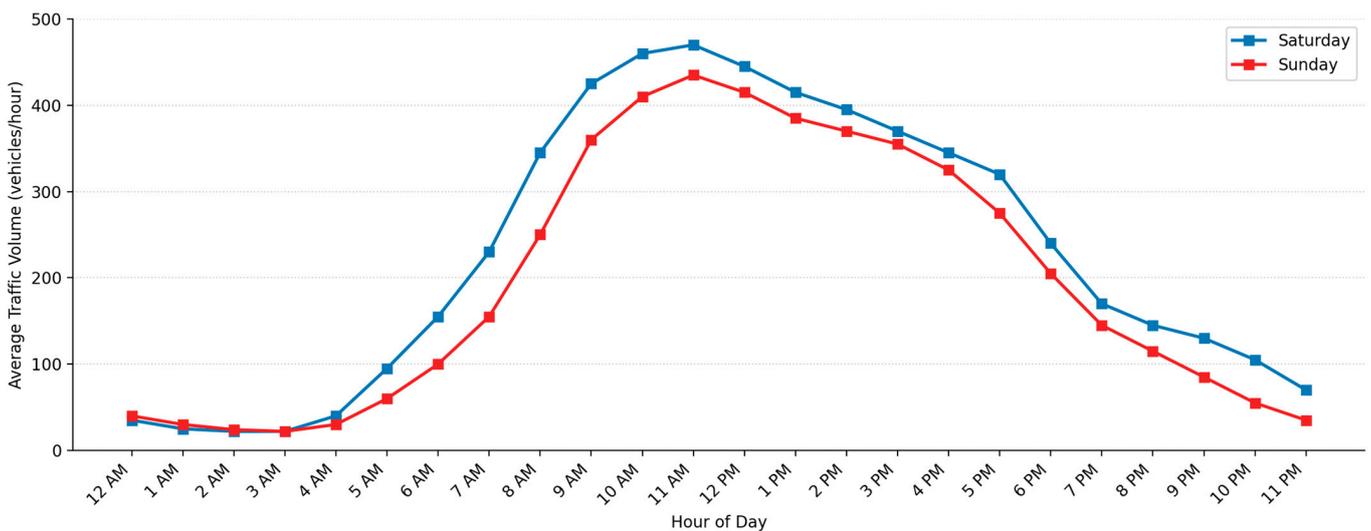
Figure 6. Temporal distribution of average weekend traffic volumes on Queensland state-controlled roads (2023). The *x*-axis represents hours of the day, while the *y*-axis represents the average traffic volume (vehicles per hour) [30]. Diagram developed by the authors.

Comparable temporal fluctuations are observed across the UK [47], where weekday traffic volumes display two pronounced peaks between 7–9 AM and 4–6 PM, corresponding

to morning and afternoon commuting periods. Weekend flows remain considerably flatter (see Figure 7). Traffic data for both weekdays and weekends were available from 7 AM to 6 PM [47]. This divergence reflects the clustering of work-related mobility and congestion within narrow time intervals. These patterns confirm that accessibility across the UK road network is governed more by temporal crowding than by physical infrastructure capacity, affirming the time-sensitive dimension captured in the proposed Duration construct.
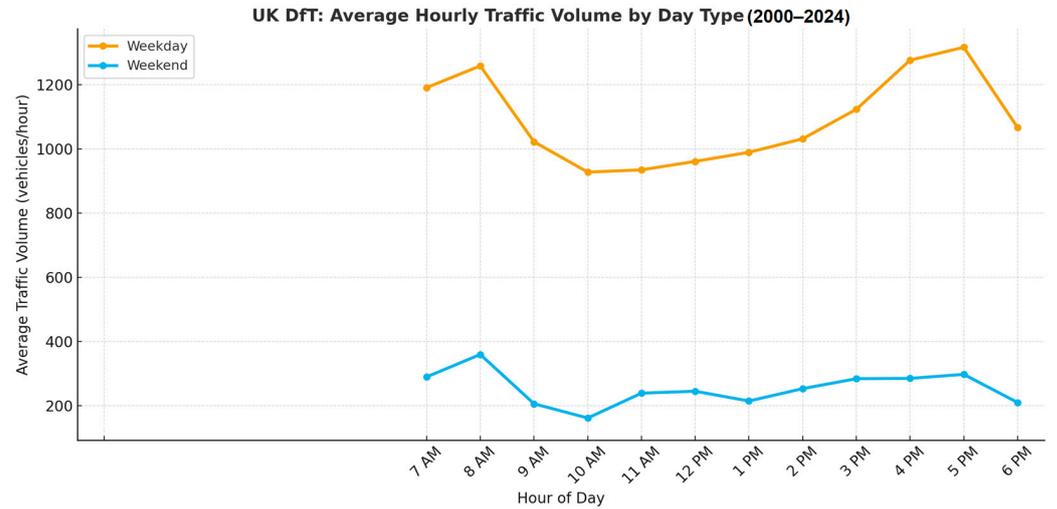
Figure 7. UK department for transport (DfT) average hourly traffic volume (vehicles/hour) by day type (2000–2024) based on DFT data [47]. Diagram developed by the authors.

In New Zealand (see Figure 8), hourly traffic volumes exhibit clear temporal variation, with steady increases between 6 AM and 9 AM, followed by gradual declines after 4 PM during weekdays [31]. Weekend patterns remain smoother and more evenly distributed [31], indicating greater stability in accessibility. These patterns demonstrate that even in smaller and less congested transport networks, accessibility is governed by Duration rather than static spatial form.
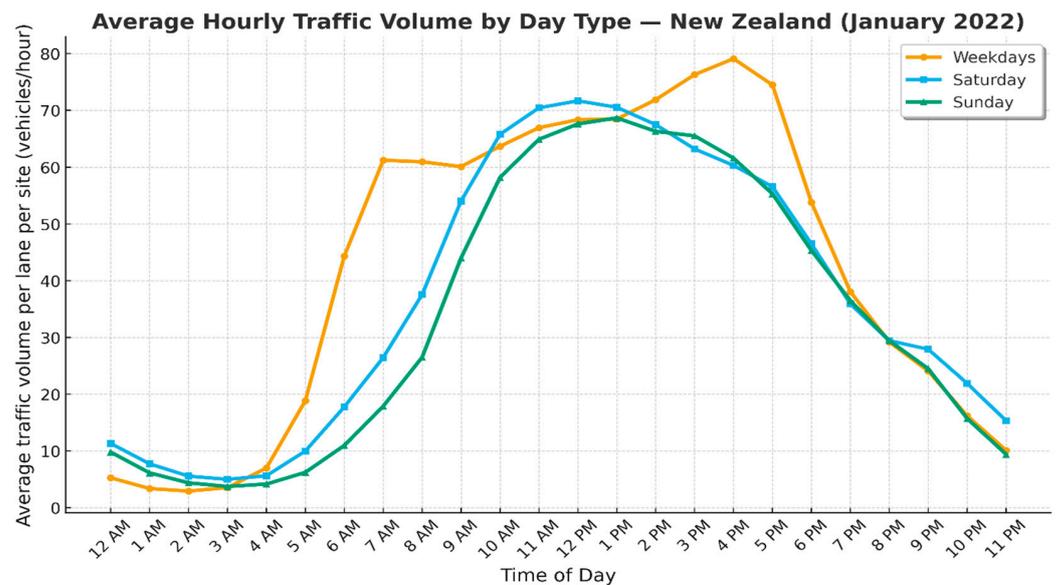
Figure 8. Average traffic volume (vehicles/hour per lane per site) across New Zealand road networks [31]. Diagram developed by the authors.

