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Transport infrastructure renewal and active mobility: a longitudinal analysis of pedestrian and cyclist behavior across demographic and temporal dimensions

Yang Liang [a,b,c], Andrea Rolando [b] and Stefan van der Spek [c]

[a]School of Art & Design, Guilin University of Electronic Technology, Guilin, Guangxi, People's Republic of China; [b]Department of Architecture and Urban Studies, Politecnico di Milano, Milan, Italy; [c]Department of Urbanism, Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands

ABSTRACT
Urban infrastructure renewal significantly influences active mobility patterns, offering opportunities to enhance urban liveability and accessibility. Much of the existing research on active mobility has been cross-sectional and is susceptible to self-selection bias, where individuals who prefer active travel tend to live in walkable neighborhoods. To address this limitation, this study employs a longitudinal approach to analyze changes in pedestrian and cyclist behavior on Viale Argonne in Milan during and after an urban renewal project. Using Strava Metro data, the analysis reveals substantial increases in leisure pedestrian trips, particularly during evening hours and among younger (18–34) and middle-aged (35–54) demographics, highlighting temporal and demographic variations. All activity types exhibited a spatial shift from sidewalks to the redesigned raised median island, reflecting the enhanced streetscape's appeal. While leisure mobility speeds generally decreased, commute mobility speeds showed variable increases. Gender differences in activity levels remained negligible. These findings underscore the value of longitudinal methods and objective mobility data in evaluating urban design interventions. The results provide actionable insights for sustainable urban design, emphasizing the role of inclusive and well-planned infrastructure in fostering active travel and improving public health outcomes.

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Active mobility; longitudinal analysis; transport infrastructure renewal; pedestrian and cyclist behavior; demographic variations; spatial–temporal analysis

1. Introduction

Creating livable, sustainable and inclusive urban spaces is a key challenge in urban design. Active mobility – primarily involving walking and cycling – has emerged as a cornerstone of these efforts, offering environmental, social, and public health benefits. From an environmental perspective, active mobility significantly reduces cities' carbon footprints and mitigates greenhouse gas emissions (Baobeid, Koç, and Al-Ghamdi 2021; Jeong et al. 2023). Socially, it enhances accessibility to urban amenities across socioeconomic groups, fostering equity and inclusivity (Arellana et al. 2021; Gehl, 2010; Speck, 2013). Moreover, active mobility plays a pivotal role in improving both physical and

CONTACT Yang Liang yang.liang@polimi.it; liangyang@guet.edu.cn

mental health. Physically, it reduces the risk of chronic diseases such as cardiovascular conditions, diabetes, and certain cancers through increased physical activity levels (McCormack et al. 2020; Pucher et al. 2010). Mentally, active mobility contributes to improved psychological well-being by alleviating symptoms of depression and anxiety and fostering a sense of relaxation and connection with the environment (Li et al. 2021; Siqueira Junior et al. 2022; Wang et al. 2019). Active mobility also enhances urban vitality, contributing to the social cohesion and livability of cities (Kim 2020; Li et al. 2022; Sonta and Jiang 2023; Sung and Lee 2015). It facilitates spontaneous encounters, gatherings, and communication among residents, thereby increasing social inclusiveness and cohesion (Boyce 2010; Gehl 2011; Huang, White, and Langenheim 2022).

Research examining the relationship between the built environment and active mobility has predominantly employed cross-sectional methods. While such studies have successfully established correlations between walkable and bikeable environments and increased levels of walking and cycling (Brüchert, Quentin, and Bolte 2022; Handy, Cao, and Mokhtarian 2005; Hinckson et al. 2014), they are often limited by self-selection bias (Ettema and Nieuwenhuis 2017; Handy and Clifton 2001), where individuals with a preference for active travel are more likely to reside in walkable and bikeable neighborhoods (Cao, Mokhtarian, and Handy 2009; Van Dyck et al. 2011). This bias underscores the need for longitudinal approaches to explore behavioral changes in active mobility over time or induced by specific urban interventions, providing critical insights into the effectiveness of infrastructure renewal projects (Mokhtarian and Cao 2008).

Among various interventions, the renewal of transport infrastructure stands out as a critical strategy for promoting active mobility (Ewing et al. 2016; Hsu et al. 2024; Marqués et al. 2015; Zhang et al. 2022). High-quality infrastructure improvements, such as dedicated bike lanes, pedestrian-friendly streets, and well-designed urban spaces, have been shown to encourage walking and cycling, particularly for leisure and commuting purposes (Cambra and Moura 2020; Zeng and Shen 2020). However, most existing studies on the relationship between infrastructure and active mobility are cross-sectional, which limits their ability to capture the dynamic changes brought about by infrastructure renewal. In contrast, longitudinal research, though less common, is better suited to understanding how infrastructure changes influence active mobility over time. In addition, evidence on the impacts of street-level reconstructions remains limited where everyday walking and cycling decisions are made, particularly in European contexts with scarce evidence on substantial street-level reconstructions. Furthermore, few studies explicitly examine temporal and demographic heterogeneity, leaving important questions about who benefits from renewal projects and under what conditions. These considerations motivate our longitudinal investigation of the renewal of Viale Argonne in Milan, using Strava Metro data to examine variations across time periods, user groups, and spatial segments.

This study employs a longitudinal approach to examine the influence of transport infrastructure renewal on active mobility patterns on Viale Argonne, Milan. The street's raised median island underwent significant infrastructure renewal from 2018 to 2022, transforming into a vibrant space equipped with pedestrian amenities, recreational facilities, and cycling infrastructure. Using Strava Metro data spanning this time period, this study addresses three key research questions:

1. How does urban infrastructure renewal influence leisure and commute activities for pedestrians and cyclists in terms of trip counts, spatial distribution, and speed?
2. What are the temporal and seasonal variations in the impact of urban infrastructure renewal on active mobility patterns?
3. How do demographic factors, including age and gender, affect the responses to infrastructure renewal in active mobility behaviors?

In this case, this study contributes to a deeper understanding of how transport infrastructure renewal can influence active mobility and supports evidence-based urban planning and design. This paper is structured as follows: Section 2 outlines the theoretical framework, highlighting key concepts and existing studies on built environment and active mobility. Section 3 describes the research design, including case selection, data collection, processing, and visualization methods, data structure, longitudinal analysis framework, and indicator calculation methods. Section 4 presents the results, focusing on the temporal and demographic variations in mobility patterns. Section 5 discusses the implications for urban design and sustainable mobility, advantages and limitations of Strava Metro data, and future research directions. Finally, Section 6 presents a brief conclusion for the paper.

