

The Urban Environment and Active Living: The Case of Bogotá, Colombia

Hiwot Yayeh Zewdie

A dissertation

submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

2025

Reading Committee:

Stephen J. Mooney, Chair

Anjum Hajat

Olga Lucia Sarmiento

Program Authorized to Offer Degree:

Epidemiology

©Copyright 2025
Hiwot Yayeh Zewdie

University of Washington

Abstract

The Urban Environment and Active Living: The Case of Bogotá, Colombia

Hiwot Yayeh Zewdie

Chair of the Supervisory Committee:

Stephen J. Mooney

Department of Epidemiology

The built environment fundamentally shapes health opportunities, including those for active living. While research from the Global North has identified the types of built environments that support choice-based physical activity, less is known about their distribution and active-living promoting potential in Global South cities, where activity is often necessity-driven and socioeconomic inequalities and segregation are pronounced. This dissertation addressed this gap by using a neighborhood typology approach to examine how socioeconomic residential segregation and neighborhood built environments relate to shape active living patterns in Bogotá, Colombia. Findings showed that more segregated neighborhoods were less likely to be characterized as active living-supporting built environments, but were not directly associated with physical activity levels, likely due to misalignment between researcher-defined and perceived access to neighborhood characteristics. Despite limitations, including cross-sectional data, temporal mismatches, and reliance on proximity-based measures, this work highlights important areas for future place-based epidemiologic research in Global South cities. When

leveraged intentionally, the built environment has the potential to foster cities that are fundamentally just, promoting equitable opportunities, mobility, and health for all residents.

Table of Contents

Chapter 1. Introduction	5
Chapter 2. Investigating equity in the distribution of active living-promoting environments across socioeconomic residential segregation in Bogotá	8
Table 1. Distribution of Built Environment Variables in Bogotá, overall and across estimated built environment typology	16
Figure 1. Spatial distribution of built environment neighborhood typology and segregation quartiles	17
Figure 2. Distribution of features across estimated built environment neighborhood typology	19
Table 2. Distribution of segregation values across built environment neighborhood typology	20
Table 3. Pooled estimates corresponding to the association between segregation and active-living supporting neighborhood classification	22
Chapter 2 Supplemental Material	28
Table S-1. Built Environment Variables: Definitions, operationalization, and source	28
Figure S-1. Histograms of built environment variables	31
Figure S-2. Spatial distribution of built environment variables ^a	32
Figure S-3. LCA model fit statistics: Relative Entropy, Average Maximum Posterior, BIC, AIC	33
Figure S-4. Spatial Distribution of class probabilities ^a	34
Figure S-5. Stability of effect estimates across pseudo-class draws ^a	35
Table S-2: Comparison of pooled estimated effects across varying spatial weighting approaches for segregation composite count	36
Chapter 3. Neighborhood built environments, socioeconomic segregation, and active-transport and leisure-based physical activity in Bogotá, CO: A lesson on neighborhood measurement in place-based epidemiologic research in the Global South	38
Table 1. Descriptive characteristics of study sample	46
Figure 1. Associations between neighborhood exposures and continuous physical activity outcomes expressed as percent change, 2015 National Survey of Nutritional Situation (Encuesta Nacional de Situación Nutricional; ENSIN)	47
Figure 2. Associations between neighborhood exposures and meeting physical activity recommendations expressed as prevalence ratios, 2015 National Survey of Nutritional Situation (Encuesta Nacional de Situación Nutricional; ENSIN)	49
Figure 3. Predicted values to depict potential effect measure modification by active-living promoting built environment for the association between segregation and physical activity	51

Figure 4. Post hoc analysis examining socioeconomic segregation as a predictor of discrepancies between investigator-assigned and perceived access to built environment amenities	52
Chapter 3 Supplemental Material	58
Table S-1. Built environment features included in latent class analysis-derived built environment typology ..	58
Figure S-1: Survey-weighted model results from fitting quasi-Poisson models using the svyglm function in the srvyr R package	60
Figure S-2: Post hoc analysis comparing associations between investigator-assigned and perceived exposure to built environment features and continuous weekly physical activity	61
Chapter 4. Conclusion	62
References	64

Chapter 1. Introduction

The built environment, the human-made environment that shapes human mobility, fundamentally structures our opportunities for health. For example, investments in quality pedestrian infrastructure can facilitate safe, active transport, while mixed-use land development can bring amenities closer to where people live. Together, these kinds of planning decisions connect communities to employment, economic, and social opportunities, while also promoting physical activity—all of which are foundational to health.^{1,2} As such, the role of the built environment in shaping health is widely recognized, and health-centered approaches are now an established focus of urban planning.^{3–5}

However, planning for health alone is not sufficient to equitably promote health. Urban planning is not immune to the systems of oppression that have produced disparate health trajectories for marginalized populations. For example, in Addis Ababa, Ethiopia, eminent domain was used in 2024 to construct a city corridor intended to improve connectivity.⁶ While the project has been celebrated for expanding walking and cycling infrastructure, it simultaneously displaced predominantly low-income households, relocating them to the city's periphery and away from central economic and social opportunities.^{7–10} As a result, the corridor, though health-promoting in principle, primarily benefits more affluent residents who remained in place, while displaced lower-income individuals now face new barriers to mobility and access. This example illustrates how health-oriented planning, when divorced from explicit considerations of equity, can reproduce or exacerbate social and spatial inequalities, undermining its potential to promote equitable health outcomes.

Addis Ababa is not unique. Cities worldwide demonstrate that urban planning is rarely neutral: even interventions framed as promoting health or public benefit can reinforce existing social hierarchies and power imbalances. In the United States, for example, urban renewal projects have frequently been used to justify racially motivated displacement under the guise of public improvement.^{11–13} Take, for example, the clearance of Reno, a predominantly Black neighborhood in Washington, D.C., to make way for Fort Reno Park in the 1920s.^{14,15} Under the pretense of creating public green space, residents were forcibly displaced, homes were demolished, and a once thriving community was erased. This same story has played out across U.S. cities through highway construction,^{13,16,17} housing development,^{18,19} and other planning interventions that privileged the mobility, property values, and recreational spaces of more affluent and often White populations while marginalizing communities of color.^{11,12}

Therefore, urban planning that fails to acknowledge underlying social processes that are equally important for shaping both the distribution of and access to quality built environments renders even well-intentioned, health-oriented urban planning interventions insufficient for equitably promoting population health. As Tan et al. argue, planning for *health equity*, rather than health alone, must be the guiding principle in efforts to meaningfully and equitably advance population health through urban planning.¹¹

This dissertation builds on this argument in two ways. First, it focuses on residential segregation, as an important metric for assessing equity in urban planning. Segregation is not simply a demographic pattern, but a structuring force that organizes the spatial distribution of resources, risks, and opportunities.^{20–22} In this way, segregation provides the socio-spatial fabric against which planning interventions play out: the same investment in parks, transit, or pedestrian infrastructure can improve opportunity for one community while entrenching disadvantage in another. Examining how the distribution of built environment resources aligns (or misaligns) with the spatial patterning of populations by social identity can therefore provide information into how health inequities emerge, persist, and may be disrupted.

Second, this dissertation focuses specifically on active living—a way of life that integrates physical activity into daily routines (e.g., biking or walking to work) — as a particularly powerful and underutilized emergent measure of health equity to guide urban planning processes.^{23–25} Cities that prioritize equitable active living design streets, public spaces, and transportation systems to make physical activity safe, convenient, and accessible for all residents. By shaping opportunities for movement in daily life, active living influences health through multiple physiological and psychosocial pathways and is consistently associated with lower risk of chronic diseases, including cardiovascular disease,^{26,27} cognitive decline,^{28,29} and some cancers,^{30–32} along with improved mental health,^{33–35} and lower overall mortality.^{36–38} As such, equitable promotion of active living through urban planning represents not only a pathway to reducing disparities across multiple disease outcomes but also a tangible marker of whether planning is truly advancing mobility, opportunity, and health equity across space.

Using physical activity as a metric for health equity, however, becomes more complex in the Global South where activity is largely necessity-driven.^{39,40} Individuals often walk or bike for transport and engage in physically demanding labor, not out of preference, but because of economic, spatial, and infrastructural constraints. If measured only at face value, these populations appear “active”, suggesting their urban environments support health equity. Yet this form of activity is fragile: as individuals gain access to motorized transport, for example, they are likely to lose these forms of movement—a process known as the physical activity transition. At scale, this threatens entire populations with declining energy expenditure unless environments simultaneously expand opportunities for choice-based activity (e.g., choice-based active transport). Without such environments, activity will become concentrated among those with time and resources, typically more affluent groups, reproducing inequities. Thus, the goal is to center and promote choice-based physical activity as a more sustainable and equitable metric for health-oriented urban planning.

While data limitations make it difficult to fully disentangle choice-based from necessity-driven physical activity, we know from research in the Global North the types of built environments that can support choice-based activity. What remains less clear is how these built environments are distributed in Global South cities, which are characterized by wide socioeconomic inequalities

and segregation, and if these built environments have the potential to similarly foster physical activity in settings where physical activity is primarily driven by necessity.

This dissertation aims to fill this gap by investigating how socioeconomic residential segregation and the built environment relate and co-occur to shape active living patterns in Bogotá, Colombia. More specifically, the dissertation begins by examining whether active-living–promoting environments are equitably distributed in Bogotá, using socioeconomic residential segregation as an indicator of the social processes that shape health opportunities, including, potentially, access to environments that support active living (Chapter 2). Next, it investigates how socioeconomic segregation and built environments influence active living, to provide evidence on potential contextual determinants of physical activity in this underrepresented physical activity setting (Chapter 3). Finally, the dissertation assesses whether specific built environments can mitigate the potential negative implications of living in socioeconomically segregated neighborhoods on physical activity, exploring how planning interventions can function as potential levers for promoting physical activity equity (Chapter 3).

Global South cities, including Bogotá, provide an important context for understanding the relationship between the built environment and health equity through active living for several reasons. First, Global South cities are home to the majority of the global population and will account for most urban growth in the coming decades.⁴¹ Second, these regions are underrepresented in active living research, leaving the mechanisms, drivers, and distribution of activity in these contexts poorly understood.^{39,42} Third, despite relatively high baseline levels of physical activity, these cities are experiencing a rising chronic disease burden,⁴³ making the potential physical activity transition particularly consequential for health systems if prevention is not prioritized. Finally, and perhaps most importantly, these cities are still being built, offering an opportunity to “build in” health equity and promote well-being for generations to come.

By answering these questions, this dissertation seeks to advance a more equity-driven and globally relevant understanding of the ways urban environments shape health equity, particularly in Global South cities, like Bogotá, where the ongoing process of urbanization offers important opportunities to intervene and build healthier, more just cities

Chapter 2. Investigating equity in the distribution of active living-promoting environments across socioeconomic residential segregation in Bogotá

Abstract

Background: Understanding the equitable distribution of active-living -promoting built environments in rapidly developing and economically divided cities like Bogotá is important for minimizing future health disparities. We investigate the distribution of active living environments in Bogotá by residential socioeconomic segregation.

Methods: Socioeconomic segregation was measured using the 2018 multidimensional poverty index provided by the Colombian National Department of Statistics. We calculated local spatial measures of dissimilarity and isolation, both deprived and non-deprived). Active-living-promoting built environments were identified through latent class analysis, which estimated a neighborhood built environment typology based on the distribution of fifteen built environment features collected from various sources. We fit robust Poisson regression models, using pseudo-class draws to account for class uncertainty, to estimate prevalence ratios corresponding to the cross-sectional association between socioeconomic segregation and the characterization of a neighborhood as active living-promoting.

Results: We included 2,740 Census sections in Bogotá (98%) with complete data in the analysis. We found that socioeconomic segregation patterns in Bogotá demonstrate a stark spatial pattern, where the residential distribution by socioeconomic status is most divergent from the city distribution in the Northeast and peripheries of the city, whereas households are most socioeconomically isolated in the Western and Southern parts of the city. A 3-profile latent class model was selected, resulting in the following class definitions based on the underlying distribution of active-living related built environment features: “Class 1: Amenity- and Traffic Signal-Limited Active Living Environment”, “Class 2: Multi-Domain Active Living environment”, and “Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment” built environments. These classes characterized 20%, 50%, and 30% of neighborhoods in Bogotá, respectively. We found that segregated neighborhoods, as defined by dissimilarity and isolation, were less likely to be characterized as active-living promoting compared to those with lower levels of segregation (Dissimilarity Prevalence Ratio: 0.52, 95% CI: 0.46, 0.56; Deprived Isolation Prevalence Ratio: 0.18, 95% CI: 0.15, 0.22; Non-Deprived Isolation Prevalence Ratio: 0.83; 95% CI: 0.75, 0.93).

Conclusion: Active living-promoting environments are inequitably distributed across neighborhoods in Bogotá. If unaddressed, this inequity in opportunity may perpetuate activity-related health disparities.

1. Introduction

Latin America is one of the most socioeconomically unequal regions in the world.⁴⁴ Colombia, particularly its capital city, Bogotá, has been the focus of considerable research on residential segregation,^{22,45–52} the spatial manifestation of inequality through the separation of populations on the basis of social conditions (e.g., socioeconomic status, ethnicity, race).²¹ Segregation is not just an incidental feature of cities but an inherent product of urban development processes, with important implications for population health.²¹ Fundamental cause theory posits that social conditions such as socioeconomic status are enduring drivers of health disparities because they determine access to flexible resources like power, knowledge, money, and social capital that are critical for health.^{20,53} Residential socioeconomic segregation reflects the spatial manifestation of these conditions. But it also tends to have an independent effect on individual outcomes. Poor people living in homogeneously deprived areas tend to have lower life chances than similar poor individuals living in more heterogeneous areas.⁵⁴ In this sense, segregation operates as a durable mechanism through which fundamental causes are spatially structured, shaping health trajectories across both space and time.

Segregation in itself is not harmful; for example, under a “voluntary” model where populations self-segregate, the preservation of shared identity and potential for collective efficacy are positive outcomes that could result from the spatial clustering of social groups (e.g., ethnic enclaves).^{21,55} However, residential segregation in Latin American cities, including Bogotá, is almost always as a result of involuntary processes that force displacement of lower-income populations for the benefit of wealthier populations.²¹ Several studies have documented the negative consequences of such imposed segregation, including restricted access to quality education,^{56–58} employment opportunities,^{59–61} and healthcare.^{62,63}

Although residential segregation in Bogotá has been well-documented and its implications for population health increasingly recognized, the mechanisms linking segregation to health remain underexplored. One important question in this area is whether segregation–health associations reflect compositional differences (i.e., health outcomes are a result of the social conditions or preferences of individuals who are spatially clustered) or contextual mechanisms (i.e., residential segregation itself exerts an influence on health through scale-concordant mechanisms). Understanding these pathways is important for informing appropriate interventions and engaging the relevant stakeholders to address the health effects of segregation. Although this study does not directly test this distinction, it aims to contribute to the growing body of research supporting contextual explanations by examining the built environment as a potential pathway linking segregation and health.

Access to built environment features such as public plazas, sidewalks, public transportation, and bicycle paths help increase opportunities for active living,^{64–67} which can reduce the risk of noncommunicable disease like cardiovascular disease, stroke, and cancer.^{68–70} However, not all communities have equal access to these health-promoting resources.^{71–75} Residential segregation

may serve as a structural mechanism that shapes the distribution of these features across neighborhoods, offering a potential pathway through which activity-related health disparities emerge.

Much of the literature investigating the just distribution of built environments, however, focuses on individual elements, such as access to greenspaces or public transportation,^{72,75–77} rather than considering a broader, integrated view of health promoting-infrastructure that may be more relevant for shaping subsequent active living behavior of residing populations. This narrow lens can lead to equally narrow policy responses. For example, although many cities, including Bogotá, have prioritized the equitable distribution of greenspaces through territorial planning policies,^{78,79} other infrastructure that is simultaneously needed to shape and sustain health behavior, like equitable access to road safety neighborhood features,^{80–82} remain underemphasized. Therefore, disrupting the pathways that link segregation, as a spatial manifestation of inequality, to poor health outcomes necessitates integrated approaches that align with the systematic ways through which these forces shape health-promoting environments.

Bogotá has experienced substantial population growth over the past several decades, with its population doubling within 30 years.⁸³ The formation of modern Bogotá began in 1954, when surrounding municipalities, Usaquén, Suba, Engativá, Fontibón, Bosa, and Usme, were annexed into what became the Special District of Bogotá.⁸³ This annexation occurred in response to massive rural-to-urban migration driven by *La Violencia*, a period of intense conflict in the early 1950s that displaced thousands of Colombian households.^{22,84} In search of safety and economic opportunity, many migrants settled in Bogotá and its adjacent municipalities, tripling the city's population in a short period of time. This population surge placed pressure on urban infrastructure and housing. In response, Bogotá undertook rapid, often uncoordinated development to connect and integrate the newly annexed areas.^{51,83} The late and often insufficient state response drove informality to become the main mechanism through which people built their houses and neighborhoods in Bogotá.^{85,86} The later intensification of narcotics-driven violence in 1988 and 1989, led to constitutional reform in 1991 that supported a more decentralized and autonomous structure for territorial states, including the Capital District, Bogotá. This shifted decision-making power regarding territorial affairs, including land use planning and development, to the city, significantly shaping its development.^{87,88} However, changing mayoral administrations, alongside increasing influence from construction and real estate sectors, has undermined the urban development structure that was introduced through constitutional reform, leading to the persistent inequities in access and distribution of urban infrastructure and services seen in Bogotá today.⁸³

Despite these challenges, Bogotá has emerged as a globally recognized innovator in sustainable and active transportation. Notable initiatives include TransMilenio,^{89,90} a high-capacity bus rapid transit (BRT) system; TransMiCable,^{91,92} a cable car connecting hillside communities to transit nodes; Ciclorutas de Bogotá,⁹³ one of the most extensive bicycle path networks in Latin America; and Ciclovía,^{67,93,94} a weekly open streets program that promotes pedestrian and cyclist

activity. The benefits of these urban innovations, however, are inequitably distributed on the basis of socioeconomic conditions potentially giving rise to subsequent disparities in health outcomes.

Recent calls to center health equity into urban planning decision-making offer a framework to guide more equitable development efforts and ground the present study.^{11,95} Specifically, we investigate if active-living promoting environments, defined using a neighborhood typology approach, are equitably distributed across Bogotá. We approach this investigation with three objectives: First, we use 2018 census data to characterize recent socioeconomic segregation patterns in Bogotá along two dimensions: isolation and dissimilarity. Second, we apply latent class analysis to identify a typology of neighborhood built environments based on the co-occurrence of multiple built environment features known to promote leisure and transport-based physical activity. Finally, we investigate whether active-living-promoting environments are equitably distributed across Bogotá by examining their association with our segregation measures. Through these study objectives we aim to provide evidence in support of health equity-centered urban planning to ensure urban planning benefits are realized equitably in developing cities like Bogotá.

2. Methods

2.1. *Socioeconomic segregation*

We measure residential socioeconomic segregation in Bogotá using two measures based on a multidimensional household poverty measure (Spanish: Índice de Pobreza Multidimensional) from the most recent administration of the National Population and Housing Census (2018).⁹⁶ The multidimensional poverty measure is an official household poverty measure provided by Colombia's national statistical agency (Spanish: Departamento Administrativo Nacional de Estadística). This measure characterizes household poverty status using 15 indicators across five domains: education, children & youth, employment, health, and housing & public services. Households are characterized as socioeconomically deprived if they are deprived in five or more of the indicators.

The multidimensional poverty variable was used to calculate two segregation measures for all administrative sections (Spanish: secciones censales) in Bogotá: dissimilarity and isolation. These two measures were chosen because they are the most widely used measures to evaluate the evenness and exposure dimensions of segregation, respectively, and have been previously used to measure segregation in Latin American cities, including Bogotá.^{21,22,48,51,97} We adopt local and spatial versions of the measures, as outlined by Oka & Wong,^{98,99} to facilitate within-city comparison of the measures and incorporate neighboring units in the calculation of the measures.

Local spatial dissimilarity was calculated as follows:

$$SD_i = \left| \frac{cg1_i}{CG1} - \frac{cg2_i}{CG2} \right|$$

Where $cg1_i$ and $cg2_i$ represent the composite counts of socioeconomically deprived (i.e., households deprived in five or more of the indicators) and non-deprived households (i.e., households in deprived in four indicators or less) in Census section i , respectively. Similarly, $cG1_i$ and $cG2_i$ denote the composite counts of deprived and non-deprived households in the city. The measure quantifies the extent to which the composition of socioeconomically deprived and non-deprived households in a given section (and its neighbors) deviates from the overall city composition. Values range from 0-1, where a value of 0 indicates that the neighborhood's composition matches the city's overall distribution, while a value closer to 1 indicates greater dissimilarity, meaning the Census section and its surroundings differ from the city's demographic distribution.

We calculate two local spatial isolation measures, one to measure isolation of deprived populations and one for non-deprived populations. Local spatial isolation was calculated as follows:

$$SI_i = \frac{cg1_i}{G1} * \frac{cg1_i}{ct_i}$$

Where ct_i corresponds to the composite population count in Census section i , and $G1$ the total count of deprived or non-deprived households in the city, and $cg1_i$ is the composite count of deprived or non-deprived households in the Census section, as above. The isolation measure for deprived populations quantifies the extent to which socioeconomically deprived individuals in a given section (and its neighbors) are isolated from non-deprived individuals in the city, whereas the isolation measure for non-deprived individuals quantifies the reciprocal relationship. This measure also ranges from 0-1, where higher values indicate greater isolation, meaning individuals are more surrounded by others from the same group rather than a mix of individuals from both socioeconomic groups.

For both measures, we use composite counts, a concept first proposed by Wong to provide flexibility in neighborhood definition and proxy the spatial dimension of segregation quantitatively.¹⁰⁰ Composite counts are created by incorporating the population counts of neighboring units into the calculation of segregation measures. Composite counts capture group interactions across administrative boundaries, which would otherwise be treated as rigid if counts were confined solely to the administrative unit.

There are multiple methods for defining neighboring units and subsequently weighting their contributions to generate composite counts.^{101,102} We adopted a K-nearest neighbors inverse distance weighting approach for our calculations. Specifically, we define a fixed number of neighbors for all Census sections, based on the median number of contiguous neighbors across all sections in the city. The population counts of each neighboring section are then weighted according to their inverse distance from the centroid of a given section such that closer neighbors have a greater influence on the composite count, aligning with the probability of interaction. We chose this approach because it balanced both spatial proximity and the need for a consistent

comparison across neighborhoods with varying land areas with theoretical assumptions about how spatial interaction decays with distance. Sensitivity analyses were conducted using both contiguity and inverse distance weighting approaches to calculate composite counts (**Table S-2**) to ensure findings are robust across varying neighborhood definition and weighting approaches.

Local segregation measures such as the two calculated here can often result in very small values when population counts are low, as is common when examining segregation patterns at small spatial scales. This occurs because the variation between groups tends to be less pronounced at smaller scales, and the resulting smaller segregation values may be difficult to interpret.⁹⁸ To address this, we normalized each value by scaling it relative to the maximum observed value, then classified the normalized values into quartiles for analysis. For instance, the isolation value for each Census section was divided by the maximum value across all Census sections, resulting in a normalized range from 0 to 1, and then categorized into quartiles. We chose this approach to facilitate a more intuitive interpretation and comparison of segregation measures across neighborhoods. We recognize that the maximum value may vary across cities or time periods, so comparisons across studies should account for this.