3.4.5. How Duration Interacts with the Other Ds

As illustrated in Figure 9, temporal conditions regulate how the built environment's spatial attributes translate into lived accessibility and health outcomes. The figure illustrates how the temporal dimension interacts with the five established Ds, regulating their combined influence on accessibility, mobility efficiency, and health outcomes under low- and high-time conditions. Figure 9 contrasts settings characterised by shorter, more stable travel times with those characterised by prolonged, unpredictable journeys. Under favourable conditions, mobility efficiency is preserved, walking and cycling remain viable, public transport operates reliably, and overall modal balance is maintained. By contrast, extended or unstable travel times are associated with congestion, delay, and disengagement from active and public modes. In such contexts, the advantages of compact, well-connected environments are diminished, leading to inefficiency and lower PA levels. Empirical evidence by Chen et al. [55] demonstrates that macro-scale BE characteristics, operationalised through the five Ds (density, diversity, design, destination accessibility, and distance to transit), are strongly associated with pedestrian volume.
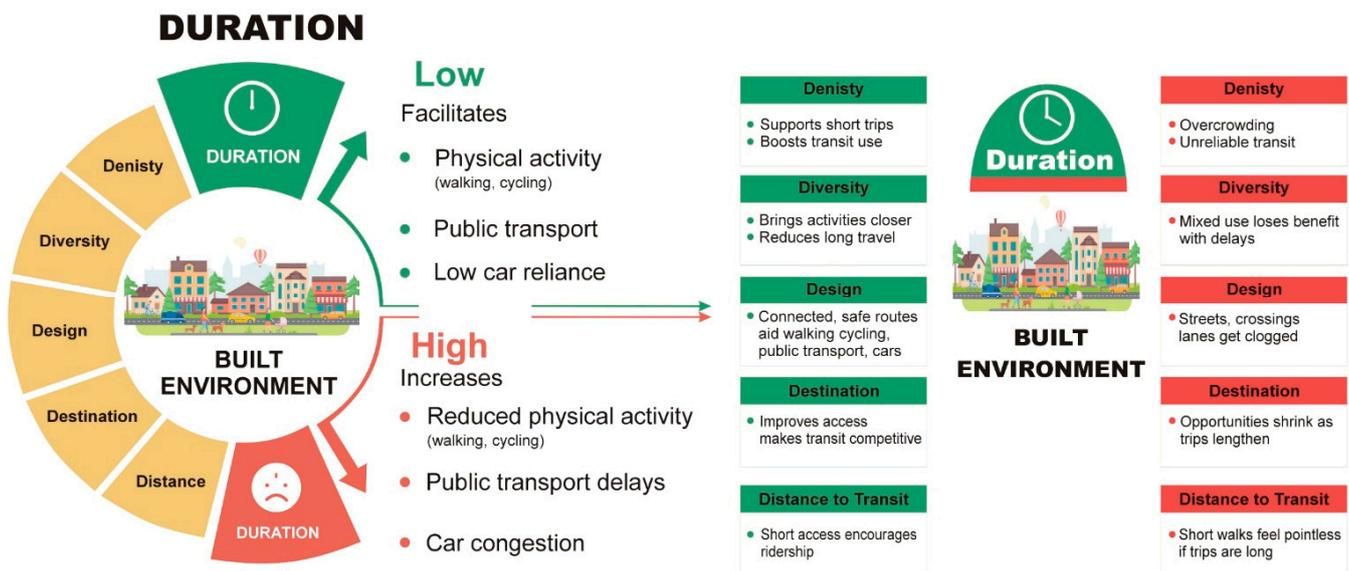
Figure 9. Conceptual model of *Duration* as the sixth D of the BE. The green arrow denotes favourable conditions associated with low Duration, and the red arrow denotes unfavourable conditions associated with high Duration. Horizontal green and red arrows link these conditions to illustrative manifestations of the BE 5Ds shown on the right. Diagram developed by the authors.

The five Ds respond unevenly as temporal demands intensify. Density supports short trips and active travel when journeys remain manageable but contributes to overcrowding and unreliable movement as travel times lengthen. Diversity reduces spatial separation among activities; however, its benefits diminish when time constraints limit practical access to nearby destinations. Design features such as connected street networks and protected lanes encourage active mobility under stable conditions yet appear unsafe or inefficient when delays predominate. Destination accessibility expands opportunity space when travel times are moderate but contracts under prolonged delays, whereas proximity to transit loses effectiveness as journeys become longer.

These interactions indicate that *Duration* operates as a regulating dimension of the BE. Stable and predictable travel conditions reinforce the influence of density, diversity, design, destination accessibility, and distance to transit, whereas prolonged or volatile conditions weaken their effects. In this sense, Duration functions as a sixth D, shifting the built environment from a purely spatial construct toward a system shaped by both spatial form and temporal

performance. This perspective highlights that the effectiveness of the five Ds depends not only on urban form but on the stability and manageability of everyday mobility conditions.

4. Discussion

Urban design often fails to anticipate future peak-period travel dynamics, creating a persistent gap between planned and lived accessibility. Transport research shows that commuters value reliability almost as much as average duration [104,114,115], yet most infrastructure and land-use planning continues to rely on mean travel times [116], even though commuters' perceived travel time and wellbeing are shaped by urban form and BE elements [117]. Existing evidence confirms this misalignment: transport network performance computed using real-time monitoring (e.g., AVM and GPS) is significantly lower than estimates derived from scheduled transit feeds (GTFS), particularly in peripheral areas and during disruptions [105]. This reliance on static representations of accessibility therefore risks overstating system efficiency while systematically concealing the temporal stress experienced by commuters under everyday peak conditions.

In response to this documented disconnect between planned accessibility and lived peak-period experience, this study conceptualises Duration as a system-level temporal property of the built environment. Duration refers to how spatial distance is experienced over time under everyday travel conditions, particularly during peak periods, rather than replacing distance or conventional travel-time measures. While distance reflects spatial extent, Duration captures how intersection density, crossing frequency, and time-of-day conditions translate that distance into longer or shorter journeys. By reframing time as a structural characteristic of urban systems, Duration directly addresses the limitations of static accessibility metrics identified above.

The policy relevance of Duration is evident in real-world interventions that explicitly target temporal performance rather than spatial proximity alone. Bogotá's TransMilenio BRT demonstrates how cities can directly target commute durations, with ex-post evaluation showing that over half of the system's total benefits came from user travel time savings [118]. Similarly, the Stockholm congestion charging trial reduced inner-city traffic, delivering measurable commute time improvements that were visible to citizens [119]. The associated cost–benefit analyses confirmed that reduced congestion, emissions, and accidents repaid system costs within a few years [119]. Together, these examples illustrate that peak-sensitive policies can sustainably moderate Duration, although their effectiveness depends on continuous recalibration to prevent temporal spillover and rebound effects.

However, interventions that reduce Duration locally through BE modifications, without transport network–wide calibration, can generate unintended spatial redistribution and temporal displacement of congestion and mobility stress. The Barcelona superblock (Superilles) model provides another illustrative case [120]. By reorganising street hierarchies, restricting through-traffic, and reclaiming public space, Barcelona sought to stabilise local mobility while promoting AT (walking and cycling). Health impact assessments estimate substantial gains in PA, air quality, and noise reduction across proposed superblock zones [120]. Evaluations also show higher pedestrian activity and social interaction [121]. At the same time, evidence of traffic relocation to surrounding and peripheral areas underscores the need to assess Duration at the transport network scale, rather than solely within treated neighbourhoods [120].