2. Theoretical framework

2.1. Correlations between built environment and active travel behaviors

Walkability and bikeability, characterized by factors such as connectivity, density, land use diversity, and accessibility to transport and recreational infrastructure, are critical factors in promoting active mobility (De Vos et al. 2023; Fonseca et al. 2022; Marqués et al. 2015). For example, compact urban forms with shorter block lengths and higher intersection densities often correlate with increased walking and cycling trips, as they enhance accessibility to destinations and reduce the perceived effort required for active mobility (Baobeid, Koç, and Al-Ghamdi 2021; Venerandi et al. 2024). Conversely, barriers such as traffic congestion, safety concerns, and a lack of dedicated infrastructure for non-motorized transport can discourage active mobility and lead to greater reliance on motorized transport (Baobeid, Koç, and Al-Ghamdi 2021; Job 2020). In addition to urban form characteristics, safety, air quality, and individual physical capacity (such as energy expenditure) are also influential determinants of active travel, particularly for cycling (Bigazzi and Gehrke 2018; Cappelli et al. 2024).

Further research revealed that not all built environment features are equally associated with all forms of active travel. Existing research on the correlation between the built environment and active travel behavior has primarily adopted two complementary perspectives: one that classifies the types of environmental attributes (functional and recreational) and the other emphasizing the purposes of travel behavior (utilitarian and recreational). These perspectives reflect supply-side (infrastructure) and demand-side (behavioral purpose) approaches to environment-behavior correlations. The literature shows strong and consistent evidence that functional built environment attributes are robustly associated with utilitarian walking and cycling, while recreational attributes are more selectively associated with leisure travel, particularly walking (Gao et al. 2020; Hsieh and Chuang 2021; Wang, Ettema, and Helbich 2021).

Specifically, for functional attributes, utilitarian walking correlates with land-use mix and diversity (Hsieh and Chuang 2021; Wang, Ettema, and Helbich 2021), street connectivity (Hsieh and Chuang 2021), residential density (Hsieh and Chuang 2021; Wang, Ettema, and Helbich 2021), higher intersection density (Gao et al. 2020). Similarly, utilitarian cycling correlates bike lanes (Porter et al. 2020), density (Koohsari et al. 2020; Porter et al. 2020), connectivity (Koohsari et al. 2020), transit and destination access (Koohsari et al. 2020; Porter et al. 2020), and bike infrastructure (Brüchert, Quentin, and Bolte 2022; Ma and Ye 2022). However, no strong correlation between functional environmental attributes and recreational walking or cycling was identified (Gao et al. 2020; Porter et al. 2020).

Beyond functional attributes, recreational built environment features, such as green spaces, aesthetic elements, and recreational facilities, have occasionally been found to correlate with recreational walking behavior. However, these associations are neither consistently strong nor uniform across studies and populations (Gao et al. 2020; Wang, Ettema, and Helbich 2021; Wang, Ettema, and Helbich 2023; Zang et al. 2021). The direction and magnitude of observed correlations appear to vary depending on contextual factors such as urban density, age group, or geographic setting. For example, empirical findings regarding features like green space are mixed, some studies report positive associations (Fonseca et al. 2022), others negative (Wang, Ettema, and Helbich 2023), while some detect no significant effects (Gao et al. 2020) or find no consistent patterns only in specific density conditions (Zang et al. 2021). In contrast, there is limited or no direct evidence of a significant relationship between recreational built environment features and recreational cycling (Porter et al. 2020). In contrast, recreational built environment attributes exhibits weak, inconsistent, or highly context-dependent correlation with utilitarian walking and cycling (Gao et al. 2020; Wang, Ettema, and Helbich 2021), sometimes appearing only in specific subgroups (Zang et al. 2021).

Demographic factors also intersect with built environment characteristics to shape mobility patterns. Age, gender, income levels, and educational backgrounds are found to influence preferences for active mobility modes (Adkins et al. 2017; Chung and Wang 2010; Hilland et al. 2020; Pollard and Wagnild 2017). For instance, research has shown that women, particularly younger women, tend to engage in more leisure walking than men, although this difference tends to diminish with age (Pollard and Wagnild 2017). For older adults, recreational walking is less environmental and more individual-health driven (Kemperman and Timmermans 2009; Procter-Gray et al. 2015). Furthermore, socioeconomically disadvantaged groups are less likely to walk, with lower perceptions of walkability and safety in their neighborhoods, which limits their active mobility (Hilland et al. 2020). Studies also indicate that the built environment's influence on walking behavior is stronger in lower-income areas, where improvements to infrastructure, such as sidewalks and safety features, can have a more significant impact (Adkins et al. 2017). For cycling activities, most studies focus on total usage, sometimes reporting on commuter (utilitarian) cycling, and less attention on recreational cycling. Women are generally more sensitive to safety and comfort conditions, such as steep slopes (Hood, Sall, and Charlton 2011). From the perspective of age, higher utilitarian cycling volumes are reported in neighborhoods with more younger adults and more whites (Chen, Zhou, and Sun 2017). Together, these factors highlight the complex interaction between demographic characteristics and environmental conditions in shaping mobility patterns.

2.2. Longitudinal research in the correlations between built environment and travel behaviors

Most studies examining the correlations between the built environment and active travel behavior are cross-sectional in nature, while longitudinal studies remain relatively limited. However, cross-sectional research was limited in its capacity to establish causal relationships, mainly due to residential self-selection – the possibility that individuals predisposed to active travel may choose to reside in more walkable or bike-friendly neighborhoods, thereby inflating observed correlations (Cao, Mokhtarian, and Handy 2009; Van Dyck et al. 2011). Compared to cross-sectional studies, longitudinal studies are able to track behavioral changes over time in response to changes in environmental exposure, which enhances their ability to mitigate reverse causation and residential self-selection.

Existing literature identifies three primary types of longitudinal research examining correlations between the built environment and active mobility. One approach investigates and compares the levels of active mobility over time within a neighborhood or region, without necessarily focusing on environmental changes (Hou et al. 2010; Joh et al. 2015; Kikuchi et al. 2018; Paiva Neto et al. 2022; Sugiyama et al. 2013; Wasfi et al. 2016). The second approach tracks the active mobility of specific groups as they relocate between neighborhoods with varying levels of walkability and bikeability (Collins et al. 2018; Curl et al. 2018; Giles-Corti et al. 2013; McCormack et al. 2023). The third approach examines changes in active mobility within the same neighborhood or region following urban renewal projects focused on improving walkability and bikeability (Cambra and Moura 2020; Curl et al. 2018; Sun, Oreskovic, and Lin 2014; Zeng and Shen 2020). This study adopts the third type of longitudinal research, focusing on changes in active mobility within the same neighborhood following an urban renewal project aimed at enhancing walkability and bikeability. Since environmental changes occurred only along Viale Argonne during and after the implementation of the renovation project, while the surrounding street environments remained largely unchanged, the issue of self-selection commonly associated with cross-sectional research could be minimized.