Census data was accessed using REDATAM,¹⁰³ publicly available dynamic tabulation tool developed by the Economic Commission of Latin America to facilitate dissemination of census data at various geographic scales, including the multidimensional poverty variable used in the construction of the socioeconomic segregation measures.

2.2. Built environment neighborhood typology

To develop a built environment typology that represents the types of active-living environments found in Bogotá, we combined 15 built environment variables sourced from publicly available geospatial data from Bogotá's District Department of Planning (Spanish: Secretaría Distrital de Planeación), Spatial Data Infrastructure for the Capital District Department (Spanish: Infraestructura de Datos Espaciales para el Distrito Capital, IDECA), District Institute of Recreation and Sport (Spanish: Instituto Distrital de Recreación y Deporte), and from a database of built environment features identified using machine learning algorithms applied to Google Street View panoramic images of Bogotá's street network.^{104,105} These variables were selected to represent built environment domains previously established as relevant for active living,^{64,66,106,107} with adaptations to include domains and variables specifically relevant to activity promotion in Latin American cities^{94,108,109}: functional factors, transport, safety, aesthetics, destination, and civic culture. The specific variables, definitions, and sources are detailed in **Table S-1**.

We used latent class analysis (LCA) to estimate a built environment typology from compiled built environment variables and characterize all Census sections in Bogotá with complete data. We tested LCA models with class solutions ranging from 1 to 6 classes to identify the optimal number of classes. Variables that were not already binary were dichotomized at the median before fitting the models to ease interpretation of the resulting typology and meet model

assumptions.¹¹⁰ We selected a latent class analysis (LCA) approach instead of latent profile analysis (LPA) or other mixture models that accommodate continuous variables to facilitate interpretation of the results. Given that the neighborhood typology is derived from the joint distribution of 15 variables, modeling all of them as continuous would make the resulting classes more difficult to interpret

The final LCA model was selected based on a combination of model fit statistics (i.e., AIC, BIC, entropy, and average maximum posterior), subjective interpretability of the resulting profiles informed by content area knowledge, and the population sizes of the profiles. After selecting our final model, classes were labeled based on the distribution of the individual built environment features. We then extracted posterior probabilities for subsequent analysis and classified the resulting classes as either promoting active living or not, based on the distribution of built environment characteristics and input from subject matter experts.

2.3 Statistical Analysis

We computed summary statistics for both the segregation measures and built environment variables. We used robust Poisson regression models to directly estimate prevalence ratios that correspond to the cross-sectional association between socioeconomic segregation and the built environment typology. Specifically, we fit models to estimate prevalence ratios with 95% confidence intervals, constructed using robust standard errors, to assess the probability of a neighborhood being characterized as active living-promoting relative to the referent (segregation quartile 1, indicating the lowest segregation level).

Because class assignments from the latent class model are probabilistic, we used pseudo-class draws to account for class assignment uncertainty in the estimation step testing for an association between segregation and the built environment typology.^{111,112} In this approach, we generate multiple datasets (i.e., draws), where neighborhoods are assigned to a class based on their estimated posterior probabilities from the selected LCA model. For example, if Neighborhood 1 has the following class membership probabilities in a four-class solution, 59% for Class 1, 1% for Class 2, 15% for Class 3, and 25% for Class 4, then across 100 draws it would be assigned to Class 1 in 59 draws, Class 2 in 1 draw, Class 3 in 15 draws, and Class 4 in 25 draws. We chose to run 50 draws to balance statistical precision and computational efficiency (**Figure S-5**). It is important to note that there are alternative approaches to handling latent class estimation uncertainty that generally outperform the pseudo-class draw method.^{111,113,114} However, many of these alternatives require the use of multiple software packages, some of which are proprietary or offer limited technical support.¹¹⁵ In contrast, the pseudo-class draw approach is relatively straightforward, as it follows a framework similar to multiple imputation for missing data.^{111,116} We selected this method as a principled alternative that better accounts for classification uncertainty than the naive approach, which assigns individuals to their most likely class (i.e., modal assignment) without incorporating the probabilistic nature of class membership.

Following class estimation, we fit robust Poisson models for each draw to generate effect estimates, which were pooled across draws using Rubin's rules to calculate corrected standard errors and corresponding confidence intervals.¹¹⁶ Distribution of covariates across the built environment typology were generated by assigning Census sections their highest probability class (i.e., modal assignment).

All analyses were conducted in R, using the poLCA package to fit the LCA model.¹¹⁰ This study used routinely collected public administrative and environmental data and was therefore exempt from human subject review.

3. Results

Of the 2,796 Census sections in Bogotá, 2,740 Census sections were included in the final analytic sample. Two percent of sections (n = 56) were dropped because traffic safety features were not counted for these Census sections.

3.1. Socioeconomic segregation

The maximum observed segregation value used for normalization for each measure was 0.24 for dissimilarity, 0.12 for isolation of deprived populations, and 0.77 for isolation of non-deprived populations. For isolation, this indicates that at the extreme, non-deprived populations are segregated to a larger degree than deprived populations. These values set the upper bound for the scaled range of both segregation measures (0-1). Using the normalized measures, the median (IQR) for dissimilarity was 0.06 (0.03–0.10), and for isolation, it was 0.05 (0.01–0.16) for deprived populations and 0.10 (0.07–0.13) for non-deprived populations. The spatial distribution of the segregation measures grouped into quartiles is shown in **Figure 1**. The highest levels of segregation, as measured by dissimilarity, appear in neighborhoods in the northeast and peripheries of Bogotá. For deprived isolation, the highest level of segregation is observed in the southern peripheries of the city, whereas the highest segregation of non-deprived isolation is concentrated in the western peripheries, with some overlap in neighborhoods also characterized by high deprived isolation.

3.2. Built Environment Typology

The distribution of built environment variables for included Census sections is described detail in **Table 1** (further descriptive information available **Figure S-1 & S-2**). A 3-class solution was selected as the optimal LCA model to estimate a built environment typology for Census sections in Bogotá (Model fit statistics available in **Figure S-3**). Using the 3-class LCA model, Census sections

Table 1. Distribution of Built Environment Variables in Bogotá, overall and across estimated built environment typology

Domain	Items	City Distribution (n = 2,740)	Class 1: n = 539 (20%)	Class 2: n = 1,366 (50%)	Class 3: n = 835 (30%)
Median (IQR) or N (%)					
Functional	Intersections , intersections per km ²	305.5 (185.1–464.1)	315.4 (86.0–496.87)	292.5 (202.9–423.9)	334.1 (176.2–507.5)
	Sidewalk coverage , sidewalk area (m ²) per Census section area (m ²)	0.11 (0.07–0.13)	0.08 (0.05–0.11)	0.11 (0.09–0.13)	0.11 (0.08–0.13)
	Bike lanes , bicycle lane length (m) per road length (m)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Transport	Transmilenio routes	1,491 (54)	41 (8)	991 (73)	459 (56)
	SITP routes , number of routes	41 (31–55)	25 (18–33)	48 (37–61)	43(34–54)
	Bus stops , bus stops per Census section area (m ²)	0.0 (0.0–9.0)	0.0(0.0–18.0)	0.0 (0.0–7.2)	0.0 (0.0–8.8)
Safety	Pedestrian signals , % pedestrian signals detected ^a	2.2 (0.0–11.6)	0.0 (0.0–0.0)	11.6 (6.5–20.7)	0.0 (0.0–0.0)
	Traffic signals , % traffic signals detected ^a	6.8 (0.0–21.4)	0.0 (0.0–0.0)	21.4 (13.4–35.2)	0.0 (0.0–2.4)
Aesthetic	Trees , number of trees	2,968 (1,076–6,205)	1,605 (383–4,678)	3,535 (1,535–6,596)	3,118 (967–6,441)
	Land use diversity (entropy index)	0.68 (0.40–0.88)	0.38 (0.20–0.57)	0.80 (0.57–0.93)	0.70 (0.46–0.83)
	Parks , park area (m ²) per Census section area (m ²)	0.04 (0.00–0.09)	0.04 (0.00–0.09)	0.04 (0.00–0.09)	0.05 (0.00–0.11)
Destination	Plazas	1,068 (39)	120 (22)	615 (45)	333 (40)
	Malls	739 (27)	30 (6)	353 (26)	356 (43)
	Ciclovía	1,295 (47)	28 (5)	841 (61)	426 (51)
Civic culture	Recrovia	626 (23)	134 (25)	273 (20)	219 (26)

^a proportion from total GoogleStreetView images available in Census section

Neighborhood built environment classes are defined as follows: Class 1: Amenity- and Traffic Signal-Limited Active Living Environment, Class 2: Multi-Domain Active Living environment, Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment.

Figure 1. Spatial distribution of built environment neighborhood typology and segregation quartiles

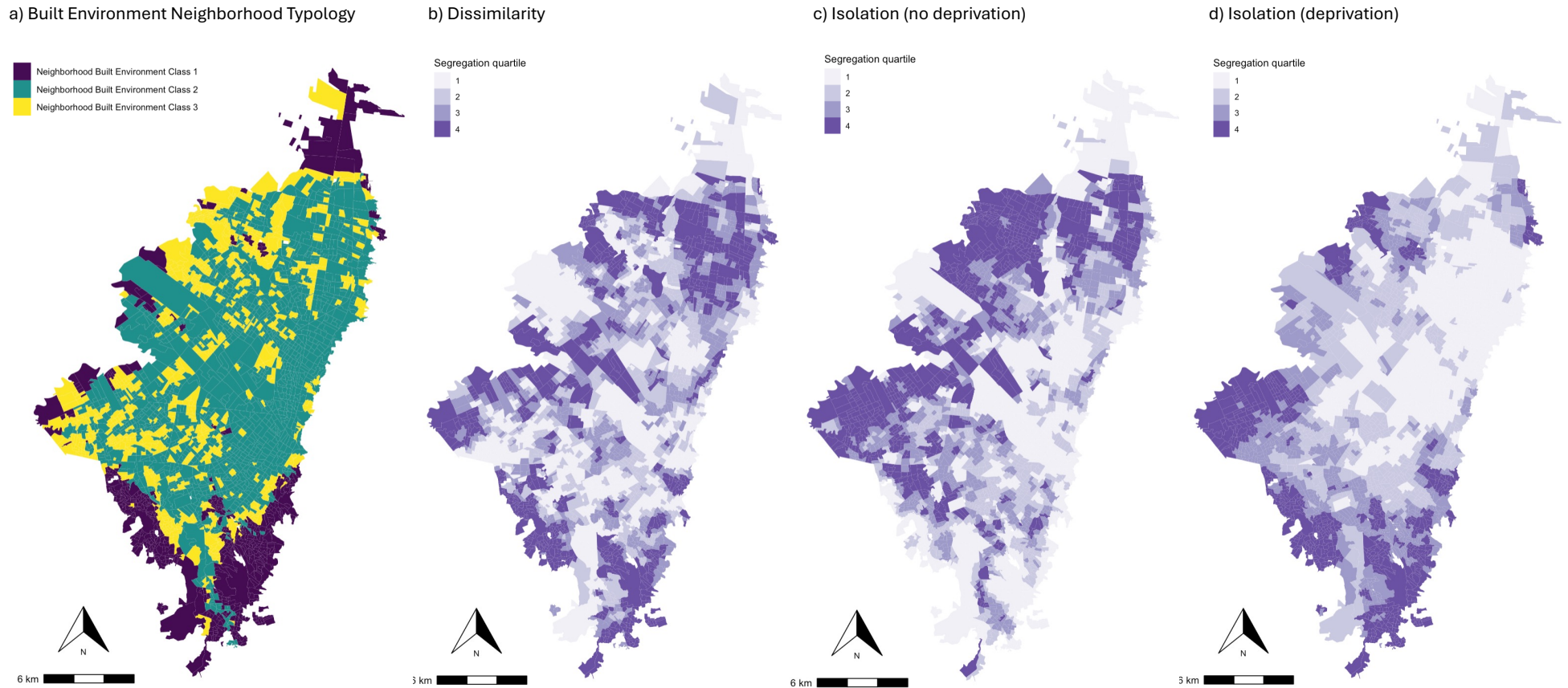


Figure 1 Caption: Neighborhood built environment classes are defined as follows: Class 1: Amenity- and Traffic Signal-Limited Active Living Environment, Class 2: Multi-Domain Active Living environment, Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment.

were characterized as the following *types* of active-living built environments: Class 1: Amenity-Limited and Traffic Signal-Limited Active Living Environment (n = 539, 20%), Class 2: Multi-Domain Active Living Environment (n= 1,366, 50%), and Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment (n=835, 30%).

Table 1 presents the distribution of features across estimated neighborhood classes and relative to the city average. **Figure 2** depicts the distribution of built environment characteristics across the estimated typology, indicating the proportion of Census sections within each built environment class that exhibit above- or below city-median density for each feature, grouped by built environment domain. For example, among neighborhoods classified as Class 1: Amenity-Limited and Traffic Signal-Limited Active Living Environment, approximately 40% had an above-median tree density. In contrast, about 60% of Class 2: Multi-Domain Active Living Environment, and 50% of Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment.

Class 1 neighborhoods appear to consistently have below-median density for nearly all built environment features relative to Class 2 and Class 3 neighborhoods. This seems to be most pronounced for features across Civic Culture, Destination, Traffic Safety, and Transportation built environment domains. Classes 2 and 3 neighborhoods were relatively similar across the built environment domains; however, Class 3 diverged the most for traffic safety features, with almost all neighborhoods characterized as Class 2 having above-median density of traffic safety features, whereas Class 3 had nearly all neighborhoods fall below-median.

Class 2: Multi-Domain Active Living Environment was characterized as an active-living promoting neighborhood class given the above-median density of nearly all built environment features. For sensitivity analyses, both Class 2 and Class 3 neighborhoods were characterized as active living.

The spatial distribution of the built environment neighborhood typology in Bogotá is shown in **Figure 1**. There is a distinct spatial patterning in the distribution of the classes. Class 2: Multi-Domain Active Living Environment neighborhoods appear to cluster in the inner ring of the city, whereas Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment neighborhoods are more prevalent in the outer ring and in pockets of predominantly Class 2 neighborhoods. Class 1: Amenity-Limited and Traffic Signal-Limited Active Living Environment neighborhoods are almost exclusively found in the periphery of the city.

Table 2 presents the distribution of Census sections across quartiles of dissimilarity and isolation based on the estimated built environment neighborhood typology. For dissimilarity, over half of Class 1: Amenity-Limited and Traffic Signal-Limited Active Living Environment neighborhoods (55%) fell into the highest quartile of segregation. In contrast, only 16% of Class 2: Multi-Domain Active Living Environment neighborhoods support neighborhoods were in quartile 4, with most classified in quartiles 1 (30%) and 2 (28%). Class 3: Amenity-Rich but Traffic Signal-

Figure 2. Distribution of features across estimated built environment neighborhood typology



Table 2. Distribution of segregation values across built environment neighborhood typology

	Built Environment Neighborhood Typology ^a		
	Class 1 (n = 539)	Class 2 (n = 1,366)	Class 3 (n = 835)
Segregation quartile	N (%)		
Dissimilarity			
Q1 (Lowest segregation)	47 (9)	411 (30)	227 (27)
Q2	76 (14)	387 (28)	218 (26)
Q3	118 (22)	353 (26)	215 (26)
Q4 (Highest segregation)	298 (55)	215 (16)	175 (21)
Isolation (Deprived)			
Q1 (Lowest segregation)	3 (1)	534 (39)	159 (19)
Q2	24 (4)	454 (33)	205 (24)
Q3	132 (24)	284 (21)	258 (31)
Q4 (Highest segregation)	380 (71)	94 (7)	213 (27)
Isolation (Non-Deprived)			
Q1 (Lowest segregation)	204 (38)	353 (26)	102 (12)
Q2	164 (30)	369 (27)	158 (19)
Q3	112 (21)	340 (25)	243 (29)
Q4 (Highest segregation)	59 (11)	304 (22)	332 (40)

^a Modal assignment used for descriptive comparison of segregation quartiles and class characterization; Neighborhood built environment classes are defined as follows: Class 1: Amenity- and Traffic Signal-Limited Active Living Environment, Class 2: Multi-Domain Active Living environment, Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment.

Limited Active Living Environment neighborhoods were more evenly distributed across quartiles of dissimilarity. A similar but more pronounced pattern was observed for deprived isolation. Specifically, 71% of Class 1 neighborhoods were in the highest deprived isolation quartile, whereas for Class 2 neighborhoods only 7% were. Class 3 neighborhoods were approximately evenly distributed across all quartiles of isolation, though had a slightly higher concentration in quartile 2 or above. In contrast, 11% of neighborhoods in Class 1 were in the highest segregation quartile for non-deprived isolation, compared to 22% of neighborhoods in Class 2, and 40% of Class 3.

3.3. Estimation

Effect estimates from robust Poisson models testing the cross-sectional association between socioeconomic segregation and active-living-promoting neighborhood built environments are presented in **Table 3**. A dose-response relationship is observed for dissimilarity and deprived isolation, where higher segregation is associated with a lower probability of a neighborhood being classified as an active-living-promoting type. Specifically, neighborhoods with a socioeconomic composition most divergent from the city are 48% (PR: 0.52, 95% CI: 0.46, 0.56) less likely to be characterized as active-living-promoting compared to the referent (lowest level of segregation). This association is even more pronounced for deprived isolation. Neighborhoods in the highest deprived isolation quartile, where deprived individuals are more likely to be surrounded by others from the same group, are 82% (PR: 0.18, 95% CI: 0.15, 0.22) less likely to be classified as active-living-promoting. Sensitivity analyses, using a broader characterization of active-living promoting neighborhoods showed similar associations, with expected attenuation of associational strength.

Non-deprived isolation followed a slightly different pattern. When using the more conservative active-living neighborhood characterization, neighborhoods with moderate levels of segregation (Quartile 2 and 3 for non-deprived isolation) were similarly likely to be characterized as active-living promoting as the referent (PR Quartile 2 Non-Deprived Isolation: 1.00, 95% CI: 0.90, 1.10; PR Quartile 3 Non-Deprived Isolation: 0.92, 95% CI: 0.93, 1.02). However, those in the highest quartile (i.e., non-deprived populations more likely to be surrounded by other non-deprived populations) were 17% less likely to live in neighborhoods characterized as active-living promoting compared to less segregated neighborhoods (PR: 0.83; 95% CI: 0.75, 0.93). Using the broader definition, however, higher non-deprived isolation is associated with higher probability of living in an active-living promoting neighborhood compared to the lowest segregation quartile. Further, we did not observe a significant association between non-deprived isolation and active-living neighborhood characterization in sensitivity analyses using different neighbor definition and weighting approaches.

Table 3. Pooled estimates corresponding to the association between segregation and active-living supporting neighborhood classification

	Class 2	Class 2+Class 3
Segregation quartile	Prevalence Ratio (95% CI) ^a	
Dissimilarity		
Q1 (Lowest segregation)	Ref	Ref
Q2	0.92 (0.85-1.01)	0.96 (0.93-0.99)
Q3	0.84 (0.76-0.92)	0.90 (0.87-0.94)
Q4 (Highest segregation)	0.52 (0.46-0.56)	0.63 (0.59-0.67)
Isolation (Deprived)		
Q1 (Lowest segregation)	Ref	Ref
Q2	0.87 (0.82-0.93)	0.98 (0.96-0.99)
Q3	0.57 (0.52-0.63)	0.81 (0.78-0.84)
Q4 (Highest segregation)	0.18 (0.15-0.22)	0.48 (0.44-0.52)
Isolation (Non-Deprived)		
Q1 (Lowest segregation)	Ref	Ref
Q2	1.00 (0.90-1.10)	1.10 (1.03-1.17)
Q3	0.92 (0.93-1.02)	1.20 (1.13-1.27)
Q4 (Highest segregation)	0.83 (0.75-0.93)	1.28 (1.22-1.36)

^a Estimates pooled over 50 draws to account for class uncertainty

Neighborhood built environment classes are defined as follows: Class 1: Amenity- and Traffic Signal-Limited Active Living Environment, Class 2: Multi-Domain Active Living environment, Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment.

4. Discussion

We characterized socioeconomic segregation in Bogotá using the most recent administration of the Colombian census (2018) and examined whether active-living promoting neighborhood environments are equitably distributed across the city. We found that segregation patterns in Bogotá demonstrate non-random spatial patterning, where the distribution of households in terms of socioeconomic status is most divergent from the city distribution in the Northeast and peripheries of the city, whereas households are most socioeconomically isolated in the Western and Southern parts of the city. We found that segregated neighborhoods, as defined by dissimilarity and isolation, were less likely to be characterized as active-living promoting compared to those with lower levels of segregation.

Socioeconomic segregation in Latin American cities has long been shaped by distinct patterns of urban development and spatial inequality. A number of urban models have emerged to help explain these dynamics and provide a useful lens through which to interpret contemporary patterns of segregation in Latin American cities like Bogotá.