At metropolitan and national scales, Duration has increasingly been recognised as a determinant of accessibility, well-being, and equity. Singapore's Land Transport Master Plan 2040 explicitly sets goals for a 45 min city and 20 min towns, embedding *Duration* thresholds into national policy [48]. While this is one of the most advanced attempts to frame accessibility in temporal terms, the plan still relies on projections rather than con-

sistent empirical verification of lived peak durations. Similarly, Seoul-based studies have quantified welfare losses from commuting through value-of-time estimates, showing that longer commutes systematically reduce subjective well-being across genders, household types, and income groups [122]. Structural equation modelling of South Korean cities shows that density, land-use mix, and connectivity exert significant effects on commuting durations, with dispersed urban form associated with longer travel times [123]. This underscores the role of urban sprawl in shaping transport sustainability. A recent study of the Seoul Metropolitan Area found that students living in suburban new towns face significantly longer commutes than those in central districts, illustrating how growth without *Duration*-sensitive design creates inequitable mobility burdens [124]. Across these diverse contexts, *Duration* emerges as both a determinant of urban access and a conditioning factor for social and health outcomes.

Despite this growing policy recognition, the theoretical treatment of time in transport research remains fragmented and conceptually constrained. Carrion and Levinson [104] established that travellers consistently account for travel time reliability, referring to the uncertainty surrounding trip duration, when selecting routes, modes, or departure times, underscoring the behavioural significance of temporal variability. In contrast, Levinson and Wu [125] argued that commuting durations often remain stable despite rising congestion and distance, suggesting a form of temporal equilibrium achieved through adaptive routing. However, this notion obscures the fluctuating and cumulative nature of everyday mobility under peak-period conditions, which is shaped by both transport network dynamics and urban form. Similarly, Delclòs-Alió and Miralles-Guasch [126] highlighted the experiential and spatial complexity of commuting across multiple temporal scales. However, the authors did not quantify the psychological or physiological strain associated with such variability. Together, these perspectives demonstrate that conventional measures of travel time and reliability capture only partial aspects of temporal accessibility. The present study advances this understanding of temporal dimensions, extending their relevance to behavioural, health, and equity outcomes. Conceptually, this aligns with Hägerstrand's [127] time geography, which frames human activity within space–time constraints and extends temporal considerations to system-level accessibility and performance. This shift is critical because cumulative access equity and mobility stress are shaped primarily by system-level temporal conditions, rather than by individual scheduling choices alone.

Addressing this conceptual gap requires distinguishing Duration from existing temporal constructs used in transport and health research. It differs from trip-based indicators such as travel time and travel-time reliability, which represent performance outcomes shaped by individual scheduling, route choice, and day-to-day variability [110]. It also differs from exposure-based measures in environmental health research, including spatio-temporal exposure models, which operationalise time as duration or scale of individual exposure to estimate health risk, rather than as a structural temporal property of the built environment itself [128]. Evidence on long commuting durations or travel-related discomfort primarily reflects behavioural responses to travel conditions rather than temporal properties of urban systems [129]. Importantly, time-geographical approaches conceptualise time primarily through individual capability constraints and activity feasibility [130], while space–time prisms and activity-based models emphasise scheduling windows rather than system-level temporal organisation [131]. Although dynamic and spatio-temporal accessibility research demonstrates that transport supply and network performance vary across the day due to service frequency, operating hours, and connectivity, time is still operationalised as a transport service parameter rather than conceptualised as an intrinsic temporal dimension of the built environment [132].

Building on this distinction, temporal considerations across built-environment and transport frameworks can be grouped into four dominant conceptualisations. Time is treated as (i) an individual constraint within time geography and space–time prism theory [130,131], (ii) a behavioural scheduling parameter, embedded within activity-based and household activity-sequencing models [133,134], (iii) a system performance characteristic, operationalised through travel-time reliability, congestion dynamics, and time-dependent network modelling [110,129,135], or (iv) an exposure duration, applied in environmental-health and temporal equity research to quantify time-dependent risk or opportunity [128,130,136,137]. These frameworks have not conceptualised time as a structural property of the BE that systematically shapes accessibility, stress exposure, and behavioural opportunity.

Commuting conditions characterised by longer trip duration, frequent congestion, and reduced journey satisfaction are consistently associated with elevated stress outcomes across modes and contexts [138]. As Duration increases, mobility shifts from a routine activity to a constraining temporal condition. Longer and less predictable travel compresses daily time budgets, reduces schedule flexibility, and increases exposure to congestion, noise, and perceived risk. These conditions elevate Temporal Mobility Stress (TMS), defined here as the cumulative psychological and behavioural strain arising from prolonged, unreliable, and time-constrained mobility. TMS is conceptually distinct from conventional commuting stress, which is typically confined to home–work travel [64,139], and from travel stress, which emphasises episodic disruptions and situational discomfort [140,141]. Drawing on appraisal–coping and chronic stress frameworks [142,143], TMS is conceptualised as a mediating mechanism linking Duration to behavioural and health outcomes, rather than a standalone outcome. In this framework, Duration does not constitute stress itself but structures the temporal conditions under which stress is generated.

At the individual level, studies demonstrate that *Duration* exerts non-linear effects on satisfaction and well-being. Commuting satisfaction remains stable for trips under 15 min, declines between 15–30 min, and drops sharply beyond 30–45 min, after which dissatisfaction dominates [103]. These findings confirm that *Duration* is not merely a technical accessibility measure but also a psychosocial stressor.

Duration also shapes opportunities for PA. Shorter, predictable trips encourage walking and cycling. In contrast, longer or unpredictable commutes shift behaviour [144–146] toward motorised modes. Prolonged sedentary travel also displaces time that could otherwise be spent in PA. Evidence shows that replacing 30 min/day of sedentary behaviour with PA is associated with up to 18% lower dementia incidence and 21% lower dementia mortality, particularly when sedentary time is replaced by more intensive forms of PA [147].

In Australia, national benchmarks classify commutes beyond 45 min as lengthy [52], and census data show a rising share of commuters travelling more than this threshold [52]. Newly presented precincts may also not align with the much-needed mobility objectives. The Northshore Hamilton Priority Development Area (PDA) is promoted as a "next-generation mobility precinct" with strong commitments to multimodality, AT, and connectivity [49]. The proposed scheme amendment outlines ambitious criteria for street networks, land-use integration, and collaboration with industry and academia. Despite these ambitions, the plan places strong emphasis on ease of access but does not include explicit *Duration* targets or peak-period performance benchmarks. It also fails to validate projected outcomes against observed datasets, such as QLD's 2023 traffic volume data [30], which provides clear evidence of peak-hour variability. Comparable benchmarks, including the report by the Bureau of Infrastructure, Transport Research Economics [148], are also not referenced within the evaluation framework or in the supporting reports [49]. A precinct may appear well designed in planning and statutory terms, yet still produce stressful and prolonged commutes when tested under real-world conditions.

5. Conclusions, Practical Implications, and Limitations

This review establishes *Duration* as the sixth dimension of the BE, reframing accessibility in terms of system-level temporal reliability rather than static spatial form. Although the traditional 5Ds capture spatial opportunity, *Duration* quantifies temporal equity, commute reliability, and mobility stress, revealing the gap between planned efficiency and lived travel conditions.

Incorporating Duration within the BE framework addresses this long-standing conceptual omission. It transforms accessibility from a static construct into a spatio-temporal system that captures how mobility and exposure evolve across the day. By integrating peak-period traffic data, population forecasts, and *Duration* thresholds, the 6D model enables planners and researchers to quantify temporal reliability as a core component of accessibility. This establishes *Duration* as both a theoretical refinement and an operational dimension linking mobility, equity, and health within urban systems.

Based on observed datasets from QLD (2023), the UK (2000–2024), and New Zealand (2022), the analysis confirms that accessibility fluctuates sharply throughout the day. Such evidence supports the view that *Duration* is a measurable determinant of accessibility and well-being. Conceptually, *Duration* advances the BE paradigm by embedding temporal resilience at its core, realigning urban design with the SDGs, and strengthening the connection between time, mobility, and health outcomes.