Despite its advantages, longitudinal research is less prevalent than cross-sectional studies due to its difficulty to implement. Several difficulties are shared across all three categories of longitudinal studies. One of the most pervasive challenges is the loss of participants over time (McCormack et al. 2023). If participants drop out in a non-random manner, it can introduce bias, potentially distorting the study results. Specifically, for longitudinal research on travel behavior over time, recall bias can be introduced if participants are asked to recall information over an extended period (Wasfi et al. 2016). Studies tracking the travel behavior of individuals before and after relocation face the challenge of participant recruitment and retention since it can be difficult to recruit and retain participants who are planning to move (Collins et al. 2018). Research examining travel behavior before and after urban renewal projects presents unique challenges as well. One significant challenge is the lack of historical data. Researchers must proactively identify government-led urban renewal projects and collect relevant data in advance. Once the project is completed, gathering the data before project completion can become challenging. In addition, the positive impacts of urban renewal projects might not be sustained over time, and the long-term effects of these projects are difficult to assess (Zeng and Shen 2020). In this research, several common risks associated with longitudinal studies were mitigated by adopting passively collected GPS-based data from Strava Metro, which eliminates concerns related to participant attrition and recall bias. Continuous data availability throughout the construction and post-construction phases also overcame challenges associated with historical data gaps. While demographic biases inherent in Strava data persist, these are acknowledged and discussed in the limitations section.

2.3. Emerging data source for longitudinal research

In recent years, the availability of urban data sources has supported longitudinal research. For example, the Google Street View image service provides several years of historical street views, which have been validated as a reliable method to assess characteristics of the built environment (Chiang, Sullivan, and Larsen 2017; Kelly et al. 2013; Li et al. 2018; Rundle et al. 2011). Additionally, studies have integrated street view image data with machine learning methods to efficiently analyze the characteristics of the built environment, thus forming effective urban analysis methodologies (Ki and Lee 2021; Ki et al. 2023; Lu 2018; Nagata et al. 2020; Rolando, D'Uva, and Scandiffio 2021; Yin and Wang 2016). Similarly, telecom operators, mobile phone applications that collect GPS data, and social media platforms can also provide data over extended periods of time that can be used to measure active mobility data (Alattar, Cottrill, and Beecroft 2021; Yang and Liu 2022). The data applied in this study, Strava Metro data, is an example of how mobile phone applications, combined with built-in GPS data, can provide data on pedestrian and cyclist activities over multiple years (Sun 2017). It has been validated as a reliable data source that shows acceptable or strong correlations with field-observed data (De Cock et al. 2023). In previous studies, Strava Metro data has been applied to investigate spatial patterns of active mobility at large scales (Lee and Sener 2020; Sun 2017), to monitor bicycle trips and predict bicycle volumes (Lee and Sener 2021), and to integrate with Google Street View imagery and deep learning approaches to study the relationship between the built environment and running activities at macro and micro scales (Jiang, Dong, and Qiu 2022). Specifically, the selected case for this longitudinal study is Viale Argonne in Milan, Italy, where the raised median island of the street experienced a significant spatial redesign and infrastructure enhancement, with the rest of the street remains largely unchanged. This multi-year renovation project (from 2018 to 2022) offers researchers a unique opportunity to study the effects of the urban renewal project on active mobility under two different conditions: a street with limited accessibility and filled with construction noise when the renewal project was ongoing, and an open, well-equipped, and active street with the completion of the project in November 2022. In addition, the situation in which the rest of the street remains largely unchanged provides an excellent control for other streetscape variables in this study, thus ensuring that changes in active mobility are predominantly due to the changes in the condition of the renovated raised median island. Using Strava Metro data, it is possible to evaluate active mobility both during and after the completion of the project to determine if and to what extent active mobility is improved. Strava data facilitates the effective and efficient collection of travel behavior patterns, providing a detailed view of how urban design interventions can influence mobility and improve urban livability.

3. Research design

This study adopts a longitudinal observational design to investigate how transport infrastructure renewal influences patterns of active mobility over time.

To clarify the procedure, the analysis followed seven steps, as illustrated in Figure 1:

1. Define study site and periods (Section 3.1): identify Viale Argonne as the intervention corridor for analysis.
2. Collect and filter Strava Metro data (Section 3.2): obtain anonymized pedestrian and cyclist trip data, disaggregated by purpose (leisure vs. commute), time of day, and demographics, extract only those trips that fall within the path of Viale Argonne.
3. Justify Data Utility and Parse Data Structure (Section 3.3): construct monthly aggregates to balance completeness and temporal resolution, avoiding gaps in daily/hourly tables.
4. Establish the longitudinal analysis framework (Section 3.4): delineate two one-year periods: during renewal (Dec 2021–Nov 2022) and post-renewal (Dec 2022–Nov 2023); set up comparisons both between these phases and across travel purposes and modes; treat the construction phase as a quasi-steady baseline for longitudinal comparisons.
5. Compute indicators (Section 3.5): calculate trip counts (total, by time of day, by age, by gender) and average speeds for each segment, using formulas detailed in Section 3.5.
6. Visualize results (Section 3.6): generate statistical charts and GIS maps to illustrate temporal, demographic, and spatial differences.

This structured sequence makes explicit how changes in pedestrian and cyclist behavior were analyzed and ensures replicability.

3.1. Case selection

Viale Argonne, located in eastern part of Milan in Italy, is an avenue that connects the Catholic Church Basilica Parish and Piazzale Susa. Between 2018 and 2022, Viale Argonne underwent significant reconstruction as part of M4 metro line project (Comune di Milano 2019). During the construction, the raised median islands were obstructed by construction fences and panels, creating noise and an overall disordered streetscape, which limited accessibility for pedestrians and cyclists. After the project's

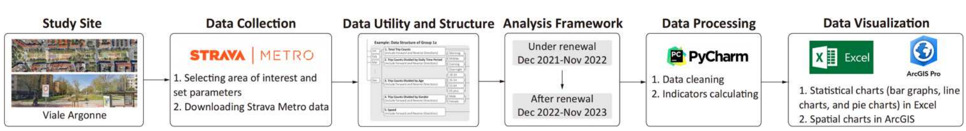

Figure 1. Workflow for data collection, processing, and visualization.

completion on November 26, 2022, the entire raised median islands were open to the public and transformed into a vibrant, pedestrian-friendly space with benches, ping pong tables, street soccer fields, children's playgrounds, and bike lanes (We Build Value Digital Magazine 2022), as presented in Figure 2. This case provides an ideal opportunity for studying the influence of urban infrastructure renewal on active mobility.