The first is Griffin and Ford's model of the Latin American city. This model presents a generalized urban structure of Latin American cities characterized initially by a central business district (CBD) inhabited by the wealthy elite. Subsequent suburbanization of affluent groups resulted in the formation of a 'commercial spine'—a linear extension from the CBD along major commercial corridors—where high-income residential areas became concentrated.^{117–119} Bähr and Mertins expanded this model by highlighting the parallel growth of informal settlements, typically along the urban periphery,⁷⁴ where low-income populations reside with limited access to services, infrastructure, or formal housing markets. These settlements often develop through semi-legal or illegal means and undergo gradual processes of consolidation or displacement as cities grow.^{120–122}

Sabatini and later Borsdorf and Hidalgo built on these models by documenting the rise of socially heterogeneous areas within Latin American cities following the suburbanization of affluent groups: zones where higher- and lower-income groups coexist in close proximity, yet remain socially and infrastructurally disconnected.^{21,123–125} A key feature catalyzing this shift is the proliferation of *barrios cerrados* (gated communities), which emerged as a response to the physical proximity of different socioeconomic groups.^{21,22,45,125–129} These secure, enclosed areas enabled the formation of islands of homogenous, predominantly affluent residents within historically lower-income neighborhoods. While such areas may appear spatially integrated on the surface, they are often marked by forms of micro-segregation that preserve sharp divides in access to public space, services, and infrastructure.^{126,130}

Although our analysis is cross-sectional, these theoretical models are useful for understanding contemporary patterns of segregation in Bogotá that we identified in the present study. We find that the spatial patterning of segregation in Bogotá largely mirrors the trajectories described in these urban models. High-income households are concentrated in the northeastern part of the

city, particularly along commercial corridors like Carrera Séptima and Avenida Caracas, aligning with the “elite spine” described by Griffin and Ford. This area became the concentration for high-income development, especially following the deregulation of land markets in the 1990s,^{21,51,124} which facilitated the expansion of affluent neighborhoods and reinforced exclusion through high land values and zoning restrictions.^{131,132} At the same time, the southern and peripheral areas of Bogotá exhibit concentrated deprivation, consistent with Bähr and Mertins’ description of informal or low-income settlements on the city’s margins. In Bogotá, these patterns have been reinforced by the location of public housing developments almost exclusively in the South, driven largely by affordability and market-driven constraints on land prices.^{21,131} These areas are characterized by lower socioeconomic status and limited access to quality infrastructure and services.¹²²

We also observe a pattern of fragmented segregation, particularly in western Bogotá, where both deprived and non-deprived groups are seen to be highly isolated. In Bogotá, the 1980s and 1990s saw an expansion of high-income residential developments beyond the traditional affluent neighborhoods of the North and Northeast into historically low-income areas in the West.^{21,51,132} This shift was fueled by globalization and neoliberal reforms that incentivized market-led development and a suburban lifestyle increasingly sought by wealthier households.^{124,125} Consistent with the patterns described by Sabatini and Borsdorf and Hidalgo, these changes catalyzed the proliferation of gated communities,^{84,125,126,133} and shifted the segregation patterns from a traditional core-periphery model, in which high-income groups were concentrated in specific, central areas of the city, to a fragmented urban landscape where high- and low-income groups live in close geographic proximity but remain socially and physically isolated. While we do not explicitly test for the presence of gated communities, prior research has documented the recent rise of walled communities in areas that align with the higher isolation values observed in our analysis.¹³³ This ‘patchwork’ pattern seen in the West contrasts with the long-standing segregation of affluent groups in the Northeast, where the historical concentration of wealth, power, and resources has likely imposed stronger barriers to housing access for poorer households—barriers that even the emergence of gated communities could not mitigate.^{51,131}

Importantly, our findings show that these patterns of segregation are associated with disparities in active-living-promoting environments. Unsurprisingly, this relationship is most pronounced in neighborhoods with the highest levels of deprived isolation, where segregated populations are less likely to live in active-living-promoting neighborhoods. This aligns with existing research that links the isolation and concentration of socially marginalized communities to disparities in access to public services and amenities in Bogotá, and other cities in Latin American and globally.^{22,58,75,131}

Interestingly, we find that neighborhoods with high non-deprived isolation are also associated with lower probability of being characterized as active-living-promoting. This suggests that the spatial concentration of affluence can also generate negative health consequences through urban

design. One likely explanation is the dominance of car-oriented infrastructure in affluent neighborhoods in Bogotá.^{134,135} Rising private vehicle use, especially among higher-income households, has shaped neighborhood form: wider roads, parking infrastructure, and reduced investment in transit infrastructure have created environments less conducive to active mobility.^{135,136} Similar patterns have been documented globally; for example, Oyeyemi et al. found that higher socioeconomic status neighborhoods in Maiduguri, Nigeria were less walkable.¹³⁷ Similarly, a study in the US found that, across 500 cities, neighborhoods with higher median household incomes were associated with lower walkability scores.¹³⁸

Another possible explanation is the decline in public investment in affluent segregated areas. Katzman describes this as the “desertion of public space” by the globalized middle and upper classes;^{57,139} when inequality reaches intolerable levels, wealthier groups may withdraw from collective investment, relying instead on private infrastructure and gated amenities that their power, privilege, and resources can provide. In such contexts, empathy and civic responsibility for shared public goods may erode, particularly when affluent residents have few interactions with more disadvantaged groups.⁵⁷ The result is a neglect of public spaces, which may help explain the patterns we observe in our study.

Overall, these findings suggest that segregation, whether driven by poverty or privilege, may shape the urban environment in ways that have direct implications for mobility and health equity. Urban policy should consider accounting for both the exclusion of marginalized groups *and* for the ways in which affluence, when spatially and socially isolated, contributes to patterns of infrastructural neglect for health promotion.

Our study has limitations. First, as a cross-sectional study, we cannot fully tease apart the relationship between residential segregation and built environments, which are reinforcing contextual mechanisms that can shape one another.^{140,141} While we aimed to align built environment data collection with the 2018 census used to measure segregation, some built environment features were captured prior to 2018. Although these features are generally stable over time, this mismatch limits our ability to establish clear temporality between the exposure and outcome. Relatedly, the cross-sectional nature of the study also limits our ability to capture segregation as a dynamic process. Findings reported may not be representative of long-term segregation patterns that characterize the city and may be stronger predictors of how health-promoting opportunities are distributed.¹⁴²

Further, the estimation of built environment typologies relied on data from multiple sources, each with varying levels of measurement accuracy. While this afforded a more holistic measurement of neighborhood built environments, this may have introduced measurement error that was not accounted for in this analysis. This is of particular concern for informal areas, where data coverage may be incomplete, potentially introducing bias in neighborhood classifications for these areas.^{143–145} This bias seems to be observed in the present analysis, with lower class separation seen for peripheral neighborhoods (**Figure S-4**), warranting caution when interpreting

these results. Future work looking to compile data across sources may consider validating geospatial data with virtual audits to quantify and correct potential measurement error.^{144,146} Relatedly, latent class models were fit using city median-dichotomized built environment feature density. This makes the resulting estimated classes generalizable only within the context of Bogotá, although we do not expect the co-occurrence of built environment features to differ substantially in other urban settings. Additionally, we identify an active-living promoting neighborhood type based on the class with an underlying distribution of built environment features that aligns with current understanding of features that support active-living in Bogotá. We, however, did not validate if these class types correspond to actual population active living behavior. This will be explored further in future work.

Finally, our segregation measures are based on the multidimensional poverty index provided by the 2018 Colombian Census, which defines households as deprived if they lack at least one-third of 15 socioeconomic indicators. While this multidimensional approach improves upon single-variable measures (e.g., highest education level), the dichotomization of socioeconomic status used in our dissimilarity and isolation measures may not align with the actual social stratification of individuals in Bogotá. This could limit the generalizability of the segregation patterns observed in the study to actual health and health-related opportunities that this work is attempting to approximate. Future research should explore alternative operationalizations of socioeconomic segregation to assess whether patterns remain consistent across different variables and classifications.

This study also has strengths. First, this study uses a comprehensive set of built environment features to understand equitable access to healthy environments. The construction of a neighborhood built environment typology from these features offers important methodological innovation in the measurement of neighborhood environments.^{147–149} Individual features from a latent modeling-derived typology can be disentangled to better understand what features co-occur to distinguish neighborhood types; this is not possible with indices, what is typically used to approximate multiple dimensions of neighborhood environments. The ability to preserve the underlying pattern of features that comprise each neighborhood subtype allows us to better understand the distribution of multiple features simultaneously and capture more nuanced patterns of inequities that might be overlooked in conventional approaches.

Second, this study employed measures capturing two dimensions of segregation to provide a more complete picture of how segregation can shape population health opportunities. As demonstrated in this work, there are important subtleties in how populations are distributed in space that can result in different patterns of segregation with varying public health impact. Continued exploration of how different dimensions of segregation are related to access to health-promoting opportunities will be important for development more informed urban and social policy to combat potential negative implications of segregation.

Further, this is one of few segregation studies in the Latin American context that incorporate spatial weighting approaches into the development of segregation measures to better capture the spatial dimension of the construct. This is an important methodological improvement to aspatial measures that treat administrative boundaries as impenetrable barriers, which is unrealistic to how populations interact.¹⁰¹ Given the absence of a universally accepted method for identifying and weighting spatial neighbors, we present our primary findings using segregation measures constructed with K-nearest neighbors-inverse distance weighting approaches, alongside contiguity-based and inverse distance weighting methods (**Table S-2**). Overall, findings are consistent across these approaches, with only modest variations in the magnitude of association depending on the method used. However, we observed differences in the direction of association when examining the association between non-deprived isolation and active-living neighborhood characterization, suggesting that associations between segregation and external variables may be sensitive to implied spatial scale of segregation induced by spatial weighting techniques. While the sensitivity of segregation measures to the scale of measurement (e.g., census tract versus metropolitan) has been extensively discussed,^{22,150–152} less attention has been given to how the spatial extent of interaction defined by weighting approaches may influence the results.¹⁵³ Future research should further explore this dimension to advance our understanding of segregation as a spatial phenomenon.

5. Conclusion

Our study suggests that socioeconomic segregation is associated with less opportunity to live in active-living promoting neighborhoods for both poor and affluent groups. This is particularly significant in the context of rising inactivity-related chronic diseases in Bogotá and globally. While the city government has implemented anti-segregation policies, primarily through housing initiatives, our findings suggest that equity must be integrated across all domains of urban policy including social, land planning, and transportation policy to engage the full spectrum of actors responsible for equitably shaping healthy environments for all communities. In doing so, Bogotá, and other cities experiencing similar socio-spatial and urban development trajectories, can more equitably foster environments that promote population health and well-being.

Chapter 2 Supplemental Material

Table S-1. Built Environment Variables: Definitions, operationalization, and source

Domain	Items	Description	Variable type	Unit	Original Scale	Year	Source
Functional	Intersections	Density of intersections in the network within the Census section	Continuous	# intersections/area (km ²)	Point	2018	Secretaría Distrital de Planeación ^a
	Sidewalk coverage	Total sidewalks area within the Census section	Continuous	Sidewalk area (m ²)/area (m ²)	Polygon	2019	IDECA ^b
	Bike lanes	Bicycle lane length per road length	Continuous	Bicycle lane length (m) /road length (m)	Tract	2020	IDECA ^b
Transport	Transit routes - Transmilenio	Presence of TransMilenio (BRT) routes within the 1km of tract centroid	Binary	1,0	Line	2019	Transmilenio SA ^c
	Transit routes - SITP	Number of unique SITP (pub transit) routes within 1km Census section centroid	Continuous	# SITP routes	Line	2020	Transmilenio SA ^c
	Bus stops	Bus stop density within Census section	Continuous	#bus stops/area (m ²)	Tract	2022	IDECA ^b
Safety	Pedestrian signals	Density of pedestrian traffic lights within Census section	Continuous	# images with ped signals detected/total images	Point	Closest image to 2018	ML Predictions ^c
	Traffic signals	Density of total traffic lights within Census section	Continuous	# images with traffic signals detected/total images	Point	Closest image to 2018	ML Predictions ^c

Aesthetic	Trees	Density of trees within Census section	Continuous	# trees/area (km2)	Tract	2022	Secretaría Distrital de Planeación ^a
Destination	Land use diversity	Land use diversity index (Shannon's index)	Continuous	0-1	Land use data at parcel-level, aggregated to tract to calculate entropy	2020	IDECA ^b
	Parks	Park area within the Census section boundary (%)	Continuous	Park area (m2) /total area (m2)	Tract	2022	Instituto Distrital de Recreación y Deporte ^d
	Public spaces - plazas	Presence plazas within 1km Census section centroid	Binary	1,0	Polygon	2022	Secretaría Distrital de Planeación ^a
	Public spaces - malls	Presence malls within 1km Census section centroid	Binary	1,0	Polygon	2022	Secretaría Distrital de Planeación ^a
Civic culture	Ciclovia	Presence of Ciclovia route (weekly open streets) within 1km Census section centroid	Binary	1,0	Line	2020	Instituto Distrital de Recreación y Deporte ^d
	Recrovia	Presence of Recrovia (weekly recreational programs) within 1km Census section centroid	Binary	1,0	Point	2020	Instituto Distrital de Recreación y Deporte ^d

^aSecretaría Distrital de Planeación (District Planning Secretariat)

^bIDECA: Infraestructura de Datos Espaciales para el Distrito Capital (Spatial Data Infrastructure for the Capital District)

^cTransmilenio SA: TransMilenio Sociedad Anónima (TransMilenio Inc)

^dInstituto Distrital de Recreación y Deporte (District Institute of Recreation and Sports)

^eFeatures were identified using machine learning algorithms applied to GoogleStreetView panoramic images. Image availability is variable (range: 2015-2019)

Figure S-1. Histograms of built environment variables

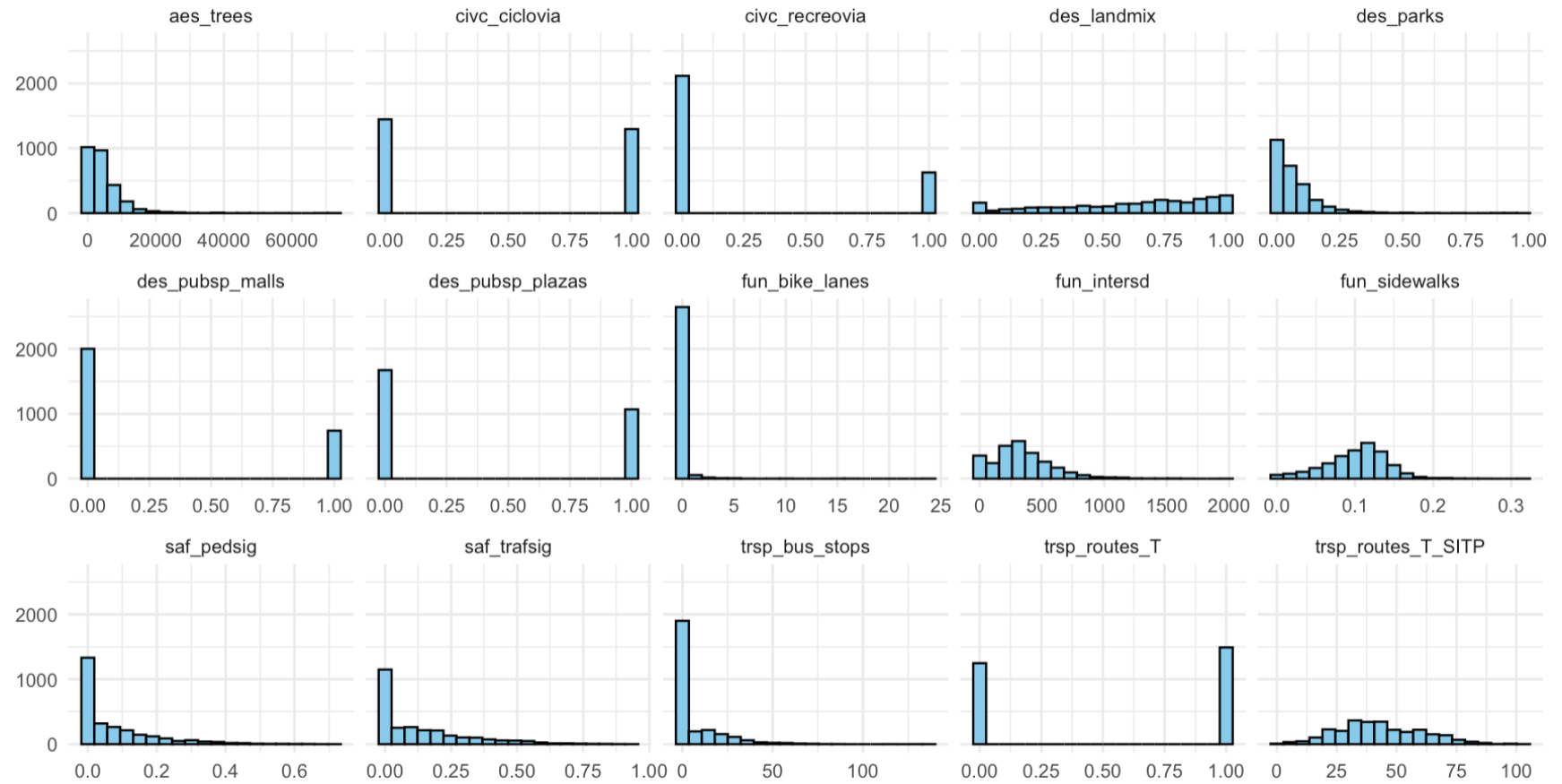


Figure S-2. Spatial distribution of built environment variables ^a

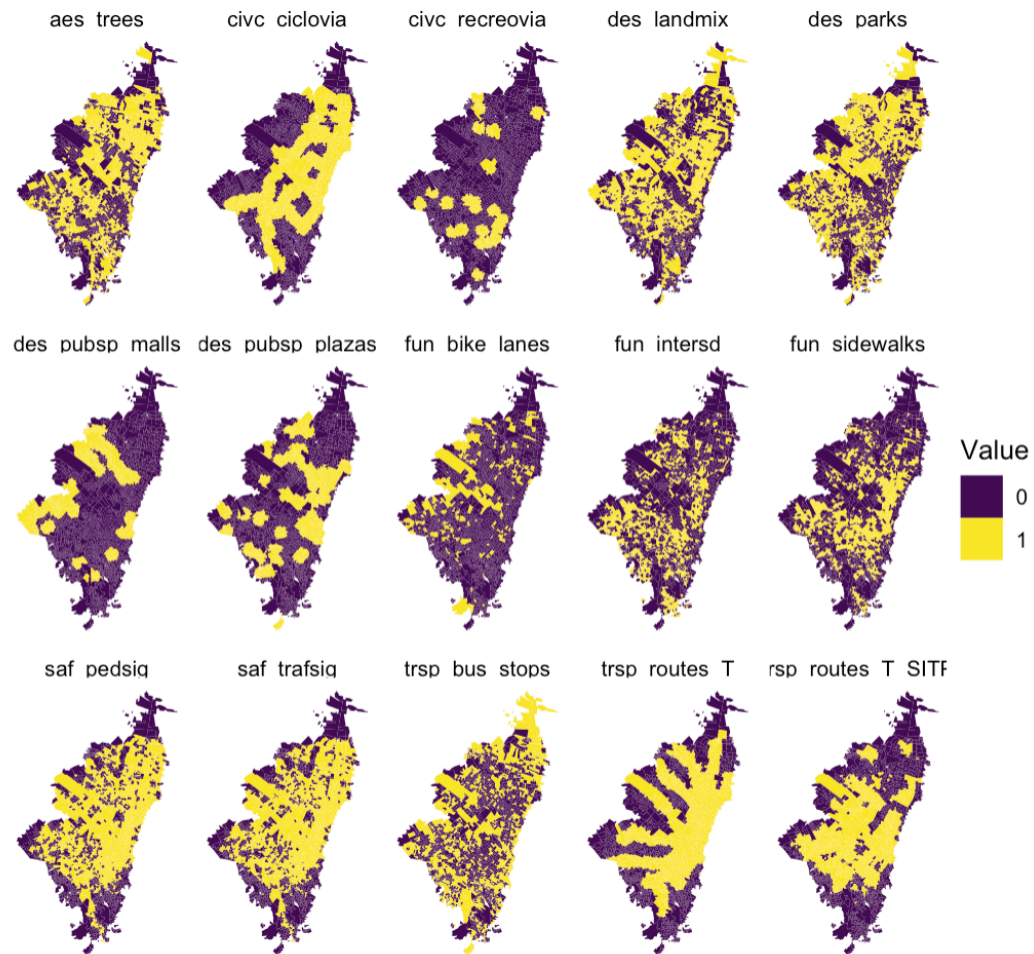


Figure S-2 Caption: Distribution of built environment variables dichotomized at city median (continuous variables) or indicating presence of feature (binary variables)

Figure S-3. LCA model fit statistics: Relative Entropy, Average Maximum Posterior, BIC, AIC

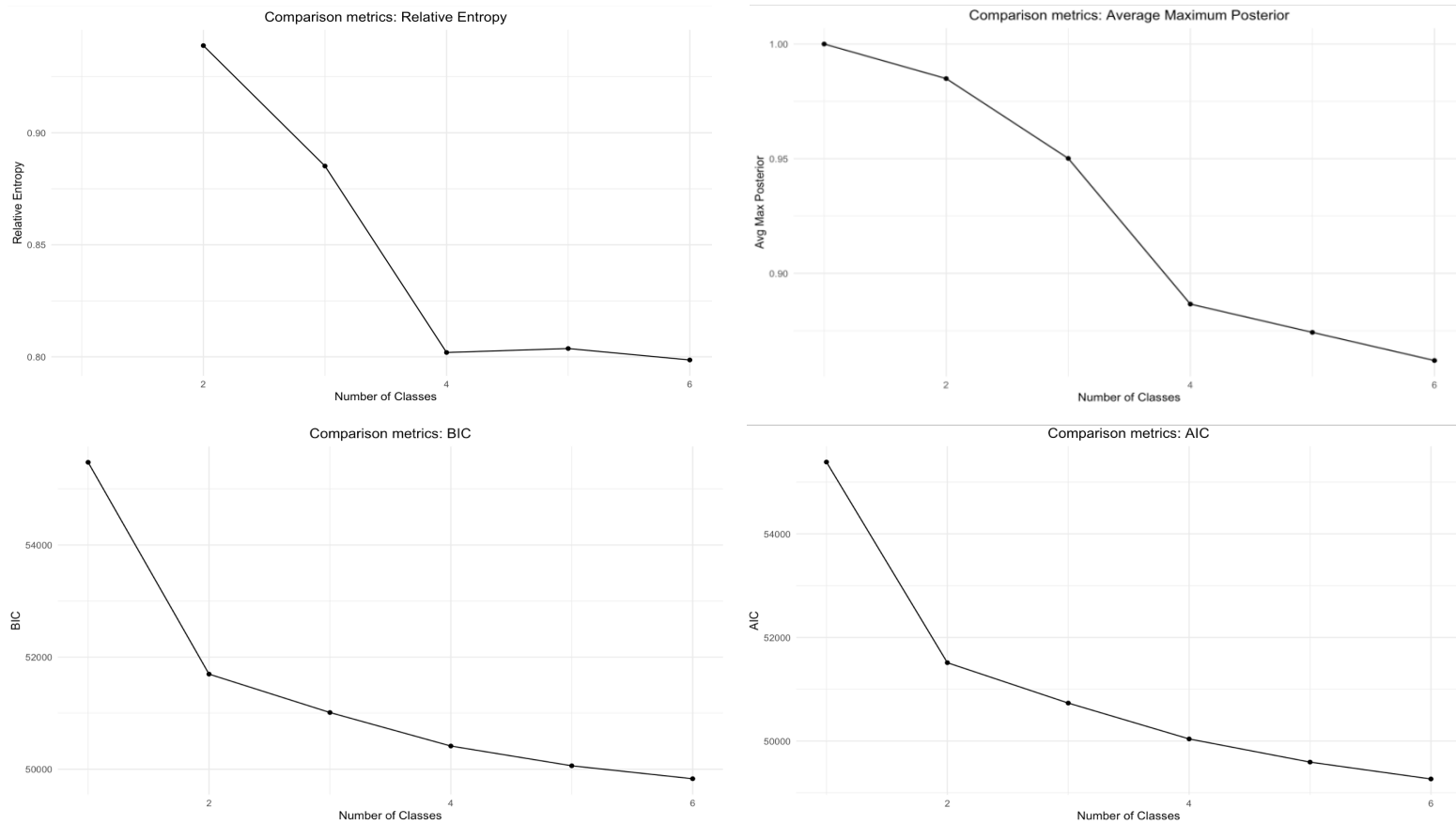


Figure S-3 Caption: Four LCA model fit statistics used to guide model selection for 1:6 class solutions. Optimal model should optimize relative entropy and average maximum posterior metrics and minimize BIC and AIC criterion