The proposed 6D model benefits multiple stakeholder groups. Urban planners and transport engineers can apply *Duration* to evaluate network reliability under real-world conditions. Public-health professionals can identify populations exposed to prolonged mobility stress, while policymakers and local governments can integrate *Duration* thresholds into accessibility benchmarks and equity assessments. For citizens, the framework has the potential to support healthier, more predictable, and time-efficient daily mobility. Ultimately, embedding *Duration* and TMS within planning practice redefines how cities are designed, making them more equitable, time-responsive, and health-promoting.

This study has some limitations. For example, the empirical demonstration of *Duration* was based on publicly available traffic datasets from only three regions, which may limit its generalisability. The analysis primarily captured vehicular traffic as a proxy for temporal variability; incorporating pedestrian and cycling datasets would enable a more comprehensive validation. Variations in study design, temporal resolution, and measurement units may also influence comparability. Moreover, the review did not empirically test the TMS construct; future research using longitudinal, physiological, and behavioural measures could strengthen its robustness. The exclusion of non-English policy documents may also have limited coverage of emerging temporal-planning frameworks.

Subsequent studies should extend the empirical validation of *Duration* through longitudinal, multi-modal, and cross-regional analyses to confirm its universality and operational thresholds. Integrating *Duration* with health outcome indicators, real-time mobility tracking, and policy evaluation frameworks will further strengthen its relevance to both planning and public-health practice. Building on this foundation, future work should empirically test TMS, which extends *Duration* beyond travel time to capture the psychological and physiological dimensions of temporal variability across modes and contexts. Together, these efforts will advance *Duration* and TMS from conceptual innovations to standard planning metrics that support equitable, time-responsive, and health-promoting cities.

Author Contributions: Conceptualisation, I.A. and F.U.; methodology, I.A. and F.U.; software, I.A.; validation, I.A.; formal analysis, I.A.; investigation, I.A.; resources, I.A. and F.U.; data curation, I.A.;

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AT	Active Transport
BE	Built Environment
DTS	Daily Traffic Stress
GIS	Geographic Information Systems
JBI	Joanna Briggs Institute
LTS	Level of Traffic Stress
PA	Physical Activity
PIA	Physical Inactivity
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SEM	Socio-Ecological Model
TMS	Temporal Mobility Stress
TPB	Theory of Planned Behaviour
TS	Traffic Stress
WHO	World Health Organization
3Ds	Density, Diversity, Design
5Ds	Density, Diversity, Design, Distance, Destination
6Ds	Density, Diversity, Design, Distance, Destination, Duration

Appendix A

Table A1. List of all articles included in this study.

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Sustainability	2025	Irfan Arif; Fahim Ullah	Impact of Traffic Stress, Built Environment, and Socioecological Factors on Active Transport Among Young Adults	Systematic review	High	Traffic stress reduces active transport among young adults; supportive environments mitigate this effect, addressing temporal gaps
The Lancet	2025	Thomas Rouvard	Effects of workplace interventions on sedentary behaviour and physical activity: an umbrella review with meta-analyses and narrative synthesis	Umbrella review	High	Workplace interventions reduce sedentary time and increase light physical activity, but do not consistently increase moderate-to-vigorous physical activity

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
The Lancet Public Health	2025	Ding Ding; Binh Nguyen; Tracy Nau; Mengyun Luo; Borja del Pozo Cruz; Paddy C. Dempsey; Zachary Munn; Barbara J. Jefferis	Daily steps and health outcomes in adults: a systematic review and dose-response meta-analysis	Systematic review and meta-analysis	High	Around 7000 daily steps reduce mortality risk, with limited benefit beyond moderate levels
Journal of Computational Social Science	2025	Yunhan Du; Takaaki Aoki; Naoya Fujiwara	A review of human mobility: Linking data, models, and real-world applications	Narrative review	High	Human mobility is regular and predictable, but models rarely capture both individual and aggregate temporal patterns
Transportation	2025	Alex Karner; Rafael H. M. Pereira; Steven Farber	Advances and pitfalls in measuring transportation equity	Narrative review	High	Standard equity metrics can misrepresent inequity under service changes
Communications in Transportation Research	2025	Alessandro Nalin; Nir Fulman; Emily Charlotte Wilke; Christina Ludwig; Alexander Zipf; Claudio Lantieri; Valeria Vignali; Andrea Simone	Evaluation of accessibility disparities in urban areas during disruptive events based on transit real data	Spatio-temporal observational study	High	Scheduled GTFS data overestimate accessibility during disruptions; real-time data show greater inequities, especially in peripheral areas.
Expert Systems with Applications	2025	Mahmoud Owais	How to incorporate machine learning and microsimulation tools in travel demand forecasting in multi-modal networks	Narrative review	High	Integrating machine learning and microsimulation improves forecasting under time-varying congestion conditions.
BMC Public Health	2025	Katherine Pérez; Laia Palència; Maria José López; Brenda Biaani León-Gómez; Anna Puig-Ribera; Anna Gómez-Gutiérrez; Mark Nieuwenhuijsen; Glòria Carrasco-Turigas; Carme Borrell	Environmental and health effects of the Barcelona superblocks	Natural experiment	High	Superblocks improved well-being and air quality, with uneven effects across neighbourhoods.
Human Relations	2025	Wladislaw Rivkin; Fabiola H Gerpott; Dana Unger	There and back again: The roles of morning- and evening commute recovery experiences for daily resources across the commute-, work-, and home domain	Longitudinal diary study	High	A relaxed morning commute supports work vitality and later recovery, with commute duration shaping how recovery processes unfold across the day.
Multimodal Transportation	2025	Siavash Saki; Mohsen Soori	Artificial Intelligence, Machine Learning and Deep Learning in Advanced Transportation Systems, A Review	Narrative review	High	Artificial intelligence applications enhance traffic safety, efficiency, and sustainability, particularly when real-time and spatiotemporal data are used, though implementation challenges persist.
Journal of Transport and Land Use	2025	Harry Schukei; Dana Rowangould	Planning beyond the metro: Rural travel behavior and the built environment	Cross-sectional observational study	High	Travel behaviour responds differently to the built environment in rural and urban settings, with regional access playing a role in rural contexts