This study conducts a longitudinal comparison of active mobility data from two periods: during the construction phase (December 2021 – November 2022) and after the reconstruction was completed (December 2022 – November 2023). Ideally, a longitudinal evaluation of infrastructure renewal would include data from the pre-renewal phase. However, the earliest accessible Strava Metro data available to researchers begins in 2019, by which time the Viale Argonne construction project had already commenced. As such, the pre-renewal baseline is unavailable. Nevertheless, the 'during construction' period still provides a meaningful reference. The infrastructure renewal spanned four years (2018–2022), representing a prolonged and stable condition that consistently affected daily mobility. Over such an extended duration, the disruption caused

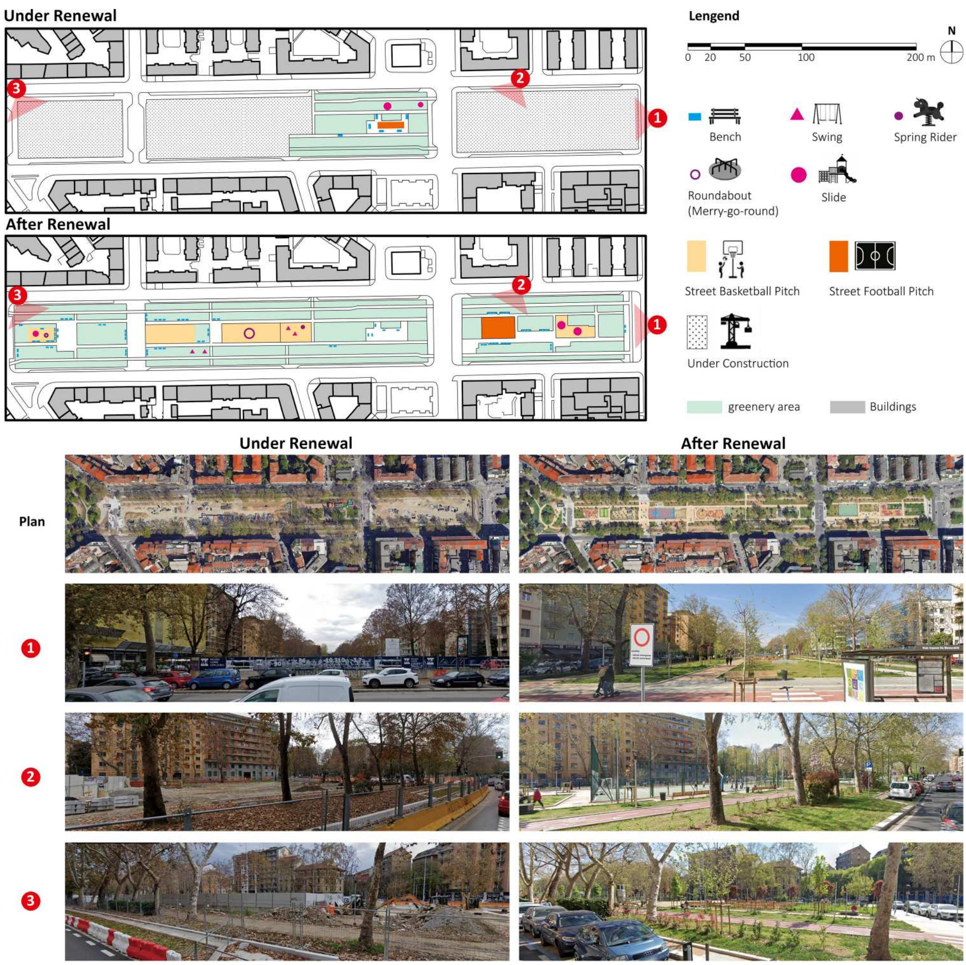

Figure 2. Viale Argonne: during and after the renewal.

by construction likely became a normalized environmental context for local users, influencing their mobility behaviors in sustained ways. In this regard, the 'construction phase' serves as a quasi-steady-state condition rather than a short-term anomaly. Comparing this long-term disrupted state with the post-renewal condition allows us to assess how mobility patterns responded once full accessibility and environmental quality were established. Moreover, the surrounding streetscape elements, such as adjacent buildings and ground-floor commercial establishments along the sidewalks, remained largely unchanged throughout the study period. This stability provides a unique opportunity to control for external variables and strengthens the internal validity of the comparison, which is often difficult to achieve in cross-sectional research.

3.2. Data collection and processing

Data for this study were collected from Strava, a mobile app that allows users to track and visualize their outdoor activities using GPS (Sun 2017). With user consent and anonymization, the aggregated data was made available through the Strava Metro platform for research purposes. The data provides trip counts and movement speed on each street segment of Viale Argonne based on the street network sourced from OpenStreetMap, with perspectives including time segmentation, seasonal variations, as well as demographic breakdowns by gender and age. The street network consists of 329 path segments, with a total of 21406 data entries. An automated Python script was developed to filter and process the data.

3.3. Data utility and structure

As illustrated in Figure 3, the Strava Metro dataset provides data at different granularity: yearly, monthly, daily, and hourly. This study uses monthly data, as it balances detail with comprehensive coverage: Yearly data, while providing annual trip counts and a singular average walking speed, lacks the temporal resolution needed to examine variations throughout the year due to seasonal temperature changes; Daily and hourly datasets, on the other hand, suffer from insufficient coverage as they cannot guarantee complete information for every date within a month or for every hour within a day; Monthly data, in contrast, includes data for twelve months throughout the year and various periods within a day, making it particularly suitable for this analysis.

As presented in Figure 3, The selected data covers two modes of travel: pedestrian's activities labeled as 'run, walk, and hike', and cyclist's activities labeled as 'ride, and E-bike ride'. Each mode of travel is further categorized by purpose into 'leisure' and 'commute'. Consequently, the data for this study are organized into four main groups and eight sub-groups: The four groups are leisure pedestrian's activity, commute pedestrian's activity, leisure cyclist's activity, and commute cyclist's activity. Each group is split into two sub-groups: 'a' for the construction period and 'b' for the post-renewal period. Each sub-group follows the same data structure. It comprises data across twelve months in a whole year. Data of each month includes 'total trip counts', 'trip counts divided by the daily time period ("morning", "midday", "evening", and "midnight")', 'trip counts divided by age group ("18–34", "35–54", "55–64", and "65+")', 'trip counts divided by gender ("male", "female", and "unspecified")', and 'average speed'.[1] All the data includes both 'forward' and 'reverse' directions.