Figure S-4. Spatial Distribution of class probabilities ^a

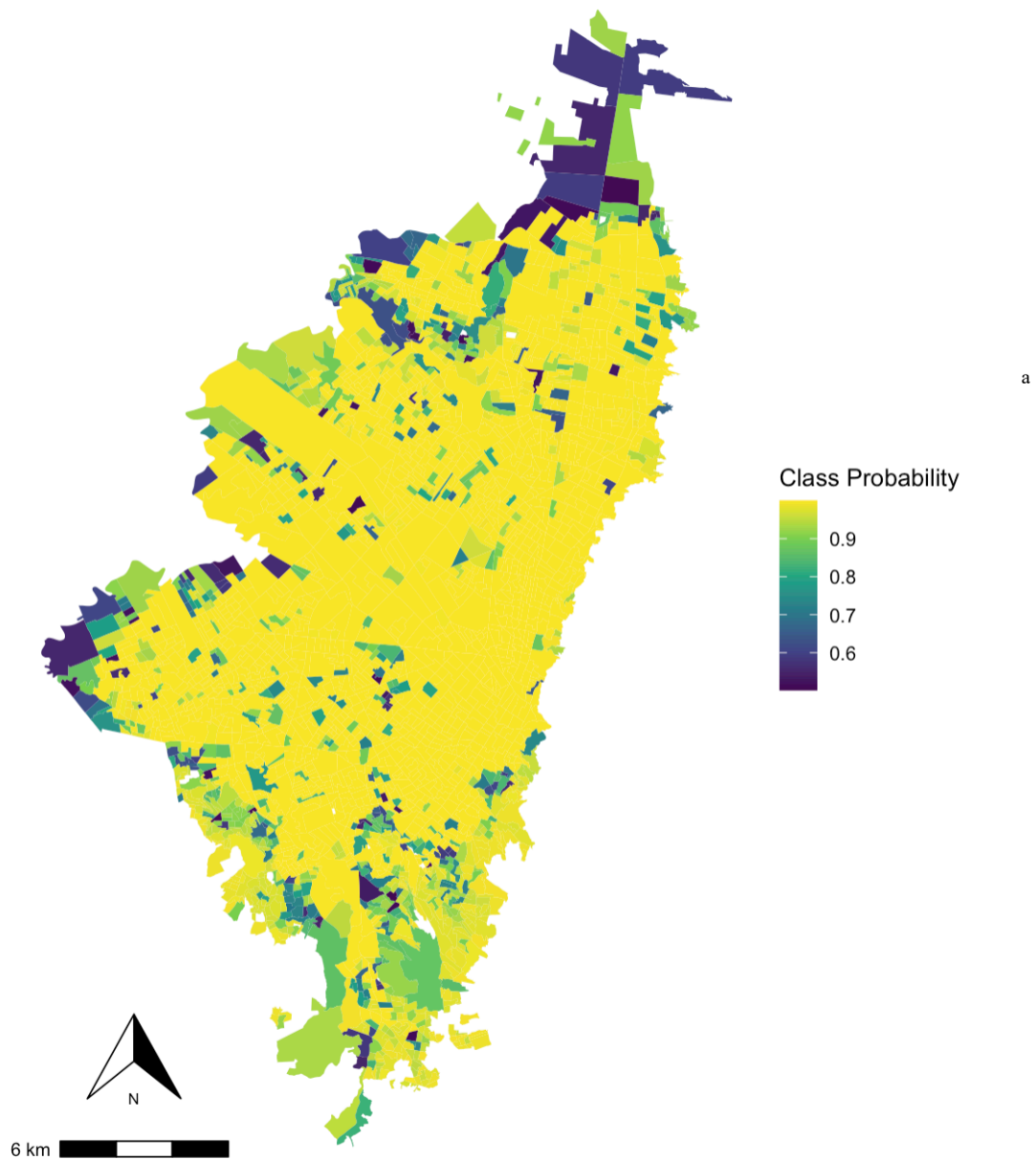


Figure S-4 Caption: Spatial distribution of posterior probabilities estimated from LCA model as an indicator for class separation. The distribution of probabilities is as follows: Min: 0.50, 1st Quartile: 0.96, Median: 0.99, Mean: 0.95, 3rd Quartile: 0.99, Max: 1.00. Class separation is high for most of the city, poorer separation is observed in the peripheries

Figure S-5. Stability of effect estimates across pseudo-class draws ^a

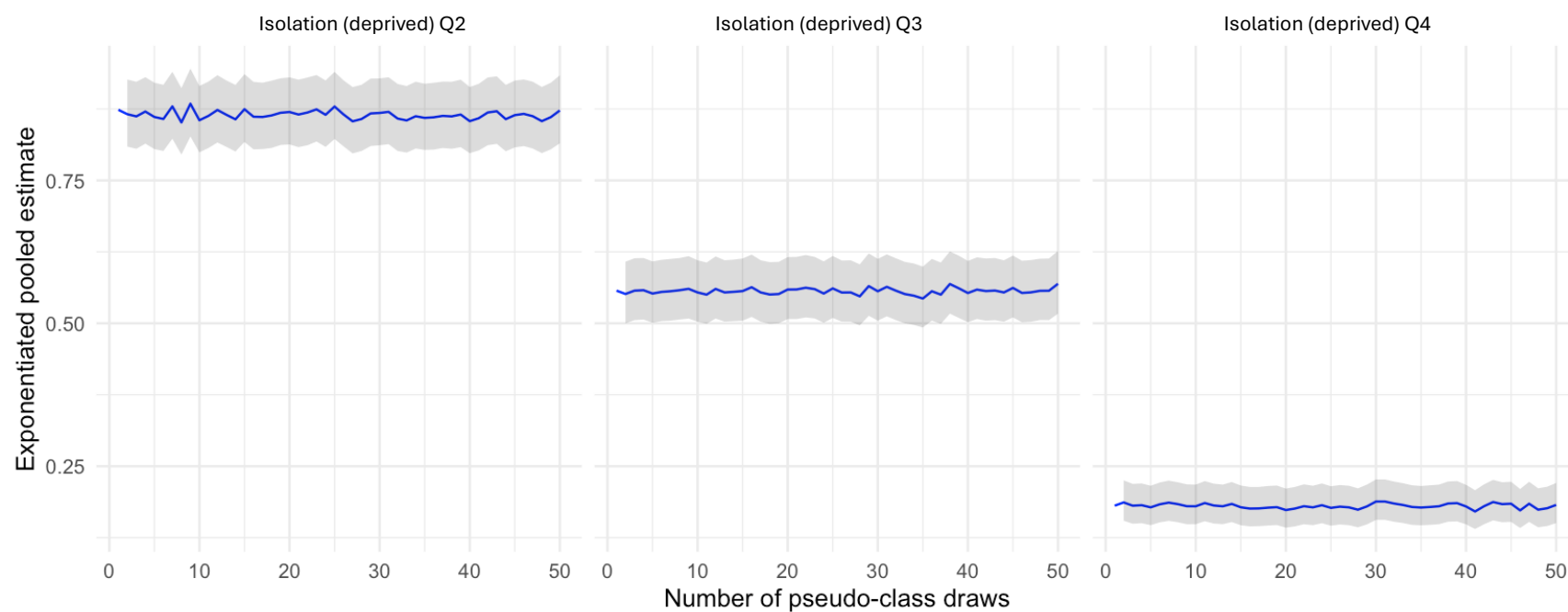


Figure S-5 Caption: Stability of effect estimates across pseudo-class draws for model estimating the association between isolation (deprived quartiles) and active-living promoting neighborhood classification (Class 2 only), with isolation quartile 1 as referent

Table S-2: Comparison of pooled estimated effects across varying spatial weighting approaches for segregation composite count

		Spatial neighbor weighting approach		
		KNN-IDW	IDW	Contiguity
Segregation quartile		Prevalence Ratio (95% CI) ^a		
Dissimilarity				
Q1 (Lowest segregation)		Ref	Ref	Ref
Q2		0.92 (0.85-1.01)	0.94 (0.86-1.03)	0.946 (0.87-1.04)
Q3		0.84 (0.76-0.92)	0.76 (0.68-0.84)	0.77 (0.70-0.86)
Q4 (Highest segregation)		0.52 (0.46-0.56)	0.62 (0.55-0.69)	0.63 (0.57-0.71)
Isolation (Deprived)				
Q1 (Lowest segregation)		Ref	Ref	Ref
Q2		0.87 (0.82-0.93)	0.89 (0.83-0.95)	0.90 (0.84-0.97)
Q3		0.57 (0.52-0.63)	0.56 (0.50-0.61)	0.61 (0.55-0.67)
Q4 (Highest segregation)		0.18 (0.15-0.22)	0.23 (0.20-0.27)	0.23 (0.19-0.27)
Isolation (Non-Deprived)				
Q1 (Lowest segregation)		Ref	Ref	Ref
Q2		1.00 (0.90-1.10)	0.99 (0.89-1.10)	1.19 (1.06-1.33)
Q3		0.92 (0.93-1.02)	1.00 (0.90-1.12)	1.20 (1.07-1.34)
Q4 (Highest segregation)		0.83 (0.75-0.93)	1.02 (0.92-1.13)	1.27 (1.13-1.41)

^a Estimated PR corresponds to probability of a segregated neighborhood being characterized as active living promoting (Class 2: Multi-Domain Active Living Environment only) compared to referent. Estimates pooled over 50 draws.

Chapter 3. Neighborhood built environments, socioeconomic segregation, and active-transport and leisure-based physical activity in Bogotá, CO: A lesson on neighborhood measurement in place-based epidemiologic research in the Global South

Abstract

Introduction: Physical inactivity is a growing concern in cities across the Global South, including Bogotá, Colombia. Neighborhood factors such as the built environment and socioeconomic segregation may shape physical activity, but evidence from Latin America remains limited. This study examines how these neighborhood exposures relate to adult physical activity in Bogotá and whether built environments modify the segregation–activity relationship, with the goal of identifying contexts that reduce socioeconomic disparities in active living in necessity-based physical activity settings.

Methods: We conducted a cross-sectional analysis using data from the 2015 National Nutritional Survey (ENSIN), including International Physical Activity Questionnaire (IPAQ) measures of leisure-time and active transport activity. Built environment typologies were derived from latent class analysis of 15 indicators, classifying census sections into three active living neighborhood types. We measured socioeconomic segregation using spatial dissimilarity and isolation indices based on 2018 census multidimensional poverty data. Associations were estimated using generalized linear models (Gamma for continuous, quasi-Poisson for dichotomous outcomes), adjusting for individual covariates. We tested interactions to assess whether built environments modified the effect of segregation on physical activity.

Results: Residents of socioeconomically isolated, high-deprivation neighborhoods were less likely to meet physical activity recommendations through leisure (PR: 0.78, 95% CI: 0.62–0.99) and more likely to meet them through active transport (PR: 1.08, 95% CI: 0.99–1.16), though the latter association includes the null. Built environment typology was not associated with physical activity across domains, nor did it modify the segregation–activity relationship. Post hoc analyses suggest differential exposure misclassification may contribute these null findings.

Conclusion: We found modest evidence linking socioeconomic segregation with physical activity, but no association with active-living-supportive built environments. Findings may reflect measurement limitations, cross-sectional design, and temporal mismatch. Future research using longitudinal data and spatial methods that capture mobility and lived experience is needed to clarify how neighborhood environments shape necessity-driven physical activity in socioeconomically unequal Global South cities.

1. Introduction

Insufficient physical activity is now among the leading modifiable risk factors for premature morbidity and mortality worldwide.^{65,154} The burden of physical inactivity, and by extension, inactivity-related non-communicable diseases (NCDs), is increasingly concentrated in the Global South, where an estimated 74% of all new NCD cases linked to physical inactivity are expected to occur between 2020 and 2030.¹⁵⁵ This epidemiological shift is occurring alongside structural changes to urban environments in the Global South, including rapid urbanization and development, and shifts in transportation and labor practices, that are reducing utilitarian forms of physical activity, which have historically dominated physical activity patterns in these settings.^{39,41,156,157}

Given these trends, identifying scalable and sustainable strategies to promote and sustain physical activity in Global South cities is a public health priority. A particular challenge is ensuring that populations continue to choose physically active options, such as walking, cycling, and recreational movement, even as motorized transport and sedentary occupations become more accessible. Research that demonstrates how urban environments can be shaped to support voluntary, rather than necessity-driven, physical activity is especially timely.^{39,154}

Neighborhood environments are a promising intervention point. A significant body of research, primarily from Global North countries, has documented the influence of the built environment, such as street connectivity, access to parks, and public transit, on physical activity behaviors.^{2,64,158,159} However, relatively little attention has been paid to how these associations may differ in Global South contexts, particularly in Latin America, where environmental and social conditions are distinct. These cities are often characterized by wide economic inequalities,^{22,45} social fragmentation,^{123,160} and uneven infrastructure development,¹³¹ all of which may influence both the availability and the accessibility of health-promoting environmental features.

In particular, socioeconomic segregation, the non-random spatial patterning of populations on the basis socioeconomic status, is a defining feature of urban development in many Global South cities, particularly in Latin America,^{21,22,123} and may play a critical but understudied role in shaping physical activity patterns. Residential segregation can limit access to safe, high-quality infrastructure for physical activity, either by constraining where such features are located or by shaping the perceived or actual ability of residents to use them. While some studies suggest that segregation is linked to disparities in access to neighborhood services,^{22,76,78} the potential consequences for physical activity have not been adequately tested.

This knowledge gap is especially relevant in fast-growing cities such as Bogotá, Colombia, where urban growth, income inequality, and policy windows for health-centered urban

development are converging. Bogotá has been internationally recognized for pioneering active transportation and inclusive mobility initiatives that have since been replicated globally. These include Ciclorutas de Bogotá, the most extensive bicycle path network in Latin America;⁹³ Ciclovías, the world's largest open-streets program;^{93,94} the TransMilenio, a high-capacity bus rapid transit (BRT) system;^{89,90} and TransMiCable, a cable car linking peripheral, mountainside neighborhoods to mass transit services.⁹² Despite these advances and the city's clear potential to support active living, achieving recommended physical activity levels remains a persistent challenge. Recent national health surveys indicate that more than half of Colombian adults and approximately 75% of youth do not meet physical activity guidelines.^{161,162}

These challenges are paralleled by the city's rapid and uneven urban development. Residential patterns marked by spatial concentration of low-income populations, driven in part by informal settlements, housing policies, and land market dynamics, have resulted in unequal distribution of urban resources and health-promoting infrastructure.^{22,45,163,164} Bogotá's experiences exemplify broader concerns facing many Global South cities undergoing similar processes of urbanization and social fragmentation. As these cities continue to grow, ensuring equitable access to environments that support physical activity will be critical. Investigating Bogotá, therefore, offers a timely and informative lens through which to understand how neighborhood environments, comprised of both built and social domains, can be leveraged to promote active living and health equity in Global South urban contexts.

Given the urgent need for context-specific evidence to inform equitable urban planning in Global South cities, this study explores the relationship between two neighborhood exposures, socioeconomic segregation and active-living-promoting built environments, and physical activity among adults in Bogotá. We further examine whether active-living-promoting built environments modify the association between socioeconomic segregation and physical activity outcomes, with the aim of identifying neighborhood contexts that may reduce socioeconomic disparities in physical activity in Global South urban settings.

2. Methods

2.1. Neighborhood exposures:

2.1.1 Built Environment Typology:

The development of the built environment typology is explained in detailed elsewhere. In brief, we used latent class analysis to categorize built environment types in Bogotá. Using model fit criteria (AIC, BIC, entropy, average maximum posterior), in combination with subjective interpretability and class size, we selected a 3-class model, applied to 15 built environment variables measured at or near 2018 (**Table S-1**) to identify three neighborhood built environment classes that characterized all census sections in Bogotá. These 15 variables were sourced from publicly available geospatial data from Bogotá's District Department of Planning (*Spanish*:

Secretaría Distrital de Planeación), Spatial Data Infrastructure for the Capital District Department (*Spanish*: Infraestructura de Datos Espaciales para el Distrito Capital, IDECA), District Institute of Recreation and Sport (*Spanish*: Instituto Distrital de Recreación y Deporte), and from a database of built environment features identified using machine learning algorithms applied to Google Street View panoramic images of Bogotá's street network.^{104,105}

The built environment classes were as follows: Class 1: *Amenity- and Traffic Signal-Limited Active Living Environment*, Class 2: *Multi-Domain Active Living environment*, Class 3: *Amenity-Rich but Traffic Signal-Limited Active Living Environment*. These names were chosen to describe the distribution of built environment characteristics within each class. Specifically, Class 1 neighborhoods (*Amenity- and Traffic Signal-Limited Active Living Environment*), comprised of neighborhoods with basic built environment features, like parks and bus stops, but lacked other active-living supporting features like public squares and plazas, recreational programs, and traffic signals. Class 2 neighborhoods (*Multi-Domain Active Living Environment*) comprised of higher density of nearly all active living promoting built environment features. Class 3 neighborhoods (*Amenity-Rich but Traffic Signal-Limited Active Living Environment*), like Class 2, comprised of higher density of nearly all active-living promoting built environment features, however lacked traffic signaling features.

Survey respondents were assigned the built environment type that characterized the census section of their residence using modal assignment.

2.1.2 Residential socioeconomic segregation:

We use the local spatial dissimilarity and isolation indices, calculated using the multidimensional poverty measure from the 2018 Colombian census. In brief, this is a poverty measure provided by Colombia's national statistical agency (*Spanish*: Departamento Administrativo Nacional de Estadística) that characterizes household poverty status using 15 indicators across five domains: education, children & youth, employment, health, and housing & public services. Households are characterized as socioeconomically deprived if they are deprived in five or more of the indicators. We used this measure to develop three segregation measures for all census sections in Bogotá: Socioeconomically deprived-non-deprived dissimilarity, deprived isolation, non-deprived isolation. These segregation indices were chosen based on prior application of these measures to evaluate the exposure and evenness dimensions of residential segregation, respectively, in Latin American cities, including Bogotá.^{21,22,48,51} We employ local and spatial versions of the measures to measure within-city segregation variation and better approximate social interaction by using composite counts (i.e., includes spatial neighbors).^{98–100}

Local spatial dissimilarity was calculated as follows:

$$SD_i = \left| \frac{cg1_i}{CG1} - \frac{cg2_i}{CG2} \right|$$

Where $cg1_i$ and $cg2_i$ represent the composite counts of socioeconomically deprived and non-deprived households in tract i , respectively, and $CG1$ and $CG2$ denote the composite counts of these groups in the city. The measure quantifies the extent to which the composition of socioeconomically deprived and non-deprived households in a given section (and its spatial neighbors) deviates from the overall city composition. Values range from 0-1, where values closer to 0 indicate alignment between a neighborhood's socioeconomic composition and the city's and values closer to 1 indicate dissimilarity of the neighborhood's socioeconomic composition and the city's.

Local spatial isolation was calculated as follows:

$$SI_i = \frac{cg1_i}{G1} * \frac{cg1_i}{ct_i}$$

Where ct_i corresponds to the composite population count in tract i , and $G1$ the total count of deprived or non-deprived households in the city. The isolation measure for deprived populations quantifies the extent to which socioeconomically deprived individuals in a given section (and its neighbors) are isolated from non-deprived individuals in the city, whereas the isolation measure for non-deprived individuals quantifies the reciprocal relationship. This measure also ranges from 0-1, where higher values indicate greater isolation, meaning individuals are more surrounded by others from the same group rather than a mix of individuals from both socioeconomic groups.

Survey respondents were assigned the segregation values of their residential census section.

2.2 Active living outcomes

Leisure-based physical activity and transport-based physical activity were primary outcomes of this study. These data were collected using the 2015 National Survey of Nutritional Situation (Encuesta Nacional de Situación Nutricional; ENSIN). ENSIN is administered every 5 years to track changes and trends in nutritional health and related outcomes over time across non-institutionalized adults and children in Colombia. The survey leverages a multistage sampling approach to obtain a representative sample of households for the six regions in Colombia, including Bogotá D.C. The survey contains a battery of questions regarding housing conditions, socioeconomic conditions, family composition and characteristics, education, economic activity, and health. To minimize survey burden and maximize information from sampled households, nested probabilistic subsamples were used to determine individuals to survey for specific modules, including the physical activity module. Subsample selection probabilities are based on region and age group to ensure that each module remains representative of the broader population.

Leisure-based and active transport-based physical activity were measured in ENSIN using the International Physical Activity Questionnaire (IPAQ), a questionnaire to assess physical activity across countries, including Colombia.^{165,166} For this study, we defined six physical activity outcomes that are commonly reported in physical activity studies. The first set includes continuous measures: (1) total minutes per week of active transport physical activity (i.e., walking and/or bicycling), (2) total minutes per week of leisure-time physical activity (i.e., walking for leisure and/or moderate to vigorous physical activity), and (3) total minutes per week combining both domains (i.e., active transport plus leisure-time physical activity). The second set of outcomes includes dichotomous indicators of whether participants met the global recommendation of at least 150 minutes of physical activity per week, both by domain and in total. We used one overall indicator for meeting this threshold through any combination of leisure and transport-based activity, and two additional indicators to distinguish how participants met the recommendation—specifically, whether they did so primarily ($\geq 75\%$ of weekly minutes) through leisure-time or through active transport physical activity.

2.3 Statistical analysis

To examine the main effects of neighborhood socioeconomic segregation and built environment typology on continuous physical activity outcomes, we fit generalized linear models (GLMs) with a log link and Gamma distribution. For segregation main effects models, Gamma GLMs were used to estimate relative differences (percent change) and corresponding 95% confidence intervals in continuous physical activity outcomes per one standard deviation difference in the segregation measure. Percent changes were derived by exponentiating parameter estimates. For built environment models, we estimated percent change in physical activity outcomes, and corresponding 95% confidence intervals, for individuals living in active-living-promoting neighborhoods. We defined these neighborhoods in two ways: first, as living in Class 2 versus not (i.e., Class 1 and 3), and second, more conservatively, as living in either Class 2 or Class 3 versus not (i.e., Class 1). Gamma models were selected due to the positively skewed distribution of the continuous physical activity outcomes. Compared to linear models with log-transformed outcomes, the Gamma GLM with a log link provides estimates on the original outcome scale and avoids bias introduced by re-transforming log-transformed outcomes.^{167,168}

For dichotomized physical activity outcomes, we used quasi-Poisson models with robust standard errors to directly estimate prevalence ratios and 95% confidence intervals. Exposures were operationalized in the same manner as in the continuous models.

To investigate whether active-living-promoting built environments modify the association between neighborhood socioeconomic segregation and physical activity, we tested multiplicative interaction terms between each segregation measure and built environment typology in models of continuous physical activity. Given that our prior work found neighborhood socioeconomic

segregation to be strongly associated with classification as an active-living-promoting environment, we used the more inclusive definition (i.e., Class 2 and 3) of such environments to ensure sufficient sample size within the joint exposure categories. Interaction terms were included based on *a priori* hypotheses that the relationship between neighborhood socioeconomic segregation and physical activity may vary depending on the built environment context. This approach allowed us to assess potential effect modification by economic conditions that may be masked in the estimation of overall associations between built environments and physical activity. Model-predicted values were generated to visualize any observed interaction effects.