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Journal of Urban Mobility	2025	Ali Shkera; Domokos Esztergár-Kiss	Applying machine learning to decode built environment thresholds for public and active transport distances in the global south	Observational modelling study	High	Built environment characteristics explain travel distances more effectively than socio-demographic factors, with threshold effects that differ by transport mode.
Applied Mobilities	2025	Adam Stražovec; Jan Daniel	Daily rhythm of the population mobility: the importance of public transport in functionally specific parts of the city	Spatio-temporal observational study	High	Public transport use follows clear daily patterns, with distinct temporal profiles across land uses; accessibility in hospital and retail areas relies heavily on public transport.
Smart Cities	2025	Katarzyna Turoń	Sustainable Urban Mobility Transitions—From Policy Uncertainty to the CalmMobility Paradigm	Conceptual policy analysis	Not applicable	Weak temporal alignment can limit the effectiveness of mobility policies; CalmMobility proposes a more gradual and inclusive transition approach.
Building and Environment	2025	Wako Golicha Wako; Tom Clemens; Scott Ogletree; Andrew James Williams; Ruth Jepson	Validity, reliability and acceptability of wearable sensor devices to monitor personal exposure to air pollution and pollen: A systematic review of mobility-based exposure studies	Systematic review	High	Wearable sensor devices show acceptable reliability, but accuracy varies by pollutant, device, and temporal resolution.
Environment International	2025	Lai Wei; Marco Helbich; Benjamin Flückiger; Youchen Shen; Jelle Vlaanderen; Ayoung Jeong; Nicole Probst-Hensch; Kees de Hoogh; Gerard Hoek; Roel Vermeulen	Variability in mobility-based air pollution exposure assessment: Effects of GPS tracking duration and temporal resolution of air pollution maps	Longitudinal methodological study	High	Short-term GPS data (7–14 days) can represent long-term mobility-based air pollution exposure, but validity depends on temporal and indoor–outdoor adjustment.
Frontiers in Sustainable Cities	2025	Syafieq Fahlevi Almas-sawa; Ernan Rusti-adi; Akhmad Fauzi; Ridwan Sutriadi	The relationship between regional development, smart mobility and transportation planning: a bibliometric analysis	Bibliometric analysis	Not applicable	Smart mobility–regional planning re-search is growing but remains weakly integrated and conceptually fragmented
Cities	2024	Avital Angel; Achituv Cohen; Trisalyn Nelson; Pnina Plaut	Evaluating the relationship between walking and street characteristics based on big data and machine learning analysis	Observational spatial study	High	Walking changes by time of day, not just by street design
Journal of Sport and Health Science	2024	Ulf Ekelund; Miguel Adriano Sanchez-Lastra; Knut Eirik Dalene; Jakob Tarp	Dose–response associations, physical activity intensity and mortality risk: A narrative review	Narrative review	High	Physical activity is linked to reduced mortality in a non-linear manner; light activity is beneficial at higher volumes, while small amounts of vigorous activity offer notable gains.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Transportation Research Part A: Policy and Practice	2024	Attiya Haseeb; Raktim Mitra	Travel behaviour changes among young adults and associated implications for social sustainability	Longitudinal observational study	High	Young adults show increasing reliance on private cars over time, while urban relocation supports continued use of public and active transport; reduced active travel may increase social exclusion.
Journal of Transport Geography	2024	Changyeon Lee	Quantifying urban sprawl and investigating the cause-effect links among urban sprawl factors, commuting modes, and time: A case study of South Korean cities	Cross-sectional modelling study	High	Higher density reduces car use but may increase commute time under congestion, while land-use mix and connectivity help shorten commuting duration.
International Journal of Behavioral Nutrition and Physical Activity	2024	Carina Nigg; Shaima A. Alothman; Abdullah F. Alghannam; Jasper Schipperijn; Reem AlAhmed; Reem F. Alsukait; Severin Rakic; Volkan Cetinkaya; Hazzaa M. Al-Hazzaa; Saleh A. Alqahtani	A systematic review on the associations between the built environment and adult's physical activity in global tropical and subtropical climate regions	Systematic review	High	Built environment features are consistently associated with higher physical activity, though evidence on climate-adaptive design remains limited and context-specific.
The Lancet Global Health	2024	Tessa Strain; Seth Flaxman; Regina Guthold; Elizaveta Semenova; Melanie Cowan; Leanne M. Riley; Fiona C. Bull; Gretchen A. Stevens;	National, regional, and global trends in insufficient physical activity among adults from 2000 to 2022: a pooled analysis of 507 population-based surveys with 5·7 million participants	Pooled global surveillance analysis	High	Globally, many adults are insufficiently physically active, increasing population-level risk of non-communicable diseases
Travel Behaviour and Society	2024	Yinhua Tao; Maarten van Ham; Ana Petrović	Changes in commuting mode and the relationship with psychological stress: A quasi-longitudinal analysis in urbanizing China	Quasi-longitudinal study	High	Longer commutes, particularly by private motorised modes, are associated with higher psychological stress, while active commuting shows protective effects that vary by urban context.
Sustainability	2024	Sai-Zu Wang; Chang-Gyu Choi	Is Development Type a Determinant of College and Graduate Students' Commute Time to School? The Case of Seoul Metropolitan Area	Cross-sectional observational study	High	Students in suburban new towns experience longer commutes, with development type exerting more influence than individual characteristics, raising social sustainability concerns.
Transportation Research Interdisciplinary Perspectives	2023	Marco Garrido-Cumbrera; Olta Braçe; David Gálvez-Ruiz; Enrique López-Lara; José Correa-Fernández	Can the mode, time, and expense of commuting to work affect our mental health?	Cross-sectional observational study	High	Longer commute times are linked to poorer mental health, whereas public and active transport users report better outcomes.
The Lancet Global Health	2023	Peter T. Katzmarzyk	Expanding our understanding of the global impact of physical inactivity	Expert commentary	High	Despite growing evidence, physical inactivity remains prevalent; increasing physical activity significantly enhances health.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Journal of Geographical Systems	2023	Luyu Liu; Adam Porr; Harvey J. Miller	Realizable accessibility: evaluating the reliability of public transit accessibility using high-resolution real-time data	Methodological study	High	Scheduled and retrospective accessibility measures often overestimate achievable access; user-centred measures highlight greater unreliability during peak periods.
Accident Analysis & Prevention	2023	Marcus Skyum Myhrmann; Stefan Eriksen Mabit	Assessing bicycle crash risks controlling for detailed exposure: A Copenhagen case study	Observational risk study	High	Bicycle crash risk changes by time of day, day of week, and weather conditions, with peak periods presenting higher risk that aggregated analyses may overlook.
Travel Behaviour and Society	2023	Andreas Nikiforiadis; Eirini Chatzali; Vasileios Ioannidis; Konstantinos Kalogiros; Maria Paipai; Socrates Basbas	Investigating factors that affect perceived quality of service on pedestrians-cyclists shared infrastructure	Cross-sectional observational study	High	Perceived service quality for cyclists depends more on infrastructure quality and behaviour than on density-based measures.
HBRC Journal	2023	Dina M. A. Noseir; Marwa A. Khalifa; Yehya M. Serag; Mohamed A. El Fayoumi	Investigating the influence of land use mix and built environment elements on travel time perception and subjective wellbeing	Mixed-methods study	High	Built environment and land-use mix influence perceived travel time and wellbeing, highlighting the experiential role of time in daily travel.
Sustainable Cities and Society	2023	Md Mokhlesur Rahman; Sharfan Upaul; Jean-Claude Thill; Mahinur Rahman	Active transportation and the built environment of a mid-size global south city	Cross-sectional observational study	High	Built environment characteristics exert a stronger influence on walking than cycling, with compactness and sidewalk quality supporting longer and more frequent walking.
J Sport Health Sci	2023	Y. Sun; C. Chen; Y. Yu; H. Zhang; X. Tan; J. Zhang; L. Qi; Y. Lu; N. Wang	Replacement of leisure-time sedentary behavior with various physical activities and the risk of dementia incidence and mortality: A prospective cohort study	Prospective cohort study	High	Replacing sedentary time with physical activity reduces dementia risk, with benefits influenced by how daily time is reallocated and age at exposure.
International Journal of Environmental Research and Public Health	2023	Yiyu Wang; Bert Steenbergen; Erwin van der Krabben; Henk-Jan Kooij; Kevin Raaphorst; Remco Hoekman	The Impact of the Built Environment and Social Environment on Physical Activity: A Scoping Review	Scoping review	High	Physical activity is shaped jointly by built and social environments, with perceived conditions often outweighing objective measures.
Land	2023	Muxia Yao; Bin Yao; Jeremy Cenci; Chenyang Liao; Jiazhen Zhang	Visualisation of High-Density City Research Evolution, Trends, and Outlook in the 21st Century	Bibliometric analysis	Not applicable	Research on high-density cities has grown rapidly but remains fragmented, with limited integration of human-centred theoretical frameworks.
Cities	2022	Long Chen; Yi Lu; Yu Ye; Yang Xiao; Linchuan Yang	Examining the association between the built environment and pedestrian volume using street view images	GIS-based observational study	High	Pedestrian volume is positively associated with both micro-scale streetscape features and macro-scale-built environment factors.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Journal of Transport Geography	2022	Eunae Jin; Danya Kim; Jangik Jin	Commuting time and perceived stress: Evidence from the intra- and inter-city commuting of young workers in Korea	Quasi-longitudinal panel study	High	The relationship between commute time and stress varies by mode; public transport may buffer stress through productive time use, whereas car commuting intensifies stress as duration increases.
Travel Behaviour and Society	2022	Jiakun Liu; Dick Ettema; Marco Helbich	Systematic review of the association between commuting, subjective wellbeing and mental health	Systematic review	High	Long commuting durations are generally linked to poorer wellbeing, particularly beyond certain thresholds, while active commuting is most consistently associated with positive outcomes.