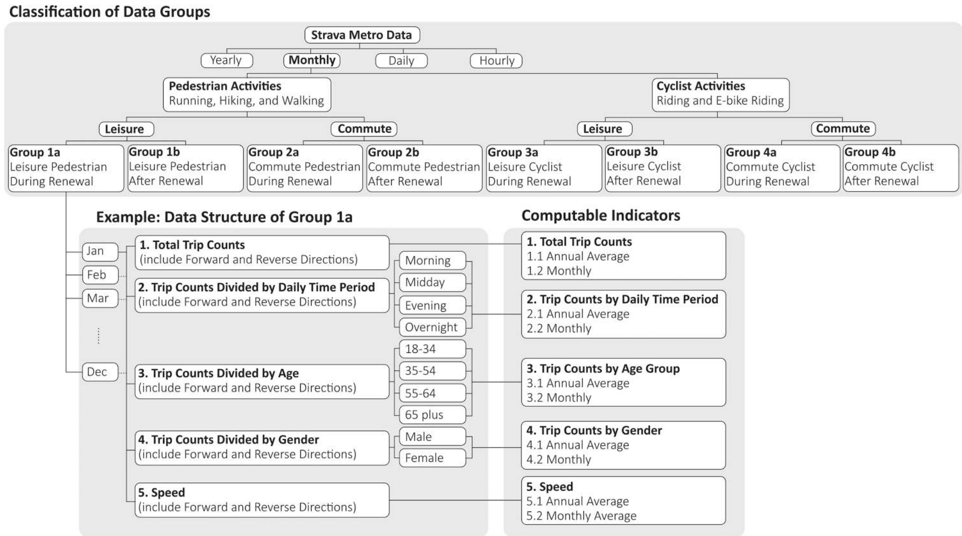

Figure 3. Strava Metro data: classification of data groups, data structure, and computable indicators.

3.4. Longitudinal analysis framework

Based on the classification of four data groups and eight sub-groups, structure of the Strava data, and corresponding computable indicators of each data group presented in Section 3.3, the longitudinal analysis framework is established. Data for each travel mode (pedestrians and cyclists) and purpose (leisure or commute) are compared under and after the renewal across different temporal granularities (annually and monthly). As illustrated in Figure 4, the analysis framework enables:

1. Comparisons between during and after the renewal in four groups respectively.
2. Comparisons between purpose, i.e. leisure and commute activities of pedestrian and cyclist activities respectively.
3. Comparisons between different travel modes, i.e. pedestrian and cyclist activities.

This longitudinal comparison will help identify patterns of change in pedestrian and cyclist activity, thus provides a comprehensive understanding of how the renewal project influenced active mobility in Viale Argonne.

3.5. Indicator calculations

Key indicators of each sub-group were calculated, as listed in Table 1. These indicators include average trip counts–further broken down by daily time period, age group, and gender–as well as average speed. Both annual and monthly values were computed. Importantly, the calculation of each indicator considers only its own categorical dimension, without incorporating the others. Specifically, total trip counts and average speed were calculated independently of time of day, age group, or gender. In contrast, trip counts segmented by daily time period were calculated without considering age or gender, trip counts by age group were calculated without considering time periods or

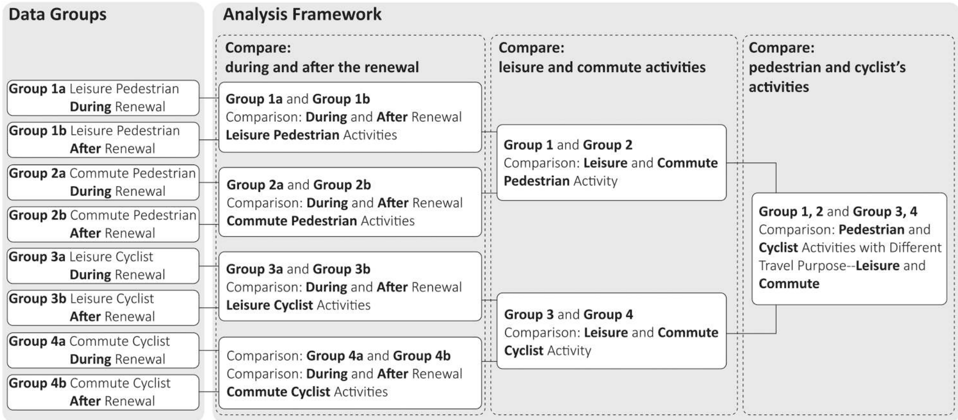

Figure 4. Longitudinal analysis framework.

gender, and trip counts by gender were calculated without considering time periods or age group. This dimensional structure is summarized in Table 1.

Specifically, for each street segment, the method to calculate its Annual Average trip counts is to sum up its forward and reverse direction counts, then divide it by twelve months:

$$\text{Average Trip Counts}\_x = (N_{x\_f\_Jan} + N_{x\_r\_Jan} + \ldots + N_{x\_f\_Dec} + N_{x\_r\_Dec})/12$$

'x' can refer to 'total', 'morning', 'midday', 'evening', 'overnight', '18-34', '35-54', '55-64', '65 plus', 'male', and 'female'; 'f' refers to the forward direction, and 'r' refers to the reverse direction.

The method to calculate its monthly trip counts is to sum up its forward and reverse direction counts. Take the trip count of January as an example:

$$\text{January Trip Counts}\_x = N_{x\_f\_Jan} + N_{x\_r\_Jan}$$

'x' can refer to 'total', 'morning', 'midday', 'evening', 'overnight', '18-34', '35-54', '55-64', '65 plus', 'male', and 'female'; 'f' refers to the forward direction, and 'r' refers to the reverse direction.

Table 1. Indicator-dimension mapping by data granularity.