All regression models were adjusted for respondent age and sex. We considered including random effects for census sections to account for the multilevel nature of covariates; however, intraclass correlation coefficients showed little variation between census units, so we did not use multilevel models. Survey weights were applied to generate representative descriptive statistics but were not incorporated into regression models. Because current R packages do not support Gamma GLM models with survey weights, and given the similarity in parameter estimates between weighted and unweighted models (**Figure S-1**), suggesting the models were reasonably specified and that weighted estimation may be unnecessary,¹⁶⁹ we elected to use unweighted models for the primary analysis.

2.4 *Post hoc analyses*

Post hoc analyses were conducted to further interpret findings from the primary analyses. Specifically, we examined responses to individual-level survey items in ENSIN to contextualize observed neighborhood–physical activity associations and understand potential discrepancies between objectively-measured and subjectively-measured neighborhood environments.

We assessed the association between three additional self-reported items, capturing perceptions and use of neighborhood built environment features, and continuous physical activity outcomes. The items were: “In the last month, have you participated in recreation classes?”; “In the last month, have you participated in Ciclovía or Active Routes?”; “Are there parks, green areas, recreational centers, or sports centers in your neighborhood?” We used Gamma GLMs to test for relative differences in physical activity based on self-reported access to or use of these amenities.

Initial results from these analyses suggested potential measurement differences between investigator-assigned exposure classifications and self-reported exposure, which may vary by external factors. To explore this further, we tested whether the probability of disagreement between perceived and measured access to amenities differed by neighborhood socioeconomic segregation using robust quasi-Poisson models.

All analyses were conducted in R. IRB approval was received by Universidad de los Andes in Bogotá (ACTA DE EVALUACIÓN N 2023103127).

3 Results

Of the 1322 survey respondents, 1278 (97%) were included in the analytic sample, and lived across 295 unique Census sections (Min = 1, Median = 6, Max = 17; captures 11% of Census sections in Bogotá). Twenty-nine participants were missing the number of days of activity and therefore weekly minutes could not be calculated for these participants, and 15 lived in sections that were not included in the built environment typology.

Of the 1,278 respondents, 57% were female, and about evenly distributed across age groups, with a slightly lower proportion aged 50–64 years (24.5%; **Table 1**). After applying survey weights, 57.5% of the population met weekly physical activity recommendations based on total active time (i.e., active transport and leisure-time physical activity). Among those, more respondents met weekly physical activity recommendations primarily ($\geq 75\%$) through active transport (25.9%) than through leisure-based activity (13.4%). Nearly half of the population (49.6%) resided in Class 2: *Multi-Domain Active-Living Environment* neighborhoods, and most lived in areas falling within the higher quartiles of Dissimilarity and Isolation (non-deprived) segregation measures.

3.1 *Neighborhood exposures and total weekly minutes of physical activity*

In models treating physical activity as a continuous outcome, living in active-living promoting built environments (defined as either Class 2 only or Class 2 and 3) was not associated with weekly minutes of physical activity across all physical activity domains when compared to not (**Figure 1**).

For neighborhood socioeconomic segregation measures, we found a negative association between isolation (no deprivation) and all domains of physical activity, however these associations were not statistically significant: Percent Change Active Transport: 0.93 (95% CI: 0.85-1.02); Percent Change Leisure: 0.91 (95% CI: 0.79-1.06); Total Percent Change: 0.92 (95% CI: 0.85-1.00). Similar to dichotomous models, a negative association between isolation (deprivation) and leisure-based physical activity, and a positive association between isolation (deprivation) and transport-based physical activity was seen, but confidence intervals included the null. We did not find evidence showing an association between dissimilarity and weekly physical activity across any of the physical activity domains.

2.1 *Neighborhood exposures and meeting physical activity recommendations*

Main effects models did not show evidence of a cross-sectional association between the built environment typology and physical activity domains (**Figure 2**). Living in Class 2: *Multi-Domain Active-Living Environment* (versus not) was not associated with meeting weekly physical activity recommendations (Total: 0.95, 95% CI: 0.85-1.05; Primarily met through leisure: 1.19, 95% CI: 0.81-1.75; Primarily met through active transport: 0.88, 95% CI: 0.73-

Table 1. Descriptive characteristics of study sample

Characteristics	Sample N = 1,278 N, (unweighted %)	Population-weighted %
Female	739 (57.8)	54.5
Age group		
18-29	449 (35.1)	28.9
30-49	515 (30.3)	39.2
50-64	314 (24.5)	31.9
Meet weekly recommendations (150 min/week)		
Total	743 (58.1)	57.5
Primarily: Active Transport ^a	378 (29.6)	25.9
Primarily: Leisure ^a	105 (8.2)	13.4
Built Environment Typology ^b		
Class 1	289 (22.3)	11.5
Class 2	412 (32.2)	49.6
Class 3	577 (45.1)	38.8
Segregation Quartile		
Dissimilarity		
Quartile 1	307 (24.0)	17.2
Quartile 2	283 (22.1)	22.1
Quartile 3	260 (20.3)	34.5
Quartile 4	428 (33.5)	26.2
Isolation (Deprivation)		
Quartile 1	71 (5.6)	23.3
Quartile 2	268 (21.0)	23.4
Quartile 3	411 (32.2)	25.6
Quartile 4	527 (41.2)	27.2
Isolation (No Deprivation)		
Quartile 1	137 (10.7)	11.1
Quartile 2	213 (16.7)	17.2
Quartile 3	371 (29.0)	35.3
Quartile 4	557 (43.6)	36.2

^a Indicators to distinguish how respondents met the weekly recommendation, i.e., whether they did so primarily ($\geq 75\%$ of weekly minutes) through leisure-time or through active transport physical activity.

^b Neighborhood built environment classes are defined as follows: Class 1: Amenity- and Traffic Signal-Limited Active Living Environment, Class 2: Multi-Domain Active Living environment, Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment

Figure 1. Associations between neighborhood exposures and continuous physical activity outcomes expressed as percent change, 2015 National Survey of Nutritional Situation (Encuesta Nacional de Situación Nutricional; ENSIN)

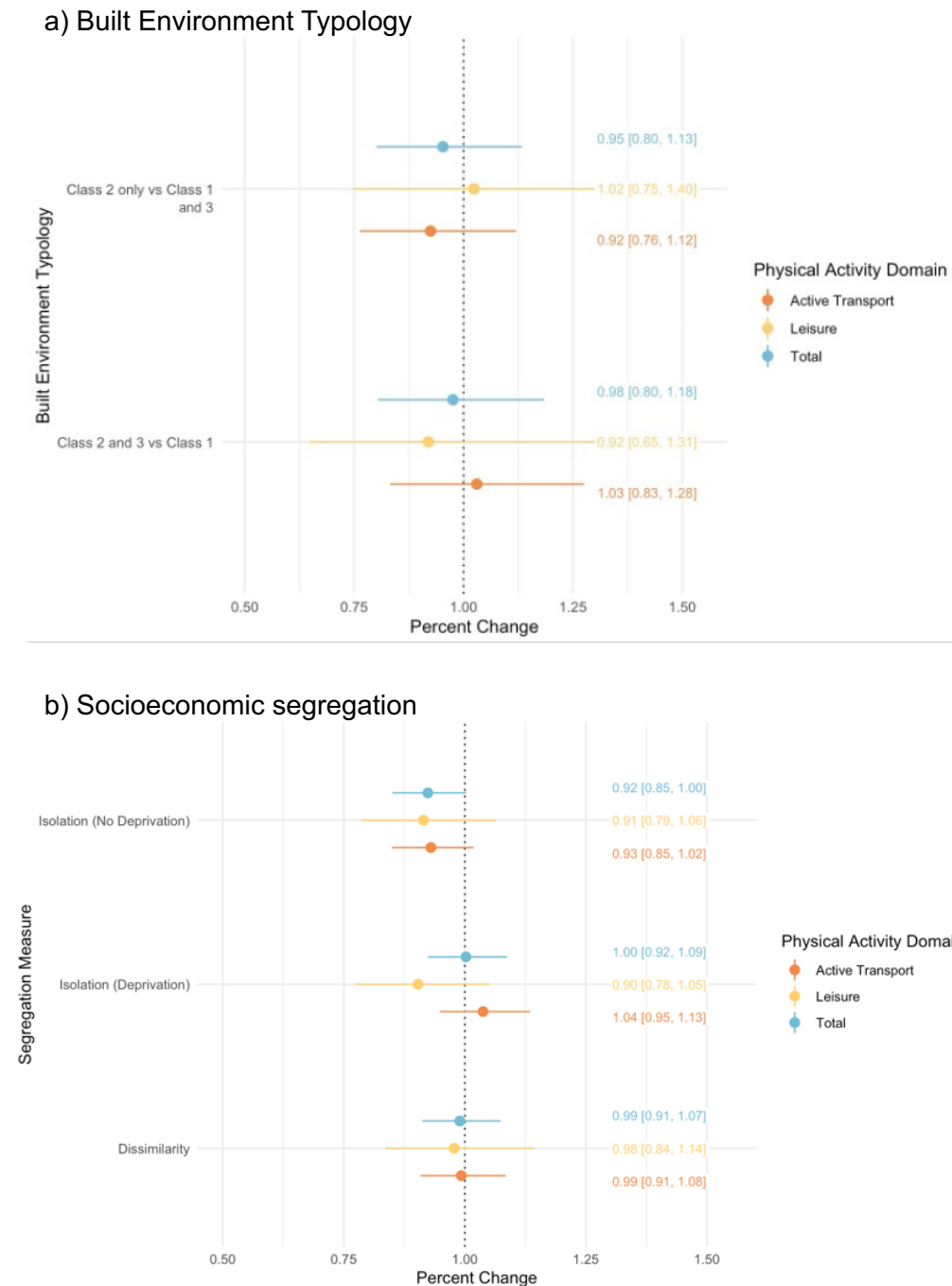


Figure 1 caption: Neighborhood built environment classes are defined as follows: Class 1: Amenity- and Traffic Signal-Limited Active Living Environment, Class 2: Multi-Domain Active Living environment, Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment.

1.06;). Similarly, we did not find a significant association between living in an active-living supporting built environment and physical activity recommendations when using a more conservative definition (active-living supporting defined as both Class 2 and Class 3: *Amenity-Rich but Traffic Signal-Limited Active Living Environment* characterized neighborhoods).

We did not find evidence of an association between neighborhood socioeconomic segregation measures and meeting physical activity recommendations overall, but some evidence of an association when sub-setting by dominating physical activity mode (**Figure 2**). Residents of more isolated neighborhoods, in terms of deprivation, were less likely to meet weekly physical activity recommendations primarily through leisure-based physical activity (PR: 0.78, 95% CI: 0.62-0.99), and more likely to meet recommendations primarily through active-transport (PR: 1.08, 95% CI: 0.99-1.16), though the latter estimate includes the null. We did not see significant associations with dissimilarity of non-deprived isolation.

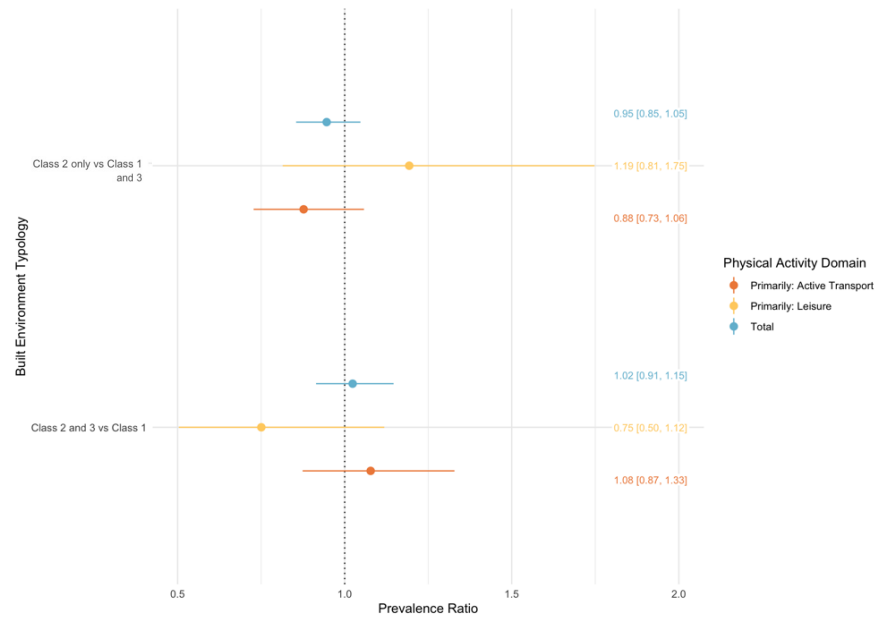
2.2 Effect measure modification by the built environment

Predicted values from models testing for effect measure modification of the association between neighborhood socioeconomic segregation and physical activity by active-living-promoting built environments are presented in **Figure 3**. Intersecting slopes suggest potential interaction between the two neighborhood exposures and physical activity for all segregation measures in relation to leisure-based physical activity, as well as for spatial dissimilarity and spatial isolation (no deprivation) in relation to active transport.

For leisure-based physical activity, the models suggest that individuals living in more segregated neighborhoods that are also active-living-promoting engaged in more leisure-based physical activity compared to those in similarly segregated neighborhoods that are not active-living-promoting. For active transport, however, greater segregation (as measured by dissimilarity) and living in active-living-promoting environments was associated with fewer minutes of active-transport physical activity. In contrast, when segregation is more clearly defined in terms of which group is divergent (i.e., isolation-no deprivation), living in more segregated and active-living-promoting neighborhoods was associated with more minutes of active-transport-related physical activity. Despite the visual suggestion of interaction based on intersecting slopes, none of the interaction coefficients were statistically significantly non-zero at $\alpha = 0.05$.

Figure 2. Associations between neighborhood exposures and meeting physical activity recommendations expressed as prevalence ratios, 2015 National Survey of Nutritional Situation (Encuesta Nacional de Situación Nutricional; ENSIN)

a) Built Environment Typology



b) Socioeconomic segregation

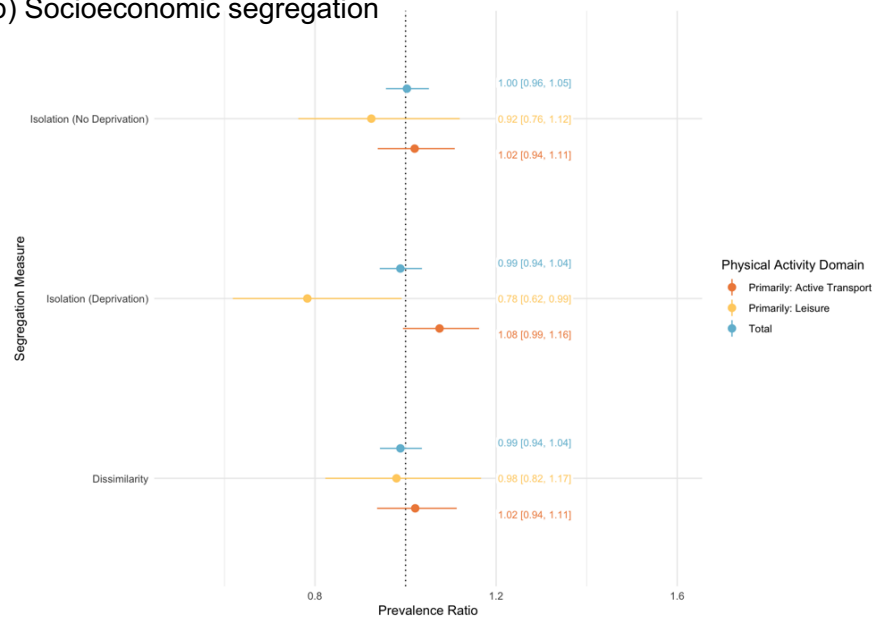


Figure 2 caption: Neighborhood built environment classes are defined as follows: Class 1: Amenity- and Traffic Signal-Limited Active Living Environment, Class 2: Multi-Domain Active

Living environment, Class 3: Amenity-Rich but Traffic Signal-Limited Active Living Environment.

Figure 3. Predicted values to depict potential effect measure modification by active-living promoting built environment for the association between segregation and physical activity

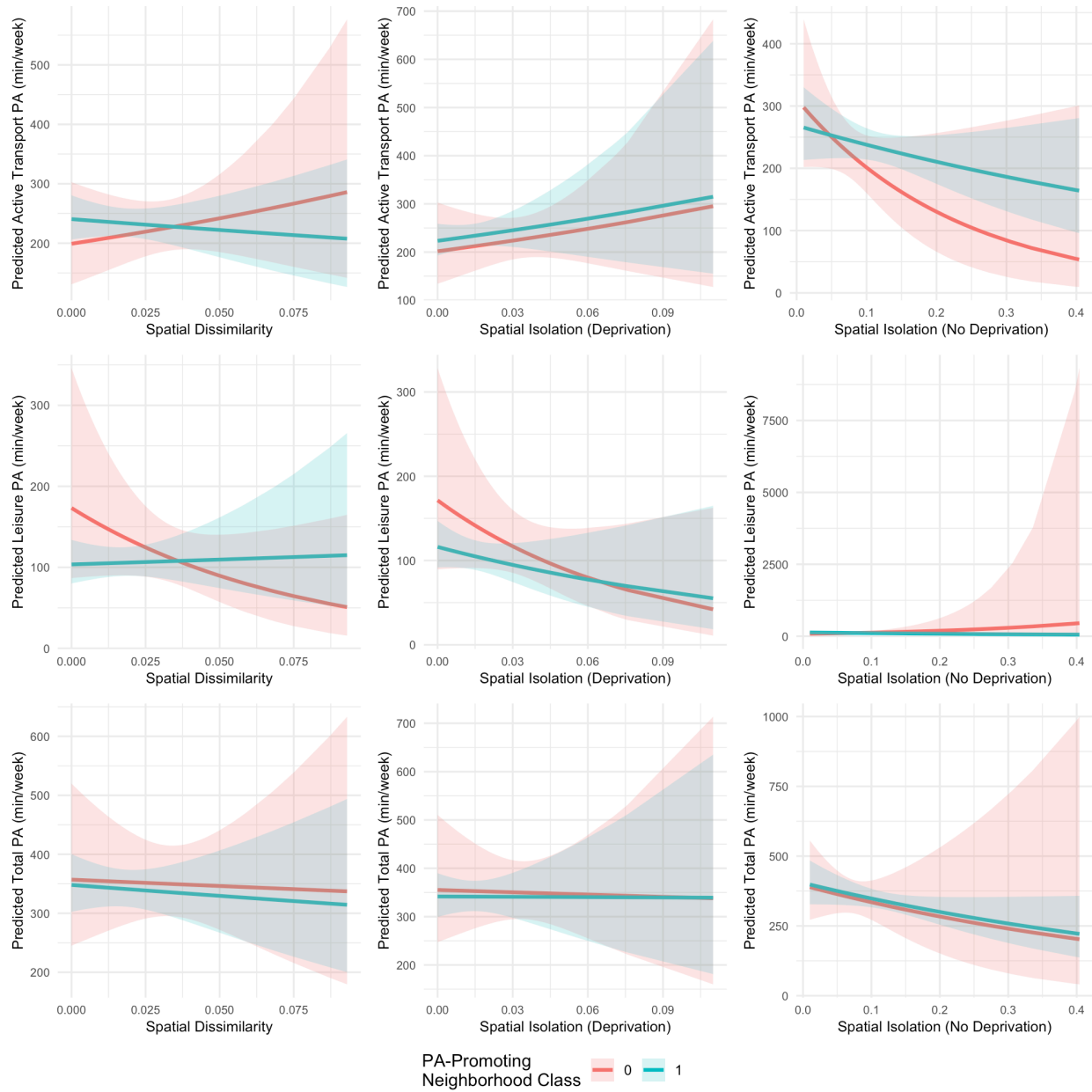


Figure 3 caption: Plots display predicted values for Gamma GLMs testing for the multiplicative interaction between socioeconomic segregation and active-living promoting built environments (defined as Class 2 and 3 neighborhood built environment types).

Figure 4. Post hoc analysis examining socioeconomic segregation as a predictor of discrepancies between investigator-assigned and perceived access to built environment amenities

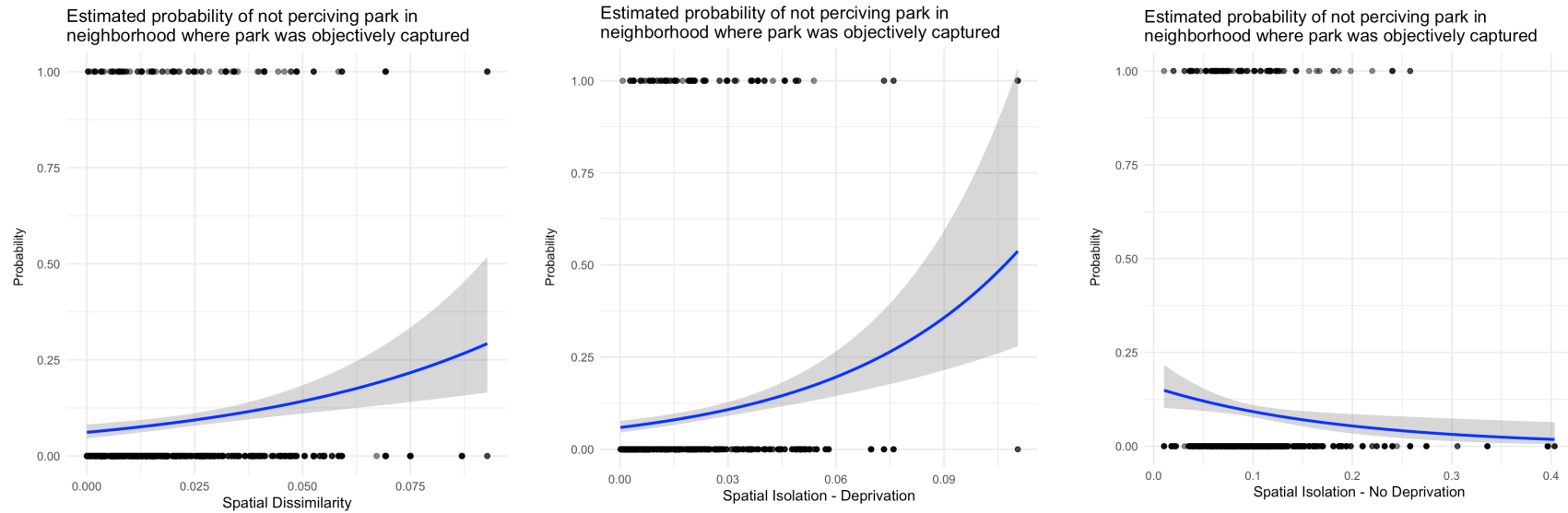


Figure 4 caption: Plots display predicted values for Quasi-Poisson models estimating the probability of a respondent reporting not perceiving a park in their neighborhood when a park was objectively captured using investigator-driven/GIS exposure definitions across values of socioeconomic segregation.