Health & Place	2022	Stephanie A. Prince; Samantha Lancione; Justin J. Lang; Nana Amankwah; Margaret de Groh; Alejandra Jaramillo Garcia; Katherine Merucci; Robert Geneau	Examining the state, quality and strength of the evidence in the research on built environments and physical activity among adults: An overview of reviews from high income countries	Overview of reviews	High	Evidence linking the built environment to adult physical activity relies largely on cross-sectional studies, with limited temporally explicit or causal research.
Sustainability	2022	Jiankun Yang; Min He; Mingwei He	Exploring the Group Difference in the Nonlinear Relationship between Commuting Satisfaction and Commuting Time	Cross-sectional empirical study	High	Commuting satisfaction declines once travel time exceeds individual tolerance thresholds. Preferences and tolerance differ across population groups.
International Journal of Health Geographics	2022	Jingjing Li	Comparing effects of Euclidean buffers and network buffers on associations between built environment and transport walking: the Multi-Ethnic Study	Cross-sectional observational study	High	Euclidean buffers underestimate walking associations; network buffers provide more accurate results.
Sensors	2022	Pamela Zontone; Antonio Affanni; Alessandro Piras; Roberto Rinaldo	Exploring Physiological Signal Responses to Traffic-Related Stress in Simulated Driving	Experimental study	High	Traffic stress occurs in brief, time-specific intervals and varies across time. Machine learning approaches allow stress detection at fine temporal scales.
Progress in Cardiovascular Diseases	2021	Amy Bantham; Sharon E. Taverno Ross; Emerson Sebastião; Grenita Hall	Overcoming barriers to physical activity in underserved populations	Narrative review	High	Underserved populations face barriers to physical activity at individual, community, and policy levels. Community-led, culturally appropriate, and place-based interventions are most effective for long-term behaviour change.
Computers, Environment and Urban Systems	2021	Gregory Dobler; Jordan Vani; Trang Tran Linh Dam	Patterns of urban foot traffic dynamics	Spatio-temporal observational study	High	Urban pedestrian activity follows regular daily patterns shaped by work schedules. Deviations from these patterns reflect disruptions and location-specific events linked to urban form.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Journal of Transport Geography	2021	José Ignacio Giménez-Nadal; José Alberto Molina; Jorge Velilla	Two-way commuting: Asymmetries from time use surveys	Observational time-use study	High	Commutes to work are typically longer and more time-concentrated than return trips. These differences vary by country, gender, and travel mode, and treating commutes as time-symmetric hides important behavioural patterns
Int J Environ Res Public Health	2021	M. P. Jimenez; N. V. DeVille; E. G. Elliott; J. E. Schiff; G. E. Wilt; J. E. Hart; P. James	Associations between Nature Exposure and Health: A Review of the Evidence	Narrative review	High	Health benefits depend on the duration, frequency, and timing of nature exposure. Sustained exposure is linked to longer-term mental and physical health benefits
Transportation	2021	Teppei Kato; Kenetsu Uchida; William H. K. Lam; Agachai Sumalee	Estimation of the value of travel time and of travel time reliability for heterogeneous drivers in a road network	Analytical modelling study	High	Travel time reliability provides benefits beyond average travel time. Ignoring variability leads to underestimation of welfare and planning benefits.
Int. J. Environ. Res. Public Health	2021	Donglin Hu	Factors That Influence Participation in Physical Activity in School-Aged Children and Adolescents: A Systematic Review from the Social Ecological Model Perspective	Systematic review	High	Physical activity participation is influenced by multiple socio-ecological factors. Interpersonal and organisational support strongly affect how much time people can allocate to activity.
The Lancet	2012	Dr Pedro C Hallal	Global physical activity levels: surveillance progress, pitfalls, and prospects	Surveillance synthesis	High	Global physical inactivity remains high. Occupational physical activity has declined over time, and active transport remains insufficiently adopted, with limited temporal monitoring.
Frontiers in Public Health	2021	Mary N. Woessner; Alexander Tacey; Ariella Levinger-Limor; Alexandra G. Parker; Pazit Levinger; Itamar Levinger	The Evolution of Technology and Physical Inactivity: The Good, the Bad, and the Way Forward	Narrative review	High	Technology use has reduced incidental physical activity and increased sedentary behaviour. Short-term digital interventions can help, but long-term success depends on sustained engagement.
Int J Environ Res Public Health	2021	T. Zhu; Z. Zhu; J. Zhang; C. Yang	Electric Bicyclist Injury Severity during Peak Traffic Periods: A Random-Parameters Approach with Heterogeneity in Means and Variances	Observational crash study	High	Injury severity varies by time of day and traffic conditions. Lighting, visibility, and roadside features increase risk during peak and low-light periods.
Br J Sports Med	2020	F. C. Bull; S. S. Al-Ansari; S. Biddle; K. Borodulin; M. P. Buman; G. Cardon; C. Carty; J. P. Chaput; S. Chastin; R. Chou; P. C. Dempsey; L. DiPietro; U. Ekelund;	World Health Organization 2020 guidelines on physical activity and sedentary behaviour	Clinical guideline	High	Health benefits from physical activity are observed even below recommended thresholds.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
PLOS ONE	2020	Sarah Elshahat; Michael O'Rorke; Deepti Adlakha	Built environment correlates of physical activity in low- and middle-income countries: A systematic review	Systematic review and meta-analysis	High	Built environment effects on activity are weaker in low- and middle-income countries. Safety from crime, especially at night, is the most consistent factor.
Occup Environ Med	2020	J. I. Halonen; A. Pulakka; J. Vahtera; J. Pentti; H. Laström; S. Stenholm; L. M. Hanson	Commuting time to work and behaviour-related health: a fixed-effect analysis	Longitudinal fixed-effects study	High	Long commuting times combined with long working hours reduce physical activity and sleep. Commuting acts as a constraint on daily time allocation.
Sustainability	2020	Jae Min Lee	Exploring Walking Behavior in the Streets of New York City Using Hourly Pedestrian Count Data	Spatio-temporal observational study	High	Walking behaviour follows daily, weekly, and seasonal patterns shaped by land use and microclimate. Thermal comfort thresholds influence route choice, showing that walking responds to system-level temporal conditions.
International Journal of Transportation Science and Technology	2020	Seyedmirsajad Mokhtarimousavi; Jason C. Anderson; Atorod Azizinamini; Mohammed Hadi	Factors affecting injury severity in vehicle-pedestrian crashes: A day-of-week analysis using random parameter ordered response models and Artificial Neural Networks	Observational crash study	High	Pedestrian injury severity differs between weekdays and weekends, with higher severity during evening and night-time periods. Alcohol use, lighting, and traffic patterns show time-dependent effects.
Environment International	2020	Natalie Mueller; David Rojas-Rueda; Haneen Khreis; Marta Cirach; David Andrés; Joan Ballester;	Changing the urban design of cities for health: The superblock model	Health impact assessment	High	Full implementation of the Superblock model in Barcelona could prevent substantial premature mortality through reduced pollution, noise, heat, and increased transport-related physical activity.
Journal of Exercise Science & Fitness	2022	Kylie D. Hesketh	Results from the Australian 2022 Report Card on physical activity for children and young people	Population surveillance synthesis	Moderate	Physical activity levels among children and young people remain low, with limited active transport participation. Supportive built environments alone have not translated into behaviour change.
The Lancet	2020	Christopher J. L. Murray; Aleksandr Y. Aravkin; Peng Zheng; Cristiana Abbafati; Kaja M. Abbas; Mohsen Abbasi-Kangevari;	Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019	Global comparative assessment	High	Despite improvements in some environmental risks, many behavioural and metabolic risk factors have worsened. Policy action has been insufficient to reduce population exposure.
Journal of Transport Geography	2020	Konstantina Bimpou, Neil S. Ferguson	Dynamic accessibility: Incorporating day-to-day travel time reliability into accessibility measurement	Methodological modelling study	High	Dynamic accessibility measures show that static approaches overestimate actual access. Accessibility varies strongly by time of day and reliability, with equity implications.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
International Journal of Sustainable Transportation	2019	Myung-Jin Jun; Ki-Hyun Kwon; Ji-Eun Jeong	An evaluation of the value of time for commuting in Seoul: A life satisfaction approach	Longitudinal observational study	High	Longer commuting time is associated with lower life satisfaction. The value of commuting time is substantial and varies by gender, income, and household structure.
Int J Behav Nutr Phys Act	2017	D. W. Barnett; A. Barnett; A. Nathan; J. Van Cauwenberg; E. Cerin	Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis	Systematic review and meta-analysis	High	Very strong evidence shows that walkable, service-rich environments with public transport, greenery, and pedestrian infrastructure support higher physical activity in older adults.
International Journal of Behavioural Nutrition and Physical Activity	2017	Ester Cerin; Andrea Nathan; Jelle van Cauwenberg; David W. Barnett; Anthony Barnett; Environment on behalf of the Council on; group Physical Activity–Older Adults working	The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis	Systematic review and meta-analysis	High	Strong evidence links walkability, density, connectivity, destination access, and perceived safety to transport walking among older adults, while evidence for cycling is limited.
Transportation Research Record	2016	Peter G. Furth; Maaza C. Mekuria; Hilary Nixon	Network Connectivity for Low-Stress Bicycling	Applied network analysis	High	Cycling feasibility depends on low-stress network connectivity rather than facility length. Fragmented networks create repeated stress barriers.
The Lancet	2016	Billie Giles-Corti; Anne Vernez-Moudon; Rodrigo Reis; Gavin Turrell; Andrew L. Dannenberg; Hannah Badland; Sarah Foster; Melanie Lowe; James F. Sallis; Mark Stevenson; Neville Owen	City planning and population health: a global challenge	Narrative policy review	High	Integrated city and transport planning influences population health through cumulative daily travel exposure. Compact, mixed-use cities reduce car dependence and support routine physical activity.
American Journal of Public Health	2016	Adela Hruby; JoAnn E. Manson; Lu Qi; Vasanti S. Malik; Eric B. Rimm; Qi Sun; Walter C. Willett; Frank B. Hu	Determinants and Consequences of Obesity	Narrative synthesis	High	Adult weight gain increases long-term disease risk. Sustained physical activity and walkable environments reduce this risk over time.