		Whether consider the dimensions (Y = Yes, N = No)		
Indicator	Data Granularity	daily time period	Age Group	Gender
1. Total Trip Counts	1.1 Annual Average	N	N	N
	1.2 Monthly	N	N	N
2. Trip Counts by daily time period	2.1 Annual Average	Y	N	N
('morning', 'midday', 'evening', and 'overnight')	2.2 Monthly	Y	N	N
3. Trip Counts by age group	3.1 Annual Average	N	Y	N
('18-34', '35-54', '55-64', '65 plus',)	3.2 Monthly	N	Y	N
4. Trip Counts by Gender	4.1 Annual Average	N	N	Y
('male', 'female')	4.2 Monthly	N	N	Y
5. Speed	5.1 Annual Average	N	N	N
	5.2 Monthly Average	N	N	N

The calculation of average speed is based on the weighted average of speeds, considering both directions and trip counts for each period. The method to calculate Annual Average speed is:

$$\text{Average Speed} = (S_{f\_Jan} * N_{total\_f\_Jan} + S_{r\_Jan} * N_{total\_r\_Jan} + \ldots + S_{f\_Dec} * N_{total\_f\_Dec} + S_{r\_Dec} * N_{total\_r\_Dec}) / (N_{total\_f\_Jan} + N_{total\_r\_Jan} + \ldots N_{total\_f\_Dec} + N_{total\_r\_Dec})$$

S_{f_Jan} refers to the forward average speed of January, $N_{total\_f\_Jan}$ refers to the forward total trip counts of January, and so on.

Similarly, monthly average speed is the weighted average of the speeds of the month. Take January as an example:

$$\text{Average Speed}_{\_Jan} = (S_{f\_Jan} * N_{total\_f\_Jan} + S_{r\_Jan} * N_{total\_r\_Jan}) / (N_{total\_f\_Jan} + N_{total\_r\_Jan})$$

S_{f_Jan} refers to the speed of the forward direction in January, $N_{total\_f\_Jan}$ refers to the total average trip counts of the forward direction in January, and so on.

3.6. Visualize findings

The processed data were visualized using both statistical charts and geographic representations. Statistical charts, including bar graphs, line charts, and pie charts, were generated to illustrate temporal variations (monthly and seasonal trends), demographic distributions (age and gender), and differences in mobility purposes (leisure vs. commute). These visualizations provide an intuitive overview of aggregated trends and enable comparisons across user groups and time periods.

In addition to charts, spatial visualization was conducted in ArcGIS by linking the Strava Metro dataset to the 329 path segments of Viale Argonne. Variations in trip counts were represented through differences in line thickness, while average travel speeds were indicated by color gradients. This mapping approach made it possible to detect localized changes in active mobility patterns and to highlight specific street segments where the impact of infrastructure renewal was most pronounced.

4. Results

This section presents the results for the indicators listed in Table 1, analyzing the influence of infrastructure renewal project on active mobility. Results are explored at both annual and monthly granularities, focusing on variations in trip counts, spatial distribution, and activity speeds.

4.1. Average trip count

4.1.1. Annual results

Figure 5 illustrates the annual changes in average trip counts across all activity types. Leisure pedestrian activity experienced the most significant growth, with trip counts increasing from 41.5 during construction to 121.3 post-construction – a 192.3% increase. In contrast, commute pedestrian activity exhibited a minimal increase, from 6.9 to 7.6 trips, presenting a 10.1% rise. For cyclists, leisure activity increased slightly from 47.4 to 51.2 trips (8.0%), while commute activity rose from 23.1 to 27.0 trips (16.9%). These findings suggest that the completed renewal project had the most pronounced impact on leisure pedestrian activities.

Spatially, as shown in Figure 6, leisure pedestrian activity not only shifted from sidewalks to the raised median islands but also increased substantially in volume, with trip counts exceeding 300 in some areas. The raised medians, enhanced with urban furniture and recreational elements, clearly became focal points for leisure walking. In contrast, commute pedestrian activity and cycling showed more modest increases in volume, with the primary change reflected in their redistribution across space rather than a significant overall growth. Notably, pedestrian activity with higher trip counts was dispersed across several street segments, whereas cyclist activity remained concentrated along linear bike lanes, highlighting the contrasting spatial and directional dynamics of walking and cycling.

4.1.2. Monthly results

The monthly distribution of average trip counts, depicted in Figure 7, reveals seasonal trends and the influence of the renewal. Leisure pedestrian activity displayed the largest increase after renewal, peaking in October. Similar trends were observed for leisure cyclist activity, with moderate growth during spring (March to June) and autumn (especially October). However, activity levels dropped during the colder months (December to February) and the hottest month (August), reflecting seasonal preferences. Commute-related activities showed a steadier pattern, with less pronounced seasonal fluctuations. While trip counts increased slightly after the renewal project, the magnitude of change was smaller compared to leisure activities.

For all activity types, August represented the lowest activity levels, likely due to extreme heat and a high number of residents vacationing outside Milan. Overall, the reconstruction positively influenced both leisure and commute activities, though leisure activities were more sensitive to seasonal factors.

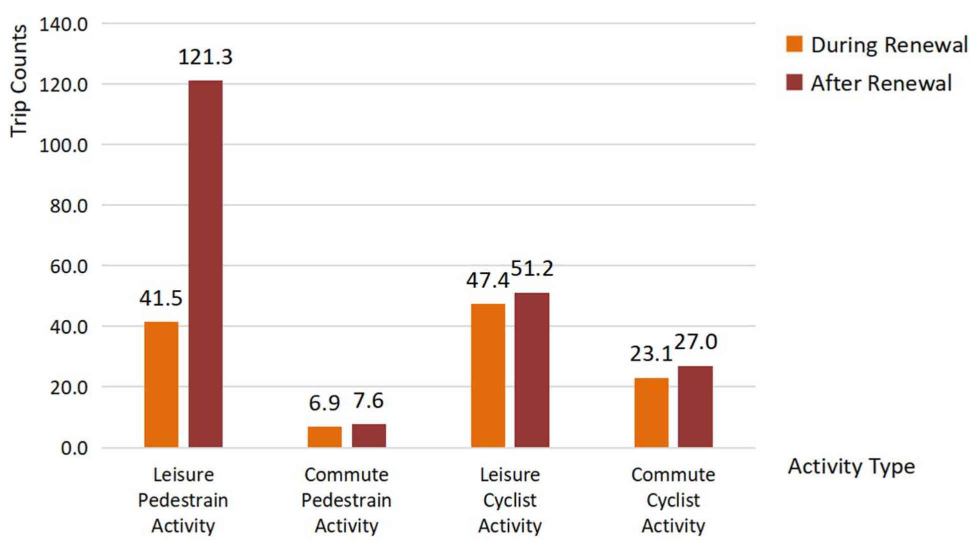

Figure 5. Annual average trip counts during and after the renewal.