2.3 *Post hoc analysis*

Subsequent models comparing investigator-assigned with perceived access to individual built environment features and its association with physical activity outcomes are shown in **Figure S-2**. Congruent with main findings, investigator-assigned access of individual built environment features was not significantly associated with physical activity outcomes. Perceived access to these features, however, was associated with physical activity domains. Respondents participating in recreation classes in the last month completed on average 57% higher weekly minutes of leisure-based physical activity compared to respondents who did not participate (Percent Change: 1.57, 95% CI: 1.05-2.37). Perceived access to parks and green areas was also associated with higher weekly minutes of leisure-based physical activity (Percent Change: 1.67, 95% CI: 1.08-2.58). Respondents who reported participating in Ciclovía reported on average higher weekly minutes of physical activity across all domains compared to those who did not: Percent Change Active Transport: 1.51, 95% CI: 1.12-2.05; Percent Change Leisure: 2.06, 95% CI: 1.25-3.39; Percent Change Total: 1.69, 95% CI: 1.29-2.23).

The discrepancy in the perception of built environment amenities and investigator-defined access to these features was explored further. Among residents of neighborhoods with investigator-identified parks, we found differences in perceptions of access based on the magnitude of socioeconomic segregation (**Figure 4**). Specifically, individuals in more socioeconomically isolated (deprived) neighborhoods were more likely to *not* perceive a park or green area in their neighborhood despite one being objectively present in their census section (PR: 1.40, 95% CI: 1.23-1.59). In contrast, those in more socioeconomically isolated but non-deprived neighborhoods were less likely to lack awareness of a nearby park (PR: 0.74, 95% CI: 0.59-0.92).

3 Discussion

Our study investigated the link between socioeconomic segregation and active-living promoting built environments, and both active-transport and leisure-based physical activity among adults in Bogotá. We also tested whether active-living-promoting environments modify the association between segregation and physical activity, aiming to build evidence on contextual factors that may reduce socioeconomic disparities in physical activity. In this cross-sectional analysis, we found modest evidence linking socioeconomic segregation with physical activity, but no association with active-living-supportive built environments. Tests for multiplicative interaction did not support the hypothesis that active-living-promoting built environments mitigate neighborhood-level socioeconomic disparities in physical activity.

Our findings align with a growing body of research suggesting that the influence of neighborhood environments on physical activity in necessity-based contexts differs from what is

observed in choice-based settings.^{65,170} Elshahat et al.'s review of built environment correlates of physical activity in low- and middle-income countries (LMICs) found that features commonly associated with higher physical activity in high-income contexts, such as mixed land use, park density, and street connectivity, were either not associated or inconsistently associated with activity levels across LMICs.⁶⁵ Similarly, Adkins et al. found that among individuals with low socioeconomic status (SES), built environment features had weaker or inverse associations with physical activity compared to higher-SES groups.¹⁷⁰ Adkins et al. propose that these differences may arise from disadvantaged groups being less able to take advantage of the activity-related benefits of their built environments—a framing that may also help interpret built environment–physical activity relationships in Global South cities, where similar necessity-driven models shape physical activity behavior.

Our post-hoc analysis provides empirical support for this hypothesis by highlighting the role of the social environment in shaping the “uptake” of built environment resources. Specifically, our findings suggest a potential mismatch between investigator-defined measure of neighborhood exposures and resident’s perceptions of these characteristics, moderated by socioeconomic segregation. We found that residents in socioeconomically isolated neighborhoods, as defined by deprivation, were less likely to report having a park nearby even when objective measurement of park using geospatial data indicated otherwise. Conversely, in wealthier socioeconomically isolated neighborhoods the opposite pattern emerged. This suggests structural factors, like segregation, may shape the ways through which individuals move about their environment, resulting in differential effects of the built environment in necessity-based contexts. In other words, access and exposure to neighborhood environments is socially constructed, and shaped by a range of factors that may be spatialized differently across unequal and segregated contexts like Bogotá.

These findings reinforce a longstanding critique of place and health research: that administrative units are often poor proxies of the lived experiences of neighborhoods.^{171–175} While this concern is not new, our study provides renewed attention to the limitations of the reliance on administrative units for place-based research in the unequal cities of the Global South in particular, where little attention to these measurement differences has been given. In settings characterized by high levels of inequality and social fragmentation, reliance on proximity-based definitions of environmental exposure may result in inaccurate or incomplete conclusions. The presence of a neighborhood feature within a defined spatial unit does not necessarily indicate that it is socially or functionally accessible to all residents, particularly in areas with socio-spatial disparities. Future research incorporating mixed-methods approaches, such as participatory mapping and citizen science,^{176,177} and activity space frameworks that account for individual mobility and patterns of daily movement may better reflect residents’ lived experiences.^{178,179}

This consideration is particularly relevant given the growing availability of objective built environment data, especially in the Global South, made possible through advances in geospatial

technologies, such as the use of Google Street View imagery and machine learning techniques to identify environmental features at scale and with high spatial resolution.^{105,180} While these tools offer important opportunities to characterize urban form and infrastructure, particularly in Global South settings, their application requires careful consideration of whether the features identified objectively correspond to how residents perceive and interact with their surroundings. Objective measures typically assess proximity, for example, the physical distance to a park or transit stop, whereas subjective measures capture perceived access, including whether individuals feel they can safely or meaningfully use a facility. Both proximity and perception are necessary components of actual use, and discrepancies between them may reflect deeper structural issues such as social exclusion. Future research aiming to leverage these technologies to investigate contextual drivers of physical activity disparities and other health outcomes should consider and attempt to account for potential discrepancies between objectively and subjectively measured environments, to avoid potentially masking important social patterning in health behaviors and outcomes.

Our findings also offer a cautionary tale on the importance residential selection processes, specifically residential self-selection bias—when individuals choose their residential environments based on characteristics related to the outcome of interest, in this case physical activity.^{181–183} Due to the cross-sectional nature of this study and the absence of data on residential histories or motivations for neighborhood choice, we were unable to assess these processes directly, however these processes at a contextual level may have also contributed to null interaction findings.

More specifically, in affluent, socioeconomically segregated neighborhoods, built environments often reflect the preferences and demands of higher-income residents, resulting in a selective concentration of amenities like parks, recreational facilities, and aesthetic enhancements. These environments emerge through cumulative investment and political influence, making them attractive to health-conscious individuals and reinforcing patterns of self-selection. At the same time, such neighborhoods may exclude or underprovide other active living supports—such as public transit or mixed-use infrastructure—due to resident opposition or restrictive zoning, shaping the built environment in ways that reflect dominant preferences rather than comprehensive health promotion. In this context, the co-occurrence of features captured by built environment typologies may reflect unequal development priorities, and associations with physical activity may be attenuated or confounded by selective exposure. Uncertainty inherent in latent class analysis, particularly in contexts where neighborhoods that fall near class boundaries, which may be the case here for some segregated neighborhoods, may make it difficult to tease this out. In other words, the classification of a neighborhood as “supportive” may not align with how residents actually engage with or benefit from its features, particularly when neighborhood environments reflect contextual privilege and exclusion rather than holistic design for active living.

In contrast, residential selection may operate differently in socioeconomically segregated neighborhoods, where structural constraints, such as limited housing availability, affordability pressures, and exclusionary housing policies, narrow the range of residential options available. In these contexts, neighborhood conditions are less likely to reflect individual health-related preferences and more likely to result from broader processes of inequality. As a result, self-selection bias may be attenuated, and observed associations between built environment typologies and physical activity may more plausibly reflect contextual effects. However, high residential turnover and tenure insecurity in these neighborhoods can complicate interpretation. Frequent displacement or recent relocation may limit residents' exposure to their current neighborhood environment, weakening potential effects on physical activity and contributing to null associations.

In either case, without prospective data on duration of residence, reasons for moving, or prior exposure to neighborhood environments, we remain limited in our ability to separate compositional from causal process, and to understand the independent and joint roles of the social and physical environments in health behavior and outcome patterning.

4.1 Limitations and Strengths

Some limitations have been discussed above, including reliance on administrative units for neighborhood classification and the limitations associated with the cross-sectional study design. Additional limitations include a temporal mismatch between neighborhood exposure data (i.e., 2015–2022) and physical activity outcomes (i.e., 2015). While delays in updated physical activity data limited temporal alignment of the analysis, socioeconomic segregation patterns and built environment characteristics likely remained stable over this period. We also relied on self-reported physical activity, which is subject to recall bias.¹⁸⁴

Strengths of this work include the application of an exposomic framework to examine urban environmental determinants of health in the Global South. By identifying co-occurring neighborhood features through latent class analysis and integrating these with spatial measures of socioeconomic segregation, our approach offers a more comprehensive understanding of how structural and environmental factors interact to shape physical activity. This study also advances place-based physical activity research in the Global South by examining novel exposures—specifically, the intersection of socioeconomic segregation and the built environment—and their influence on health behavior, providing evidence useful for resource allocation and urban planning aimed at reducing spatial health inequities. Finally, to our knowledge, this is the first study linking ENSIN microdata with geospatial data to investigate neighborhood effects on health outcomes in Colombia. By leveraging georeferenced, individual-level data from a nationally representative survey, we demonstrate the potential of integrating population health surveillance with geospatial analysis to explore place-based determinants of health. This approach opens new opportunities for contextual health research across Latin America and other

Global South settings, where such work is gaining momentum and holds promise for informing equitable, contextually relevant urban health practice.

4 Conclusion

We found modest evidence linking socioeconomic segregation with physical activity, but no evidence that active-living-supportive built environments were associated with physical activity or modified the segregation-activity relationship. While this may reflect a true lack of association, post hoc analyses suggest that differential exposure misclassification, particularly related to socioeconomic segregation, as well as other limitations such as the cross-sectional study design and temporal mismatch between exposure and outcome measures, may have contributed to the null findings.

Nonetheless, this study identifies several areas for future research to improve understanding of how built and social environments jointly shape physical activity in urban contexts of the Global South. These include the need for longitudinal data and the use of spatial approaches that better reflect individuals' mobility patterns and lived experiences of their neighborhood environments, particularly in necessity-based physical activity contexts. Continued investigation that addresses the limitations of this study will be important for advancing evidence on how neighborhood environments shape health behaviors in socially and spatially unequal cities.

Chapter 3 Supplemental Material

Table S-1. Built environment features included in latent class analysis-derived built environment typology

Domain	Items	Description	Variable type	Unit	Original Scale	Year	Source
Functional	Intersections	Density of intersections in the network within the Census section	Continuous	# intersections/area (km ²)	Point	2018	Secretaría Distrital de Planeación ^a
	Sidewalk coverage	Total sidewalks area within the Census section	Continuous	Sidewalk area (m ²)/area (m ²)	Polygon	2019	IDECA ^b
	Bike lanes	Bicycle lane length per road length	Continuous	Bicycle lane length (m) /road length (m)	Tract	2020	IDECA ^b
Transport	Transit routes - TransMilenio	Presence of TransMilenio (BRT) routes within the 1km of tract centroid	Binary	1,0	Line	2019	Transmilenio SA ^c
	Transit routes – SITP	Number of unique SITP (pub transit) routes within 1km Census section centroid	Continuous	# SITP routes	Line	2020	Transmilenio SA ^c
	Bus stops	Bus stop density within Census section	Continuous	#bus stops/area (m ²)	Tract	2022	IDECA ^b
Safety	Pedestrian signals	Density of pedestrian traffic lights within Census section	Continuous	# images with ped signals detected/total images	Point	Closest image to 2018	ML Predictions ^c
	Traffic signals	Density of total traffic lights within Census section	Continuous	# images with traffic signals detected/total images	Point	Closest image to 2018	ML Predictions ^c
Aesthetic	Trees	Density of trees within Census section	Continuous	# trees/area (km ²)	Tract	2022	Secretaría Distrital de Planeación ^a
Destination	Land use diversity	Land use diversity index (Shannon's index)	Continuous	0-1	Land use data at parcel-level,	2020	IDECA ^b

					aggregated to tract to calculate entropy		
	Parks	Park area within the Census section boundary (%)	Continuous	Park area (m2) /total area (m2)	Tract	2022	Instituto Distrital de Recreación y Deporte ^d
	Public spaces - plazas	Presence plazas within 1km Census section centroid	Binary	1,0	Polygon	2022	Secretaría Distrital de Planeación ^a
	Public spaces – malls	Presence malls within 1km Census section centroid	Binary	1,0	Polygon	2022	Secretaría Distrital de Planeación ^a
Civic culture	Ciclovia	Presence of Ciclovia route (weekly open streets) within 1km Census section centroid	Binary	1,0	Line	2020	Instituto Distrital de Recreación y Deporte ^d
	Recrovia	Presence of Recrovia (weekly recreational programs) within 1km Census section centroid	Binary	1,0	Point	2020	Instituto Distrital de Recreación y Deporte ^d

^aSecretaría Distrital de Planeación (District Planning Secretariat)

^bIDECA: Infraestructura de Datos Espaciales para el Distrito Capital (Spatial Data Infrastructure for the Capital District)

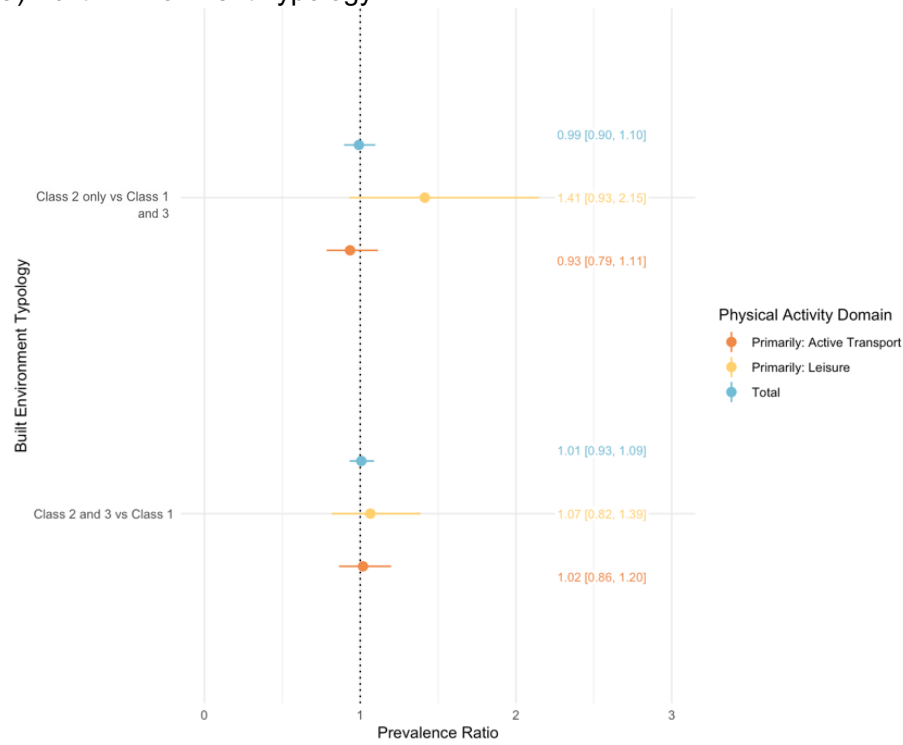
^cTransmilenio SA: TransMilenio Sociedad Anónima (TransMilenio Inc)

^dInstituto Distrital de Recreación y Deporte (District Institute of Recreation and Sports)

^eFeatures were identified using machine learning algorithms applied to GoogleStreetView panoramic images. Image availability is variable (range: 2015-2019)

Figure S-1: Survey-weighted model results from fitting quasi-Poisson models using the svyglm function in the srvyr R package

a) Built Environment Typology



b) Socioeconomic segregation

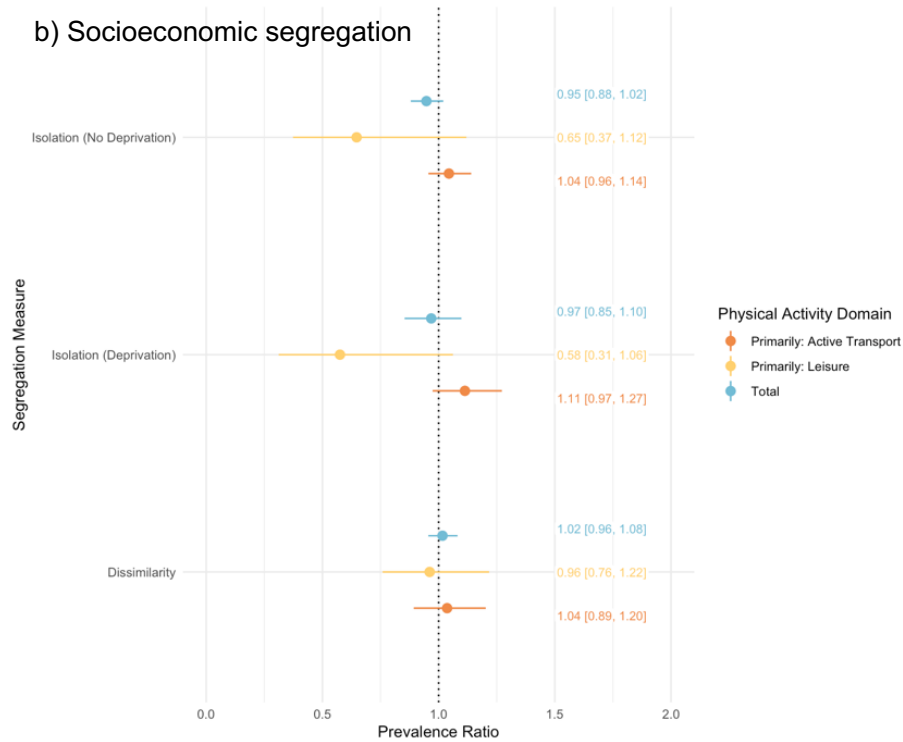
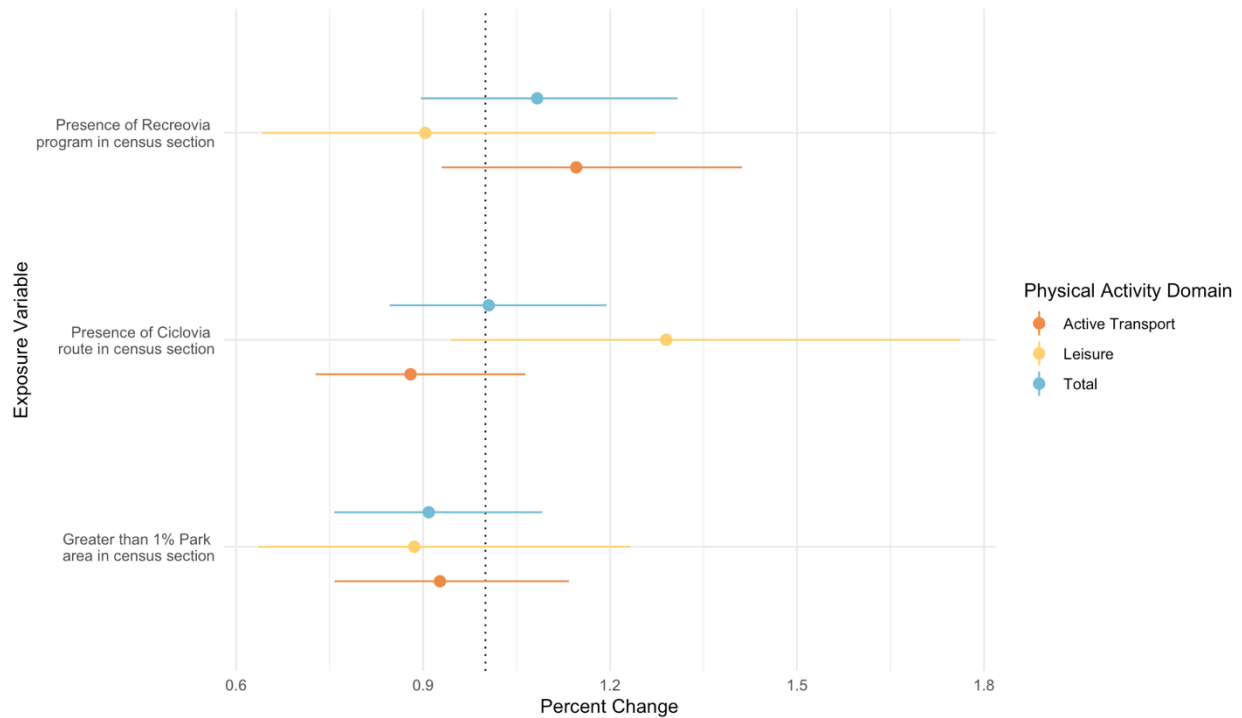
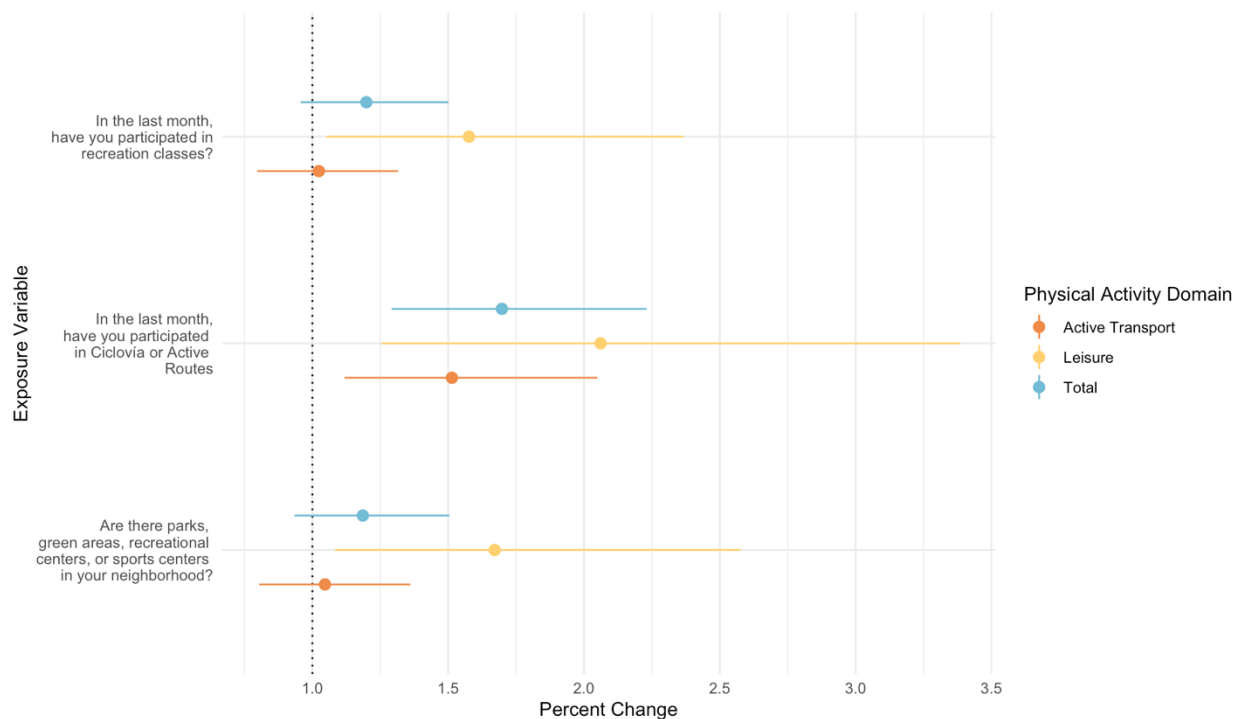


Figure S-2: Post hoc analysis comparing associations between investigator-assigned and perceived exposure to built environment features and continuous weekly physical activity

a) Investigator-assigned exposure (GIS)



b) Perceived exposure (self-report)



Chapter 4. Conclusion

Centering health equity in planning efforts offers an important framework to guide population health promotion through urban planning, especially in contexts that are still urbanizing. This dissertation sought to build evidence that supports the implementation of this framework in Global South cities, like Bogotá, by focusing specifically on active living as a barometer for health equity, socioeconomic residential segregation as the social fabric that underlies access to health promoting resources, and the built environment as a potential lever to minimize health disparities.