BMJ	2016	Hmwe H Kyu; Victoria F Bachman; Lily T Alexander; John Everett Mumford; Ashkan Afshin; Kara Estep; J Lennert Veerman; Kristen Delwiche; Marissa L Iannarone	Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013	Systematic review and meta-analysis	High	Health benefits are observed at moderate physical activity levels across all physical activity domains.
Journal of Transport & Health	2016	Myriam Langlois; Rania A. Wasfi; Nancy A. Ross; Ahmed M. El-Geneidy	Can transit-oriented developments help achieve the recommended weekly level of physical activity?	Cross-sectional observational study	High	Residents of transit-oriented developments often meet physical activity guidelines through daily travel alone. Repeated trips produce cumulative health benefits.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Transp Policy (Oxf)	2016	R. J. Lee; I. N. Sener	Transportation Planning and Quality of Life: Where Do They Intersect?	Mixed-methods policy analysis	High	Transport-related quality of life is unevenly addressed in long-term planning. Mental and social wellbeing receive less attention than physical and economic outcomes, despite cumulative effects of long commutes and stress.
The Lancet	2016	James F. Sallis; Ester Cerin; Terry L. Conway; Marc A. Adams; Lawrence D. Frank; Michael Pratt; Deborah Salvo; Jasper Schipperijn;	Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study	Multicountry observational study	High	Urban environments that support activity are consistently linked to higher objectively measured physical activity across cities worldwide.
Journal of Environmental Psychology	2015	Mei-Fang Chen	Self-efficacy or collective efficacy within the cognitive theory of stress model: Which more effectively explains people's self-reported proenvironmental behavior?	Cross-sectional analytical study	High	Collective efficacy explains pro-environmental behaviour better than individual self-efficacy. Behaviour emerges through shared stress appraisal and coping over time.
Transportation Research Part F: Traffic Psychology and Behaviour	2015	Alexander Legrain; Naveen Eluru; Ahmed M. El-Geneidy	Am stressed, must travel: The relationship between mode choice and commuting stress	Observational study	High	Commuting stress is highest for car travel and lowest for walking. Unpredictability and buffer time contribute more to stress than average travel time.
Annual review of psychology	2014	Robert Gifford	Environmental psychology matters	Narrative review	High	Behaviour is shaped by temporally structured environments. Long-term change requires structural, not short-term, interventions.
International Journal of Behavioral Nutrition and Physical Activity	2014	Paul Kelly; Sonja Kahlmeier; Thomas Götschi; Nicola Orsini; Justin Richards; Nia Roberts; Peter Scarborough; Charlie Foster	Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship	Systematic review and meta-analysis	High	Walking and cycling reduce all-cause mortality, with the greatest benefits occurring at low to moderate exposure levels.
Research in Transportation Economics	2013	Darío Hidalgo; Liliana Pereira; Nicolás Estupiñán; Pedro Luis Jiménez	TransMilenio BRT system in Bogota, high performance and positive impact–Main results of an ex-post evaluation	Natural experiment	High	The TransMilenio system delivered major peak-period time savings and health benefits, although long-term overcrowding reduced user satisfaction. Temporal performance is critical to system success.
Transportation Research Part A: Policy and Practice	2012	Carlos Carrion; David Levinson	Value of travel time reliability: A review of current evidence	Systematic review and meta-analysis	High	Travel time reliability is a distinct and important temporal factor shaping behaviour, stress, and welfare beyond average travel time.
Health Place	2012	D. Ding; K. Gebel	Built environment, physical activity, and obesity: what have we learned from reviewing the literature?	Review of reviews	High	Evidence remains inconsistent due to weak temporal alignment and reliance on cross-sectional studies. Stronger longitudinal and quasi-experimental designs are needed.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
The Lancet	2012	I. Min Lee; Eric J. Shiroma; Felipe Lobelo; Pekka Puska; Steven N. Blair; Peter T. Katzmarzyk	Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy	Comparative risk assessment	High	Physical inactivity is widespread worldwide and substantially increases the burden of major non-communicable diseases and premature mortality
Medicine & Science in Sports & Exercise	2012	JOHN C. SIEVERDES; BILLY M. RAY; XUEMEI SUI; DUCK-CHUL LEE; GREGORY A. HAND; MEGHAN BARUTH; STEVEN N. BLAIR	Association between Leisure Time Physical Activity and Depressive Symptoms in Men	Cross-sectional observational study	High	Moderate weekly physical activity levels are associated with substantially lower depressive symptoms
Journal of Physical Activity and Health	2011	Ebonee N. Butler; A. M. H. Ambs; Jill Reedy; Heather R. Bowles	Identifying GIS measures of the physical activity built environment through a review of the literature	Systematic methodological review	High	GIS-based built environment measures vary widely and lack standardisation. Temporal misalignment limits reliable interpretation.
International Journal of Behavioral Nutrition and Physical Activity	2011	Gavin R. McCormack; Alan Shiell	In search of causality: a systematic review of the relationship between the built environment and physical activity among adults	Systematic review	High	Built environment effects remain after controlling for self-selection but are weaker. Duration and behavioural adaptation are under-measured pathways.
The Lancet	2011	Chi Pang Wen; Jackson Pui Man Wai; Min Kuang Tsai; Yi Chen Yang; Ting Yuan David Cheng; Meng-Chih Lee; Hui Ting Chan; Chwen Keng Tsao; Shan Pou Tsai; Xifeng Wu	Minimum amount of physical activity for reduced mortality and extended life expectancy: a prospective cohort study	Prospective cohort study	High	Even short daily physical activity durations reduce mortality and increase life expectancy. Repeated daily exposure is key.
Transportation Research Part F: Traffic Psychology and Behaviour	2011	Richard E. Wener; Gary W. Evans	Comparing stress of car and train commuters	Cross-sectional observational study	High	Car commuters experience higher stress than train commuters. Stress is driven by unpredictability and effort rather than travel time alone.
International Journal of Behavioral Nutrition and Physical Activity	2010	Janne Boone-Heinonen; David K. Guilkey; Kelly R. Evenson; Penny Gordon-Larsen	Residential self-selection bias in the estimation of built environment effects on physical activity between adolescence and young adulthood	Longitudinal study	High	Some built environment effects persist after accounting for self-selection, particularly during young adulthood.
Journal of the American Planning Association	2010	Reid Ewing; Robert Cervero	Travel and the Built Environment	Meta-analysis	High	Built environment effects on travel are modest but consistent. Destination accessibility shows the strongest association.
British journal of sports medicine	2010	Lawrence D Frank; James F Sallis; Brian E Saelens; Lauren Leary; Kelli Cain; Terry L Conway; Paul M Hess	The development of a walkability index: application to the Neighborhood Quality of Life Study	Measurement development study	Moderate	Walkability index was developed and validated, showing that higher walkability is linked to higher physical activity.
Am J Public Health	2010	J. Pucher; R. Buehler; D. R. Bassett; A. L. Dannenberg	Walking and cycling to health: a comparative analysis of city, state, and international data	Ecological observational study	Moderate	Higher levels of walking and cycling at the population level are associated with lower obesity and diabetes prevalence across different spatial scales.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
International Journal of Sustainable Transportation	2009	Robert Cervero; Olga L. Sarmiento; Enrique Jacoby; Luis Fernando Gomez; Andrea Neiman	Influences of Built Environments on Walking and Cycling: Lessons from Bogotá	Multilevel observational study	High	Street design and access to Ciclovía programs influence walking and cycling more than land-use mix in compact cities
Transportation Research Part A: Policy and Practice	2009	Jonas Eliasson; Lars Hultkrantz; Lena Nerhagen; Lena Smidfelt Rosqvist	The Stockholm congestion–charging trial 2006: Overview of effects	Natural experiment	High	Time-based congestion pricing reduced traffic, improved reliability, and lowered emissions, with behavioural responses occurring rapidly and varying by time of day
Transportation Research Record	2008	Kate Lyman; Robert L. Bertini	Using Travel Time Reliability Measures to Improve Regional Transportation Planning and Operations	Applied planning study	High	Reliability measures reveal congestion patterns not captured by averages. These measures can change planning priorities.
Med Sci Sports Exerc	2008	B. E. Saelens; S. L. Handy	Built environment correlates of walking: a review	Narrative review	High	Transport-related walking is linked to density, land-use mix, and destination proximity. Causal inference remains limited by temporal mismatch.
American Journal of Preventive Medicine	2008	Ken R. Smith; Barbara B. Brown; Ikuho Yamada; Lori Kowaleski-Jones; Cathleen D. Zick; Jessie X. Fan	Walkability and Body Mass Index: Density, Design, and New Diversity Measures	Cross-sectional observational study	High	Higher walkability is associated with lower body mass index and reduced obesity risk. Cumulative exposure matters more than short-term environmental features.
Social Science & Medicine	2007	Lawrence Douglas Frank; Brian E. Saelens; Ken E. Powell; James E. Chapman	Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity?	Cross-sectional observational study	High	Walkability remains associated with increased walking and reduced driving even after accounting for residential self-selection. Preferences influence behaviour but do not fully explain built environment effects.
Obesity Reviews	2007	W. Wendel-Vos; M. Droomers; S. Kremers; J. Brug; F. Van Lenthe	Potential environmental determinants of physical activity in adults: a systematic review	Systematic review	High	Strong evidence exists for only a limited number of environmental determinants of activity. Effects are clearer when outcomes are measured with time-specific indicators.
Journal of the American Planning Association	2006	Lawrence D. Frank; James F. Sallis; Terry L. Conway; James E. Chapman; Brian E. Saelens; William Bachman	Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality	Observational integrative study	High	Walkable environments increase active travel time and are associated with lower obesity and emissions, thereby shaping how land-use characteristics translate into health outcomes.
Journal of the American Planning Association	2006	Susan Handy; Xinyu Cao; Patricia L. Mokhtarian	Self-Selection in the Relationship between the Built Environment and Walking: Empirical Evidence from Northern California	Quasi-longitudinal observational study	High	Built environment changes often occur prior to changes in walking behaviour, and environmental effects persist even after controlling for self-selection.