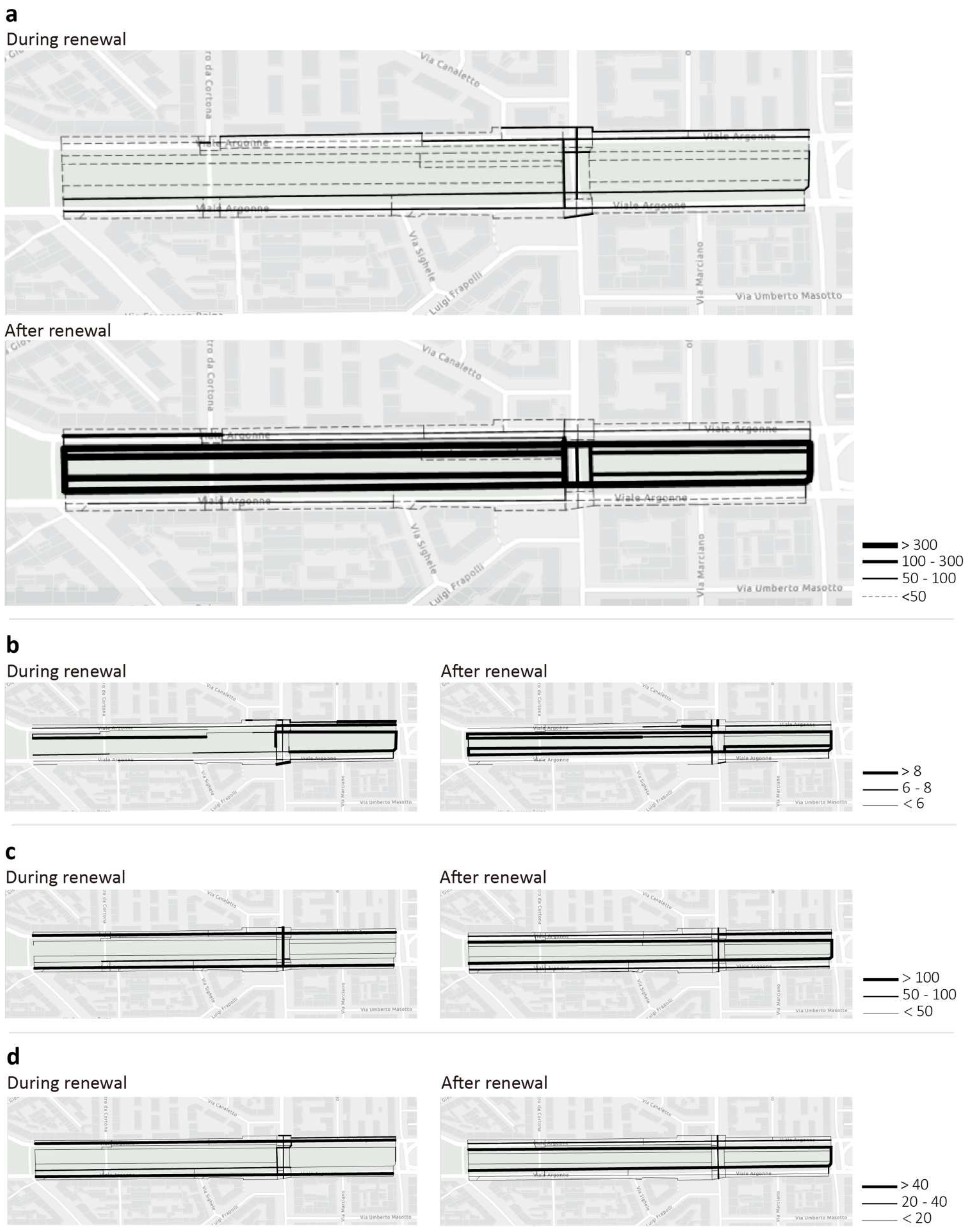

Figure 6. Spatial distribution of average trip counts during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

4.2. Average trip counts by daily time period

4.2.1. Annual results

As shown in Figure 8 and spatially in Fig. A1, all four activity types exhibited increased trip counts across daily time periods after the renewal. Among them, leisure pedestrian trips exhibited the most pronounced growth during evening hours after renewal,

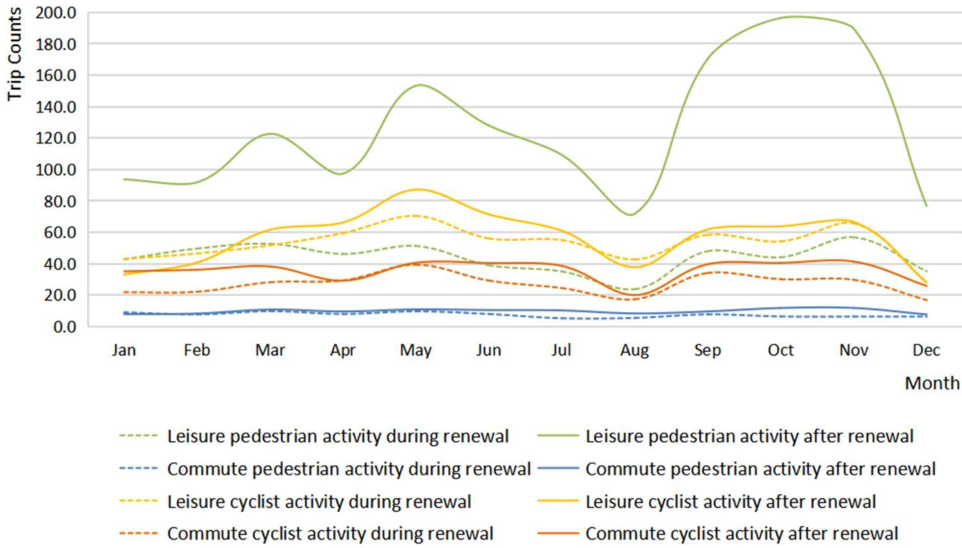

Figure 7. Monthly trip counts during and after the renewal.

indicating a preference for evening leisure walks in the reconstructed space particularly during the later hours of the day. Commute pedestrian trips, on the other hand, showed only a slight increase during the morning. For cyclists, leisure activity displayed a bell-shaped curve, with moderate increases during midday, while commute activity showed slight growth in the evening and overnight.

Spatially, all activity types showed a consistent pattern of movement from the sidewalks along the street edges toward the raised median islands, in line with observations in Section 4.1. As illustrated in Figure 9, the substantial increase in evening walking was predominantly located within these central areas, underscoring the effectiveness of the renewed space in attracting pedestrians during later hours of the day.