In short, we found that active-living promoting built environments are not equitably distributed in Bogotá, as measured by socioeconomic segregation, but that these neighborhood factors have limited influence on population physical activity in this necessity-based physical activity context. Although contrary to our hypothesis, further exploration revealed a mismatch between perceived and researcher-defined access to neighborhood characteristics, suggesting that GIS-based measures of proximity do not always align with residents' perceived access, an equally important factor in shaping how residents engage with their built environment.

These findings share several limitations that warrant consideration. These include temporal mismatches between exposure and outcome data due to source availability; the use of cross-sectional study designs, which constrain our ability to establish temporality—particularly relevant for exposures like segregation and the built environment, whose relationships with each other are often reciprocal and dynamic; and a reliance on objective measures of neighborhood environments, which may not reflect the spatial scale or lived experience through which environmental contexts shape health behaviors.

Nonetheless, this work points to critical opportunities for future research. The emergence of high-resolution environmental data (e.g., Google Street View, remote sensing) combined with theoretical and methodological innovations, such as the exposome and activity-space frameworks, can advance more precise and contextually relevant assessments of environmental exposures. Coupled with careful consideration of measurement biases, particularly when attempting to measure neighborhood exposures among marginalized groups, these innovations can support more rigorous investigation of the structural and spatial determinants of active living in necessity-based contexts. Together, these research advancements can help generate evidence to shape health equity-centered urban planning, especially in cities where the need and opportunities are highest.

Finally, this work highlights two areas for potential policy reform. First, it demonstrates that residential segregation is a critical metric shaping the distribution of health-promoting resources and should therefore be incorporated when evaluating the distributional equity of health opportunities. As a socio-spatial and relational measure, segregation provides more nuanced insight into the spatial patterning of populations than aggregate indicators such as neighborhood socioeconomic status alone. Importantly, these measures can leverage existing census data on

household socioeconomic status and can be readily integrated into evaluators' workflows. Second, this work highlights the importance of integrated, multisectoral commitment to health equity. We used a typology approach to better represent analytically how populations experience the built environment, however practice must also reflect this complexity through deliberate coordination across sectors. Ensuring that built environment interventions promote equitable health outcomes requires coordinated action among all stakeholders, clear alignment toward shared health equity goals, and continuous monitoring to prevent disparities in access from undermining their benefits.

If leveraged intentionally, the built environment can serve as a powerful tool to promote equitable health outcomes by shaping how people move, interact, and access resources within cities. In rapidly urbanizing Global South cities like Bogotá, advancing place-based epidemiologic research along this line of inquiry can equip researchers and practitioners to shape cities that are not only efficient or green, but fundamentally just in how they enable opportunity, mobility, and, ultimately, health equity.

References

1. Frank LD, Iroz-Elardo N, MacLeod KE, Hong A. Pathways from built environment to health: A conceptual framework linking behavior and exposure-based impacts. *J Transp Health*. 2019;12:319-335. doi:10.1016/j.jth.2018.11.008
2. Sallis JF, Floyd MF, Rodríguez DA, Saelens BE. Role of Built Environments in Physical Activity, Obesity, and Cardiovascular Disease. *Circulation*. 2012;125(5):729-737. doi:10.1161/CIRCULATIONAHA.110.969022
3. Grant M. Planning for Healthy Cities. In: Nieuwenhuijsen M, Khreis H, eds. *Integrating Human Health into Urban and Transport Planning: A Framework*. Springer International Publishing; 2019:221-250. doi:10.1007/978-3-319-74983-9_12
4. Grant M, Siri J, Gatzweiler F, et al. Supporting a Healthy Planet, Healthy People and Health Equity through Urban and Territorial Planning. *Plan Pract Res*. 2022;37(1):111-130. doi:10.1080/02697459.2021.2000144
5. Barton H. Land use planning and health and well-being. *Land Use Policy*. 2009;26:S115-S123. doi:10.1016/j.landusepol.2009.09.008
6. Ethiopia Corridor Development Project. Accessed August 18, 2025. <https://corridorandriverside.gov.et/>
7. Cartwright A. What Evidence Informs Urban Policy in East Africa, and How Does It Get There? Published online July 3, 2025. doi:10.20944/preprints202507.0254.v1
8. A Guardian reporter. Dismay in Addis Ababa as ‘the soul of the city’ is razed for development. *The Guardian*. <https://www.theguardian.com/global-development/2024/apr/04/dismay-in-addis-ababa-as-the-soul-of-the-city-is-raised-for-development-ethiopia>. April 4, 2024. Accessed August 18, 2025.
9. Sisay MG. The pitfalls of Ethiopian road developments: socio-economic impacts. *Cogent Soc Sci*. 2024;10(1):2319220. doi:10.1080/23311886.2024.2319220
10. Ethiopia: Federal government must pause the corridor development project and end forced evictions. Amnesty International. April 14, 2025. Accessed August 18, 2025. <https://www.amnesty.org/en/documents/afr25/9098/2025/en/>
11. Tan SB, Binet A, Thompson JP, Arcaya M. Health Equity as a Guide for Urban Planning. *J Plan Lit*. 2024;39(3):371-385. doi:10.1177/08854122231226279
12. Goetz EG, Williams RA, Damiano A. Whiteness and Urban Planning. *J Am Plann Assoc*. 2020;86(2):142-156. doi:10.1080/01944363.2019.1693907
13. Avila E. *The Folklore of the Freeway: Race and Revolt in the Modernist City*. U of Minnesota Press; 2014.

14. Flanagan N. The Battle of Fort Reno. Washington City Paper. November 2, 2017. Accessed August 18, 2025. <http://washingtoncitypaper.com/article/188488/the-battle-of-fort-reno/>
15. Taylor B. *“On the Fort”: The Fort Reno Community of Washington, DC, 1861–1951*. National Park Service U.S. Department of the Interior; 2021.
16. Connerly CE. From Racial Zoning to Community Empowerment: The Interstate Highway System and the African American Community in Birmingham, Alabama. *J Plan Educ Res*. 2002;22(2):99-114. doi:10.1177/0739456X02238441
17. Reft R, Lucas AP de, Retzlaff R. *Justice and the Interstates: The Racist Truth about Urban Highways*. Island Press; 2023.
18. Freeman L. The Ghetto in the Twenty-First Century. In: *A Haven and a Hell. The Ghetto in Black America*. Columbia University Press; 2019:203-236. Accessed August 18, 2025. <https://www.jstor.org/stable/10.7312/free18460.11>
19. Manville M, Monkkonen P, Lens M. It’s Time to End Single-Family Zoning. *J Am Plann Assoc*. 2020;86(1):106-112. doi:10.1080/01944363.2019.1651216
20. Williams DR, Collins C. Racial Residential Segregation: A Fundamental Cause of Racial Disparities in Health. *Public Health Rep*. 2001;116(5):404-416. doi:10.1093/phr/116.5.404
21. Sabatini F. The Social Spatial Segregation in the Cities of Latin America. Published online March 23, 2006. Accessed December 10, 2023. <https://publications.iadb.org/en/publication/social-spatial-segregation-cities-latin-america>
22. Aliaga-Linares L, Álvarez-Rivadulla MJ. Residential segregation in Bogotá across time and scales. *Camb MA Linc Inst Land Policy*. Published online 2010.
23. Rutter H, Cavill N, Bauman A, Bull F. Systems approaches to global and national physical activity plans. *Bull World Health Organ*. 2018;97(2):162. doi:10.2471/BLT.18.220533
24. Re L, Rp J, Lt BC, et al. Still striding toward social justice? Redirecting physical activity research in a post-COVID-19 world. *Transl Behav Med*. 2021;11(6). doi:10.1093/tbm/ibab026
25. Pc H, Im L, Ol S, Ke P. The future of physical activity: from sick individuals to healthy populations. *Int J Epidemiol*. 2024;53(5). doi:10.1093/ije/dyae129
26. Kraus WE, Powell KE, Haskell WL, et al. Physical Activity, All-Cause and Cardiovascular Mortality, and Cardiovascular Disease. *Med Sci Sports Exerc*. 2019;51(6):1270. doi:10.1249/MSS.0000000000001939
27. Az L, J B, E RS, et al. Association of Light Physical Activity Measured by Accelerometry and Incidence of Coronary Heart Disease and Cardiovascular Disease in Older Women. *JAMA Netw Open*. 2019;2(3). doi:10.1001/jamanetworkopen.2019.0419

28. Blondell SJ, Hammersley-Mather R, Veerman JL. Does physical activity prevent cognitive decline and dementia?: A systematic review and meta-analysis of longitudinal studies. *BMC Public Health*. 2014;14(1):510. doi:10.1186/1471-2458-14-510
29. L Z, J Z, Q C, et al. Unraveling the link between physical activity and cognitive function: the mediating impact of depressive symptoms. *BMC Public Health*. 2025;25(1). doi:10.1186/s12889-025-22410-2
30. del Pozo Cruz B, Ahmadi MN, Lee IM, Stamatakis E. Prospective Associations of Daily Step Counts and Intensity With Cancer and Cardiovascular Disease Incidence and Mortality and All-Cause Mortality. *JAMA Intern Med*. 2022;182(11):1139-1148. doi:10.1001/jamainternmed.2022.4000
31. N P, N D, Kk T, et al. Physical activity and risks of breast and colorectal cancer: a Mendelian randomisation analysis. *Nat Commun*. 2020;11(1). doi:10.1038/s41467-020-14389-8
32. A M, Cm F, Pt K, et al. Physical Activity in Cancer Prevention and Survival: A Systematic Review. *Med Sci Sports Exerc*. 2019;51(6). doi:10.1249/MSS.0000000000001937
33. Teychenne M, White RL, Richards J, Schuch FB, Rosenbaum S, Bennie JA. Do we need physical activity guidelines for mental health: What does the evidence tell us? *Ment Health Phys Act*. 2020;18:100315. doi:10.1016/j.mhpa.2019.100315
34. A K, G AF, J H, Cm S, B S. Physical activity and depression: Towards understanding the antidepressant mechanisms of physical activity. *Neurosci Biobehav Rev*. 2019;107. doi:10.1016/j.neubiorev.2019.09.040
35. Pearce M, Garcia L, Abbas A, et al. Association Between Physical Activity and Risk of Depression: A Systematic Review and Meta-analysis. *JAMA Psychiatry*. 2022;79(6):550-559. doi:10.1001/jamapsychiatry.2022.0609
36. Paluch AE, Gabriel KP, Fulton JE, et al. Steps per Day and All-Cause Mortality in Middle-aged Adults in the Coronary Artery Risk Development in Young Adults Study. *JAMA Netw Open*. 2021;4(9):e2124516. doi:10.1001/jamanetworkopen.2021.24516
37. Ding D, Nguyen B, Nau T, et al. Daily steps and health outcomes in adults: a systematic review and dose-response meta-analysis. *Lancet Public Health*. 2025;0(0). doi:10.1016/S2468-2667(25)00164-1
38. Arem H, Moore SC, Patel A, et al. Leisure Time Physical Activity and Mortality: A Detailed Pooled Analysis of the Dose-Response Relationship. *JAMA Intern Med*. 2015;175(6):959-967. doi:10.1001/jamainternmed.2015.0533
39. Salvo D, Jáuregui A, Adlakha D, Sarmiento OL, Reis RS. When Moving Is the Only Option: The Role of Necessity Versus Choice for Understanding and Promoting Physical Activity in Low- and Middle-Income Countries. *Annu Rev Public Health*. 2023;44(1):151-169. doi:10.1146/annurev-publhealth-071321-042211

40. Sallis JF, Bull F, Guthold R, et al. Progress in physical activity over the Olympic quadrennium. *The Lancet*. 2016;388(10051):1325-1336. doi:10.1016/S0140-6736(16)30581-5
41. Eckert S, Kohler S. Urbanization and health in developing countries: a systematic review. *World Health Popul*. 2014;15(1):7-20.
42. Salvo D, Varela AR, Jáuregui A. Moving Together to Advance Physical Activity Research in Low- and Middle-Income Countries: The Case of Latin America. *J Phys Act Health*. 2022;19(9):589-591. doi:10.1123/jpah.2022-0374
43. Oni T, Unwin N. Why the communicable/non-communicable disease dichotomy is problematic for public health control strategies: implications of multimorbidity for health systems in an era of health transition. *Int Health*. 2015;7(6):390-399. doi:10.1093/inthealth/ihv040
44. Inter-American Development Bank. The Complexities of Inequality in Latin America and the Caribbean. Accessed April 13, 2025. <https://www.iadb.org/en/news/complexities-inequality-latin-america-and-caribbean>
45. Martínez AL, Mina OEC. Socioeconomic Residential Segregation and Income Inequality in Bogotá: An Analysis Based on Census Data of 2005. *Urban Socio-Econ Segreg Income Inequal*. Published online 2021:433.
46. Mayorga Henao JM, Ortiz Veliz J. Segregation and inequality in the access to education, culture, and recreation services in Bogotá, Colombia. *Cuad Geogr Rev Colomb Geogr*. 2020;29(1):171-189.
47. Czerny M, Czerny A. Bogota–urban expansion social segregation and land degradation. *Pap Glob Change*. 2016;(23):127-149.
48. Useche AF, Sarmiento OL, Álvarez-Rivadulla MJ, Medina P, Higuera-Mendieta D, Montes F. Spatial segregation patterns and association with built environment features in Colombian cities. *Cities*. 2024;152:105217. doi:10.1016/j.cities.2024.105217
49. López-Martínez A. Segregación socioespacial bajo el nuevo modelo de ciudad en América Latina. Características, perspectivas e implicaciones*. *Hallazgos*. 2018;15(30):99-124.
50. Secretaría Distrital de Planeación. Segregación Socioeconómica en el Espacio Urbano de Bogotá. Diciembre 2013. Accessed January 7, 2024. <https://www.sdp.gov.co/transparencia/informacion-interes/otras-publicaciones/segregacion-socioeconomica-espacio-urbano-de-bogota>
51. Dureau F, Barbary O, Lulle T. Dinámicas metropolitanas de poblamiento y segregación. *F Dureau O Barbary V Goüeset O Pissoat T Lulle Coords Ciudad Soc En Mutación Lect Cruzadas Sobre Colomb*. Published online 2007:161-236.

52. Mayorga Henao JM, Hernández Ortega LM, Lozano MC. Segregación y pobreza multidimensional en el sistema urbano colombiano. *Bitácora Urbano Territ.* 2021;31(2):113-129.
53. Link BG, Phelan J. Social Conditions As Fundamental Causes of Disease. *J Health Soc Behav.* Published online 1995:80-94. doi:10.2307/2626958
54. Sampson RJ, Morenoff JD, Gannon-Rowley T. Assessing “Neighborhood Effects”: Social Processes and New Directions in Research. *Annu Rev Sociol.* 2002;28(Volume 28, 2002):443-478. doi:10.1146/annurev.soc.28.110601.141114
55. Kramer MR, Hogue CR. Is Segregation Bad for Your Health? *Epidemiol Rev.* 2009;31(1):178-194. doi:10.1093/epirev/mxp001
56. Álvarez A, Jaramillo-Echeverri J. The persistence of segregation in education: Evidence from historical elites and ethnic surnames in Colombia. *Cuad Hist Económica No 58.* Published online 2023. Accessed April 13, 2025. https://repositorio.banrep.gov.co/bitstream/handle/20.500.12134/10641/CHE_58.pdf
57. Kaztman F, Retamoso A. Efectos de la segregación urbana sobre la educación en Montevideo. *Rev CEPAL.* 2007;2007(91):133-152.
58. Mayorga Henao JM, Ortiz Veliz J, Mayorga Henao JM, Ortiz Veliz J. Segregación e inequidad en el acceso a servicios de educación, cultura y recreación en Bogotá, Colombia. *Cuad Geogr Rev Colomb Geogr.* 2020;29(1):171-189. doi:10.15446/rcdg.v29n1.73395
59. Guzman LA, Oviedo D, Rivera C. Assessing equity in transport accessibility to work and study: The Bogotá region. *J Transp Geogr.* 2017;58:236-246. doi:10.1016/j.jtrangeo.2016.12.016
60. Oviedo D, Guzmán LA, Oviedo-Dávila N. Productive exclusion: Accessibility inequalities and informal employment in Bogotá. *Geoforum.* 2025;159:104208. doi:10.1016/j.geoforum.2025.104208
61. Guzman LA, Bocarejo JP. Urban form and spatial urban equity in Bogota, Colombia. *Transp Res Procedia.* 2017;25:4491-4506. doi:10.1016/j.trpro.2017.05.345
62. Lucumi DI, Schulz AJ, Israel BA. Local Actors’ Frames of the Role of Living Conditions in Shaping Hypertension Risk and Disparities in a Colombian Municipality. *J Urban Health.* 2016;93(2):345-363. doi:10.1007/s11524-016-0039-8
63. Barber S, Diez Roux AV, Cardoso L, et al. At the intersection of place, race, and health in Brazil: Residential segregation and cardio-metabolic risk factors in the Brazilian Longitudinal Study of Adult Health (ELSA-Brasil). *Soc Sci Med.* 2018;199:67-76. doi:10.1016/j.socscimed.2017.05.047

64. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the Built Environment for Physical Activity: State of the Science. *Am J Prev Med.* 2009;36(4, Supplement):S99-S123.e12. doi:10.1016/j.amepre.2009.01.005
65. Elshahat S, O'Rourke M, Adlakha D. Built environment correlates of physical activity in low- and middle-income countries: A systematic review. *PLOS ONE.* 2020;15(3):e0230454. doi:10.1371/journal.pone.0230454
66. Sallis JF, Cerin E, Kerr J, et al. Built Environment, Physical Activity, and Obesity: Findings from the International Physical Activity and Environment Network (IPEN) Adult Study. *Annu Rev Public Health.* 2020;41(1):119-139. doi:10.1146/annurev-publhealth-040218-043657
67. Parra D, Gomez L, Pratt M, Sarmiento OL, Mosquera J, Triche E. Policy and built environment changes in Bogotá and their importance in health promotion. *Indoor Built Environ.* 2007;16(4):344-348.
68. Kerr J, Anderson C, Lippman SM. Physical activity, sedentary behaviour, diet, and cancer: an update and emerging new evidence. *Lancet Oncol.* 2017;18(8):e457-e471. doi:10.1016/S1470-2045(17)30411-4
69. Kyu HH, Bachman VF, Alexander LT, et al. 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. *BMJ.* 2016;354:i3857. doi:10.1136/bmj.i3857
70. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. *Lancet Glob Health.* 2018;6(10):e1077-e1086. doi:10.1016/S2214-109X(18)30357-7
71. Rigolon A, Flohr TL. Access to Parks for Youth as an Environmental Justice Issue: Access Inequalities and Possible Solutions. *Buildings.* 2014;4(2):69-94. doi:10.3390/buildings4020069
72. Nardone A, Rudolph KE, Morello-Frosch R, Casey JA. Redlines and Greenspace: The Relationship between Historical Redlining and 2010 Greenspace across the United States. *Environ Health Perspect.* 2021;129(1):017006. doi:10.1289/EHP7495
73. Lara-Valencia F, García-Pérez H. Space for equity: socioeconomic variations in the provision of public parks in Hermosillo, Mexico. *Local Environ.* 2015;20(3):350-368. doi:10.1080/13549839.2013.857647
74. Landry SM, Chakraborty J. Street Trees and Equity: Evaluating the Spatial Distribution of an Urban Amenity. *Environ Plan Econ Space.* 2009;41(11):2651-2670. doi:10.1068/a41236
75. Henao JMM, Lopez DF. RELACIÓN ENTRE CALIDAD DE VIDA Y DISTRIBUCIÓN DEL ARBOLADO URBANO EN BOGOTÁ: UNA PERSPECTIVA DESDE LA JUSTICIA

AMBIENTAL URBANA. *Rev Direito Cid.* 2022;13:1762-1782.
doi:<https://doi.org/10.12957/rdc.2021.40272>

76. Haddad MA. Residential income segregation and commuting in a Latin American city. *Appl Geogr.* 2020;117:102186.
77. Escobedo FJ, Clerici N, Staudhammer CL, Corzo GT. Socio-ecological dynamics and inequality in Bogotá, Colombia's public urban forests and their ecosystem services. *Urban For Urban Green.* 2015;14(4):1040-1053. doi:10.1016/j.ufug.2015.09.011
78. González JR. *Segregación Socioeconómica En El Espacio Urbano de Bogotá, DC.* Alcaldía Mayor de Bogotá DC, Secretaría Distrital de Planeación; 2007.
79. Secretaría Distrital de Planeación. *PLAN DE ORDENAMIENTO TERRITORIAL, BOGOTÁ REVERDECE 2022-2035.*
https://www.sdp.gov.co/sites/default/files/generales/pot_digital.pdf
80. Torres-Barragan CA, Cottrill CD, Beecroft M. Spatial inequalities and media representation of cycling safety in Bogotá, Colombia. *Transp Res Interdiscip Perspect.* 2020;7:100208.
81. Carvajal GA, Sarmiento OL, Medaglia AL, et al. Bicycle safety in Bogotá: A seven-year analysis of bicyclists' collisions and fatalities. *Accid Anal Prev.* 2020;144:105596.
doi:10.1016/j.aap.2020.105596
82. Zewdie HY, Sarmiento OL, Pinzon JD, et al. Road Traffic Injuries and the Built Environment in Bogotá, Colombia, 2015–2019: A Cross-Sectional Analysis. *J Urban Health.* 2024;101(4):815-826.
83. Guzman LA, Oviedo D, Bocarejo JP. City profile: The Bogotá Metropolitan Area that never was. *Cities.* 2017;60:202-215. doi:10.1016/j.cities.2016.09.004
84. Tamayo F, and Ariza L. Building a secure city: Urban governance, crime control, and segregation in Bogotá. *City.* 2022;26(2-3):243-260. doi:10.1080/13604813.2022.2056349
85. Camargo Sierra AP, Hurtado Tarazona A. Urbanización informal en Bogotá: agentes y lógicas de producción del espacio urbano. *Rev Invi.* 2013;28(78):77-107.
86. Torres Carrillo A. *La Ciudad En La Sombra: Barrios y Luchas Populares En Bogotá 1950–1977.* Universidad Piloto de Colombia; 2013. Accessed July 28, 2025.
<https://books.google.com/books?hl=en&lr=&id=-uk0DwAAQBAJ&oi=fnd&pg=PT16&dq=La+ciudad+en+la+sombra:+Barrios+y+luchas+populares+en+Bogot%C3%A1+1950%E2%80%931977&ots=1SEeI26eJ7&sig=biSP2-t9JNdg96X-jXampdOfFpg>
87. Bocarejo JP, Tafur LE. Urban land use transformation driven by an innovative transportation project, Bogotá, Colombia. *Nairobi Case Study Prep Glob Rep Hum Settl.* Published online 2013. Accessed July 28, 2025.

https://unhabitat.org/sites/default/files/2013/06/GRHS.2013.Case_.Study_.Bogota.Colombia.pdf

88. Berney R. Learning from Bogotá: How Municipal Experts Transformed Public Space. *J Urban Des.* 2010;15(4):539-558. doi:10.1080/13574809.2010.502344
89. Sandoval EE, Hidalgo D. TransMilenio: A High Capacity - Low Cost Bus Rapid Transit System Developed for Bogotá, Colombia. Published online April 26, 2012:37-49. doi:10.1061/40717(148)4
90. Hidalgo D, Pereira L, Estupiñán N, Jiménez PL. TransMilenio BRT system in Bogota, high performance and positive impact – Main results of an ex-post evaluation. *Res Transp Econ.* 2013;39(1):133-138. doi:10.1016/j.retrec.2012.06.005
91. Guevara-Aladino P, Baldovino-Chiquillo L, Rubio MA, et al. Winds of change: the case of TransMiCable, a community-engaged transport intervention improving equity and health in Bogotá, Colombia. *Cities Health.* 2023;7(1):32-40. doi:10.1080/23748834.2022.2038981
92. Rubio MA, Sarmiento OL, Guevara T, et al. The Impacts of an Urban Cable Car System on Liveability: A Mixed Methods Study in Bogotá, Colombia. In: Biloría N, Sebag G, Robertson H, eds. *The Empathic City: An Urban Health and Wellbeing Perspective*. Springer Nature Switzerland; 2023:311-345. doi:10.1007/978-3-031-32840-4_14
93. Torres A, Sarmiento OL, Stauber C, Zarama R. The Ciclovía and Cicloruta Programs: Promising Interventions to Promote Physical Activity and Social Capital in Bogotá, Colombia. *Am J Public Health.* 2013;103(2):e23-e30. doi:10.2105/AJPH.2012.301142
94. Mejia-Arbelaez C, Sarmiento OL, Mora Vega R, et al. Social Inclusion and Physical Activity in Ciclovía Recreativa Programs in Latin America. *Int J Environ Res Public Health.* 2021;18(2):655. doi:10.3390/ijerph18020655
95. Pineo H. Towards healthy urbanism: inclusive, equitable and sustainable (THRIVES) – an urban design and planning framework from theory to praxis. *Cities Health.* 2022;6(5):974-992. doi:10.1080/23748834.2020.1769527
96. DEPARTAMENTO ADMINISTRATIVO NACIONAL DE ESTADÍSTICA. Censo Nacional de Población y Vivienda 2018. Accessed April 13, 2025. <https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/censo-nacional-de-poblacion-y-vivienda-2018>
97. Massey DS, Denton NA. The Dimensions of Residential Segregation*. *Soc Forces.* 1988;67(2):281-315. doi:10.1093/sf/67.2.281
98. Oka M, Wong DW. Spatializing segregation measures: An approach to better depict social relationships. *Cityscape.* 2015;17(1):97-114.