Table A1. *Cont.*

Name of Journal	Year	Authors	Title	Study Design/Scope	Methodological Quality	Key Findings
Journal of Travel Research	2005	Yvette Reisinger; Felix Mavondo	Travel Anxiety and Intentions to Travel Internationally: Implications of Travel Risk Perception	Cross-sectional analytical study	High	Travel anxiety links risk perception to future travel behaviour. Anxiety operates as a time-sensitive behavioural mechanism.
BMJ	2004	David Ogilvie; Matt Egan; Val Hamilton; Mark Petticrew	Promoting walking and cycling as an alternative to using cars: systematic review	Systematic review	High	Behaviour-change programmes can shift a small proportion of trips. Evidence of large population-level modal change remains limited.
J Sports Sci	2004	J. Waterhouse; T. Reilly; B. Edwards	The stress of travel	Narrative physiological review	High	Travel-related stress follows daily temporal patterns. Disruption of circadian rhythms affects performance and wellbeing.
American Journal of Preventive Medicine	2002	Susan L. Handy; Marlon G. Boarnet; Reid Ewing; Richard E. Killingsworth	How the built environment affects physical activity: Views from urban planning	Narrative conceptual review	High	The built environment shapes physical activity by influencing travel time and the experience of walking and cycling.
Transportation Research Part E: Logistics and Transportation Review	2001	John Bates; John Polak; Peter Jones; Andrew Cook	The valuation of reliability for personal travel	Analytical synthesis study	High	Travel time reliability has independent value beyond mean travel time. Ignoring reliability leads to incomplete assessment of transport benefits.
Transportation Research Part D: Transport and Environment	1997	Robert Cervero; Kara Kockelman	Travel demand and the 3Ds: Density, diversity, and design	Cross-sectional observational study	High	Density, diversity, and design jointly reduce vehicle travel and increase non-motorised trips. These effects are strongest for non-work travel.

References

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