99. Oka M, Wong DWS. Capturing the Two Dimensions of Residential Segregation at the Neighborhood Level for Health Research. *Front Public Health*. 2014;2:118. doi:10.3389/fpubh.2014.00118
100. Wong DWS. MEASURING MULTIETHNIC SPATIAL SEGREGATION. *Urban Geogr*. 1998;19(1):77-87. doi:10.2747/0272-3638.19.1.77
101. Wong DW. Formulating a General Spatial Segregation Measure. *Prof Geogr*. 2005;57(2):285-294. doi:10.1111/j.0033-0124.2005.00478.x
102. Hennerdal P, and Nielsen MM. A Multiscalar Approach for Identifying Clusters and Segregation Patterns That Avoids the Modifiable Areal Unit Problem. *Ann Am Assoc Geogr*. 2017;107(3):555-574. doi:10.1080/24694452.2016.1261685
103. Latin American and Caribbean Demographic Centre, Population Division of Economic Commission for Latin America and the Caribbean - United Nations. REDATAM. Accessed April 13, 2025. <https://redatam.org/en>
104. Quistberg A, Gonzalez CI, Arbeláez P, et al. 430 Training neural networks to identify built environment features for pedestrian safety. *Inj Prev*. 2022;28(Suppl 2):A65-A65.
105. González C, Ayobi N, Escallón F, et al. STRIDE: Street View-based Environmental Feature Detection and Pedestrian Collision Prediction. In: *2023 IEEE/CVF International Conference on Computer Vision Workshops (ICCVW)*. ; 2023:3222-3234. doi:10.1109/ICCVW60793.2023.00347
106. Frank LD, Sallis ,James F., Conway ,Terry L., Chapman ,James E., Saelens ,Brian E., and Bachman W. Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality. *J Am Plann Assoc*. 2006;72(1):75-87. doi:10.1080/01944360608976725
107. Ewing R, Cervero R. Travel and the Built Environment: A Meta-Analysis. *J Am Plann Assoc*. 2010;76(3):265-294. doi:10.1080/01944361003766766
108. Salvo D, Sarmiento OL, Reis RS, et al. Where Latin Americans are physically active, and why does it matter? Findings from the IPEN-adult study in Bogota, Colombia; Cuernavaca, Mexico; and Curitiba, Brazil. *Prev Med*. 2017;103:S27-S33. doi:10.1016/j.ypmed.2016.09.007
109. Guzman LA, Peña J, Carrasco JA. Assessing the role of the built environment and sociodemographic characteristics on walking travel distances in Bogotá. *J Transp Geogr*. 2020;88:102844.
110. Linzer DA, Lewis JB. poLCA: An R package for polytomous variable latent class analysis. *J Stat Softw*. 2011;42:1-29.

111. Collier ZK, and Leite WL. A Comparison of Three-Step Approaches for Auxiliary Variables in Latent Class and Latent Profile Analysis. *Struct Equ Model Multidiscip J*. 2017;24(6):819-830. doi:10.1080/10705511.2017.1365304
112. Bandeen-Roche K, Miglioretti ,Diana L., Zeger ,Scott L., and Rathouz PJ. Latent Variable Regression for Multiple Discrete Outcomes. *J Am Stat Assoc*. 1997;92(440):1375-1386. doi:10.1080/01621459.1997.10473658
113. Bakk Z, Kuha J. Relating latent class membership to external variables: An overview. *Br J Math Stat Psychol*. 2021;74(2):340-362. doi:10.1111/bmsp.12227
114. Vermunt JK. Latent Class Modeling with Covariates: Two Improved Three-Step Approaches. *Polit Anal*. 2010;18(4):450-469.
115. Tompsett D, De Stavola, Bianca L. Three Step Latent Class Analysis in R and STATA. Presented at: September 2022.
https://www.stata.com/meeting/uk22/slides/UK22_Tompsett.pdf
116. Rubin DB. Multiple imputation. In: *Flexible Imputation of Missing Data, Second Edition*. Chapman and Hall/CRC; 2018:29-62. Accessed April 13, 2025.
<https://www.taylorfrancis.com/chapters/edit/10.1201/9780429492259-2/multiple-imputation-donald-rubin>
117. Ford LR. A new and improved model of Latin American city structure. *Geogr Rev*. 1996;86(3):437-440.
118. Griffin E, Ford L. A model of Latin American city structure. *Geogr Rev*. Published online 1980:397-422.
119. Ford LR. Latin American City Models Revisited. *Geogr Rev*. 1999;89(1):129-131. doi:10.1111/j.1931-0846.1999.tb00205.x
120. Bähr J, Mertins G. Un modelo de la diferenciación socio-espacial de las metrópolis de América Latina. *Rev Geográfica*. 1983;(98):23-29.
121. Inostroza L. Informal urban development in Latin American urban peripheries. Spatial assessment in Bogotá, Lima and Santiago de Chile. *Landsc Urban Plan*. 2017;165:267-279. doi:10.1016/j.landurbplan.2016.03.021
122. Sierra APC, Solano ASA, Lozano DH. Understanding urban densification in Latin American cities: determinants of the production of built space in informal areas in Bogota (2007-2018). *Cities*. 2024;148:104839. doi:10.1016/j.cities.2024.104839
123. Borsdorf A, Hidalgo R. From Polarization to Fragmentation. Recent Changes in Latin American Urbanization. In: Lindert P, Verkoren O, eds. *Decentralized Development in Latin America: Experiences in Local Governance and Local Development*. Springer Netherlands; 2010:23-34. doi:10.1007/978-90-481-3739-8_2

124. Portes A, Roberts BR. The free-market city: Latin American urbanization in the years of the neoliberal experiment. *Stud Comp Int Dev*. 2005;40(1):43-82. doi:10.1007/BF02686288
125. Thibert J, Osorio GA. Urban Segregation and Metropolitics in Latin America: The Case of Bogotá, Colombia. *Int J Urban Reg Res*. 2014;38(4):1319-1343. doi:10.1111/1468-2427.12021
126. Borsdorf A, Hidalgo R. The fragmented city. *Urban Reinventors Online J*. 2009;3(09):1-18.
127. Janoschka M, Borsdorf A. *Condominios Fechados and Barrios Privados: The Rise of Private Residential Neighbourhoods in Latin America*. na; 2004. Accessed April 13, 2025. https://www.researchgate.net/profile/Axel-Borsdorf/publication/258837046_Condominios_fechados_and_Barrios_privados_the_rise_of_private_residential_neighbourhoods_in_Latin_America/links/02e7e5292109509788000000/Condominios-fechados-and-Barrios-privados-the-rise-of-private-residential-neighbourhoods-in-Latin-America.pdf
128. Coy M. Gated communities and urban fragmentation in Latin America: the Brazilian experience. *GeoJournal*. 2006;66(1):121-132.
129. Duren NL de. Peripheral Growth in Latin American and Caribbean Metropolis: Gated Communities and Spatial Path Dependence. In: *The Routledge Handbook of Urban Studies in Latin America and the Caribbean*. Routledge; 2022.
130. Álvarez-Rivadulla MJ. Golden Ghettos: Gated Communities and Class Residential Segregation in Montevideo, Uruguay. *Environ Plan A*. 2007;39(1):47-63. doi:10.1068/a38469
131. Sánchez-Ayala L. Planning to Segregate: The Case of Bogota, Colombia. In: Thakur RR, Dutt AK, Thakur SK, Pomeroy GM, eds. *Urban and Regional Planning and Development*. Springer International Publishing; 2020:361-370. doi:10.1007/978-3-030-31776-8_23
132. Anson K. Fragmented Bodies, Divided Cities; Civic Literature and Urban Segregation in Bogota, Colombia During the Consolidation of the Nation. *Hisp J*. 2019;40(2):11-28.
133. Kostenwein D, and Ruiz Carvajal F. Exclusive Spaces - How Gated Communities in Bogotá Threaten Democratic Access and Security for All in the Streets Outside the Gates. *Hous Theory Soc*.:1-18. doi:10.1080/14036096.2024.2419018
134. Oviedo D, Sabogal-Cardona O. Arguments for cycling as a mechanism for sustainable modal shifts in Bogotá. *J Transp Geogr*. 2022;99:103291.
135. Guzman LA, Oviedo D, Arellana J, Cantillo-García V. Buying a car and the street: Transport justice and urban space distribution. *Transp Res Part Transp Environ*. 2021;95:102860.

136. MASAKI A, KUBO T. Does the introduction of bus rapid transit affect car use? Travel mode choice among high-income households in Bogotá, Colombia. *Europe*. 2021;1(44):875.
137. Oyeyemi A, Ishaku C, Deforche B, Oyeyemi A, De Bourdeaudhuij I, Van Dyck D. Perception of built environmental factors and physical activity among adolescents in Nigeria. *Int J Behav Nutr Phys Act*. 2014;11(1):56.
138. Conderino SE, Feldman JM, Spoer B, Gourevitch MN, Thorpe LE. Social and economic differences in neighborhood walkability across 500 US cities. *Am J Prev Med*. 2021;61(3):394-401.
139. Barry B. Social exclusion, social isolation and the distribution of income. Published online 1998. Accessed April 13, 2025. <https://eprints.lse.ac.uk/6516>
140. Korver-Glenn E, Roberto E, Binkovitz L, Mayorga S. Barriers and Boundaries: How Residents Make Meaning of Segregating Built Environments. *Sociol Perspect*. 2024;67(4-6):261-288. doi:10.1177/07311214241274159
141. Roberto E, Korver-Glenn E. The Spatial Structure and Local Experience of Residential Segregation. *Spat Demogr*. 2021;9(3):277-307. doi:10.1007/s40980-021-00086-7
142. Musterd S. Towards further understanding of urban segregation. In: *Handbook of Urban Segregation*. Edward Elgar Publishing; 2020:411-424. Accessed April 13, 2025. <https://www.elgaronline.com/abstract/edcoll/9781788115599/9781788115599.00034.xml>
143. Fry D, Mooney SJ, Rodríguez DA, Caiaffa WT, Lovasi GS. Assessing Google Street View Image Availability in Latin American Cities. *J Urban Health*. 2020;97(4):552-560. doi:10.1007/s11524-019-00408-7
144. Umar F, Amoah J, Asamoah M, et al. On the potential of Google Street View for environmental waste quantification in urban Africa: An assessment of bias in spatial coverage. Bloor M, ed. *Sustain Environ*. 2023;9(1):2251799. doi:10.1080/27658511.2023.2251799
145. Curtis JW, Curtis A, Mapes J, Szell AB, Cinderich A. Using google street view for systematic observation of the built environment: analysis of spatio-temporal instability of imagery dates. *Int J Health Geogr*. 2013;12(1):53. doi:10.1186/1476-072X-12-53
146. Mooney SJ, Bader MD, Lovasi GS, Neckerman KM, Teitler JO, Rundle AG. Validity of an ecometric neighborhood physical disorder measure constructed by virtual street audit. *Am J Epidemiol*. 2014;180(6):626-635.
147. Lekkas P, Stankov I, Daniel M, Paquet C. Finite mixture models in neighbourhoods-to-health research: A systematic review. *Health Place*. 2019;59:102140. doi:10.1016/j.healthplace.2019.05.018

148. Weden MM, Bird CE, Escarce JJ, Lurie N. Neighborhood archetypes for population health research: Is there no place like home? *Health Place*. 2011;17(1):289-299. doi:10.1016/j.healthplace.2010.11.002
149. Sarmiento OL, Useche AF, Rodriguez DA, et al. Built environment profiles for Latin American urban settings: The SALURBAL study. *PLOS ONE*. 2021;16(10):e0257528. doi:10.1371/journal.pone.0257528
150. Wong DWS, Lasus H, Falk RF. Exploring the Variability of Segregation Index D with Scale and Zonal Systems: An Analysis of Thirty US Cities. *Environ Plan A*. 1999;31(3):507-522. doi:10.1068/a310507
151. Reardon SF, Farrell CR, Matthews SA, O'Sullivan D, Bischoff K, Firebaugh G. Race and space in the 1990s: Changes in the geographic scale of racial residential segregation, 1990–2000. *Soc Sci Res*. 2009;38(1):55-70. doi:10.1016/j.ssresearch.2008.10.002
152. REARDON SF, MATTHEWS SA, O'SULLIVAN D, et al. The Geographic Scale of Metropolitan Racial Segregation. *Demography*. 2008;45(3):489-514.
153. Yao J, Wong DWS, Bailey N, Minton J. Spatial Segregation Measures: A Methodological Review. *Tijdschr Voor Econ En Soc Geogr*. 2019;110(3):235-250. doi:10.1111/tesg.12305
154. Lambert EV, Kolbe-Alexander T, Adlakha D, et al. Making the case for 'physical activity security': the 2020 WHO guidelines on physical activity and sedentary behaviour from a Global South perspective. *Br J Sports Med*. 2020;54(24):1447-1448. doi:10.1136/bjsports-2020-103524
155. Santos AC, Willumsen J, Meheus F, Ilbawi A, Bull FC. The cost of inaction on physical inactivity to public health-care systems: a population-attributable fraction analysis. *Lancet Glob Health*. 2023;11(1):e32-e39. doi:10.1016/S2214-109X(22)00464-8
156. García-Ayllón S. Rapid development as a factor of imbalance in urban growth of cities in Latin America: A perspective based on territorial indicators. *Habitat Int*. 2016;58:127-142. doi:10.1016/j.habitatint.2016.10.005
157. Boakye K, Bovbjerg M, Schuna J, et al. Urbanization and physical activity in the global Prospective Urban and Rural Epidemiology study. *Sci Rep*. 2023;13(1):290. doi:10.1038/s41598-022-26406-5
158. Sallis JF, Cerin E, Conway TL, et al. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. *The Lancet*. 2016;387(10034):2207-2217. doi:10.1016/S0140-6736(15)01284-2
159. Heath G, Brownson R, Kruger J, Miles R, Powell K, Ramsey L. The Effectiveness of Urban Design and Land Use and Transport Policies and Practices to Increase Physical Activity: A Systematic Review. *J Phys Act Health*. 2006;3:S55-S76. doi:10.1123/jpah.3.s1.s55

160. Borsdorf A, Hidalgo R. New dimensions of social exclusion in Latin America: From gated communities to gated cities, the case of Santiago de Chile. *Land Use Policy*. 2008;25(2):153-160. doi:10.1016/j.landusepol.2007.04.001
161. Gomez LF, Sarmiento OL, Parra DC, et al. Characteristics of the built environment associated with leisure-time physical activity among adults in Bogota, Colombia: a multilevel study. *J Phys Act Health*. 2010;7(s2):S196-S203.
162. González SA, Castiblanco MA, Arias-Gómez LF, et al. Results From Colombia's 2016 Report Card on Physical Activity for Children and Youth. *J Phys Act Health*. 2016;13(s2):S129-S136. doi:10.1123/jpah.2016-0369
163. Bocarejo JP, Guzman LA, Portilla I, Meléndez D, Gómez AM, Rivera C. Access as a determinant variable in the residential location choice of low-income households in Bogotá. *Transp Res Procedia*. 2017;25:5121-5143. doi:10.1016/j.trpro.2018.02.042
164. Yunda JG, Sletto B. Property rights, urban land markets and the contradictions of redevelopment in centrally located informal settlements in Bogotá, Colombia, and Buenos Aires, Argentina. *Plan Perspect*. 2017;32(4):601-621. doi:10.1080/02665433.2017.1314792
165. Craig CL, Marshall AL, Sjöström M, et al. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc*. 2003;35(8):1381-1395. doi:10.1249/01.MSS.0000078924.61453.FB
166. Hallal PC, Gomez LF, Parra DC, et al. Lessons Learned After 10 Years of IPAQ Use in Brazil and Colombia. *J Phys Act Health*. 2010;7(s2):S259-S264. doi:10.1123/jpah.7.s2.s259
167. Akram M, Cerin E, Lamb KE, White SR. Modelling count, bounded and skewed continuous outcomes in physical activity research: beyond linear regression models. *Int J Behav Nutr Phys Act*. 2023;20(1):57. doi:10.1186/s12966-023-01460-y
168. Baldwin SA, Fellingham GW, Baldwin AS. Statistical models for multilevel skewed physical activity data in health research and behavioral medicine. *Health Psychol*. 2016;35(6):552-562. doi:10.1037/hea0000292
169. Si Y, Lee S, Heeringa SG. Population Weighting in Statistical Analysis. *JAMA Intern Med*. 2024;184(1):98-99. doi:10.1001/jamainternmed.2023.6300
170. Adkins A, Makarewicz C, Scanze M, Ingram M, Luhr G. Contextualizing Walkability: Do Relationships Between Built Environments and Walking Vary by Socioeconomic Context? *J Am Plann Assoc*. 2017;83(3):296-314. doi:10.1080/01944363.2017.1322527
171. Cummins S, Curtis S, Diez-Roux AV, Macintyre S. Understanding and representing 'place' in health research: A relational approach. *Soc Sci Med*. 2007;65(9):1825-1838. doi:10.1016/j.socscimed.2007.05.036

172. Chaix B, Merlo J, Evans D, Leal C, Havard S. Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. *Soc Sci Med*. 2009;69(9):1306-1310.
173. Hasanzadeh K, Broberg A, Kyttä M. Where is my neighborhood? A dynamic individual-based definition of home ranges and implementation of multiple evaluation criteria. *Appl Geogr*. 2017;84:1-10. doi:10.1016/j.apgeog.2017.04.006
174. Schaefer-McDaniel N, Caughy MO, O'Campo P, Gearey W. Examining methodological details of neighbourhood observations and the relationship to health: a literature review. *Soc Sci Med* 1982. 2010;70(2):277-292. doi:10.1016/j.socscimed.2009.10.018
175. Vallée J, Le Roux G, Chaix B, Kestens Y, Chauvin P. The 'constant size neighbourhood trap' in accessibility and health studies. *Urban Stud*. 2015;52(2):338-357. doi:10.1177/0042098014528393
176. Denwood T, Huck JJ, Lindley S. Participatory Mapping: A Systematic Review and Open Science Framework for Future Research. *Ann Am Assoc Geogr*. 2022;112(8):2324-2343. doi:10.1080/24694452.2022.2065964
177. King AC, King DK, Banchoff A, et al. Employing Participatory Citizen Science Methods to Promote Age-Friendly Environments Worldwide. *Int J Environ Res Public Health*. 2020;17(5):1541. doi:10.3390/ijerph17051541
178. Perchoux C, Chaix B, Cummins S, Kestens Y. Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility. *Health Place*. 2013;21:86-93. doi:10.1016/j.healthplace.2013.01.005
179. Kwan MP. Beyond Space (As We Knew It): Toward Temporally Integrated Geographies of Segregation, Health, and Accessibility: Space–Time Integration in Geography and GIScience. *Ann Assoc Am Geogr*. 2013;103(5):1078-1086. doi:10.1080/00045608.2013.792177
180. Dyer GMC, Khomenko S, Adlakha D, et al. Commentary: A road map for future data-driven urban planning and environmental health research. *Cities*. 2024;155:105340. doi:10.1016/j.cities.2024.105340
181. van Wee B, Cao XJ. Chapter Four - Residential self-selection in the relationship between the built environment and travel behavior: A literature review and research agenda. In: Cao XJ, Ding C, Yang J, eds. *Advances in Transport Policy and Planning*. Vol 9. Urban Transport and Land Use Planning: A Synthesis of Global Knowledge. Academic Press; 2022:75-94. doi:10.1016/bs.atpp.2020.08.004
182. Cao J, Mokhtarian P, Handy S, Ltd F, Sgm. Examining the Impacts of Residential Self-Selection on Travel Behaviour: A Focus on Empirical Findings. *Transp Rev*. 2009;29:359-3951464. doi:10.1080/01441640802539195

183. Boone-Heinonen J, Gordon-Larsen P, Guilkey DK, Jacobs DR, Popkin BM. Environment and physical activity dynamics: The role of residential self-selection. *Psychol Sport Exerc.* 2011;12(1):54-60. doi:10.1016/j.psychsport.2009.09.003
184. Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *Int J Behav Nutr Phys Act.* 2008;5(1):56. doi:10.1186/1479-5868-5-56