4.2.2. Monthly results

Figure 10 examines the monthly variations in trip counts by daily time period. Leisure pedestrian activity peaked in October, particularly during evening hours. In addition, March and May also see high levels of leisure pedestrian activity in the morning, midday, and evening, with the peak extending into July in the morning. In contrast, commute pedestrian activity has significantly lower trip counts than leisure pedestrian activity. The monthly breakdown reveals almost no obvious trend in each time period, likely due to the smaller data set for this group. Cyclist activity displayed a similar seasonal pattern under and after the renewal.

Similarly, the number in leisure cyclist activity are noticeably greater than those in commute cyclist activity. For leisure cyclist activity after the construction, it experienced its peak in midday and evening trips during the spring and autumn months, morning trips in November, and overnight trips during May to July. For commute cyclists, the increase after the renewal is subtle, suggesting a minimal influence of the renewal project on commuting habits.

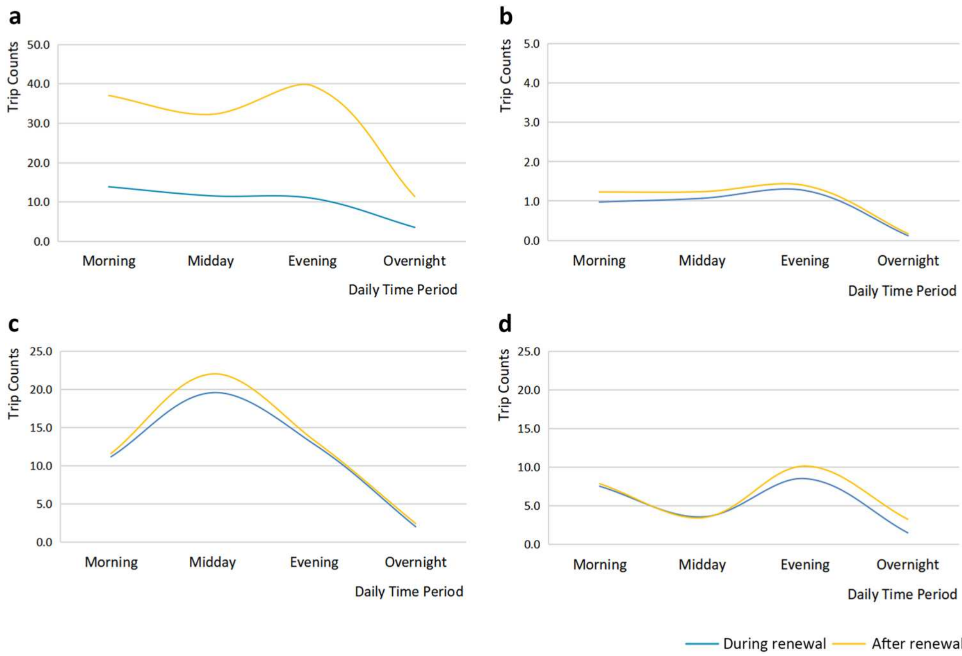

Figure 8. Average trip counts by daily time period during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

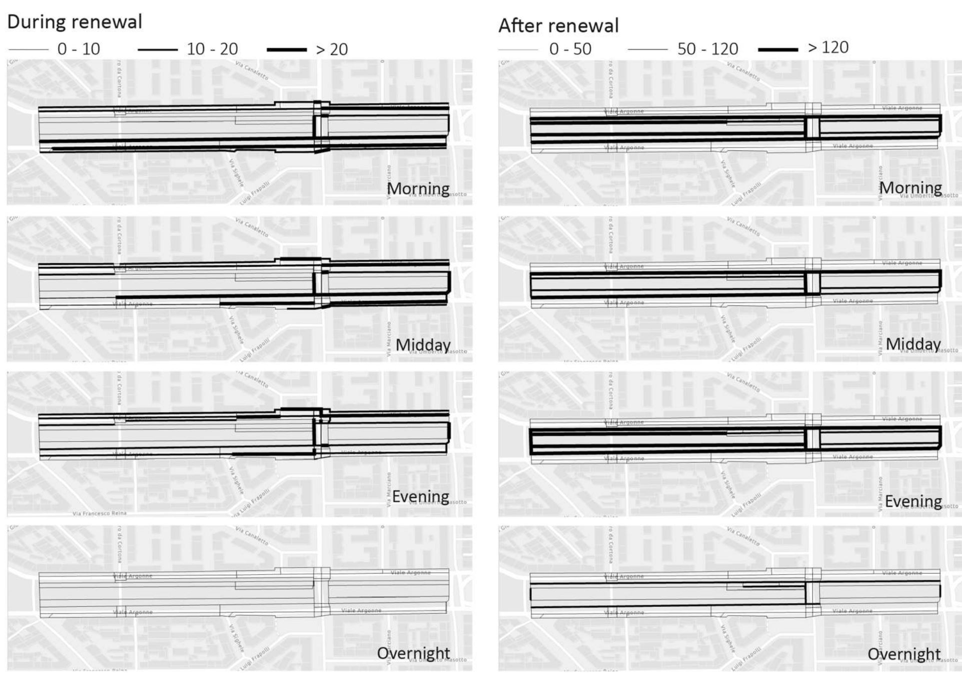

Figure 9. Spatial distribution of average leisure pedestrian trip counts by daily time period during and after the renewal.

4.3. Average trip counts by age group

4.3.1. Annual results

As shown in Fig. A2 and Fig. A3, all activity types[2] demonstrated increases in average trip counts across all age groups with valid data. Among these, leisure pedestrian activity showed the most substantial growth, particularly among individuals aged 18–34 and 35–54. Despite these increases in volume, the proportional distribution of age groups remained relatively stable before and after the renewal across most activity types, except for leisure pedestrian activity, where the share of the 18–34 age group increased significantly, suggesting a marked shift in age composition for this particular mode.

In terms of spatial distribution, all age groups exhibited a consistent trend of shifting from sidewalks along the street edges toward the raised median islands, a pattern that aligns closely with those observed for pedestrian and cyclist activities in Section 4.1. Within leisure pedestrian activity, detailed in Figures 11 and 12, the growth was especially pronounced. Trip counts for the 18–34 and 35–54 age groups rose sharply, and users aged 55–64 showed a higher degree of spatial concentration on the raised median islands compared to younger groups.

4.3.2. Monthly results

Figure 13 highlights monthly fluctuations in trip counts by age group. The age group 18–34 and 35–54 in leisure pedestrian activities exhibited the most significant increases, with

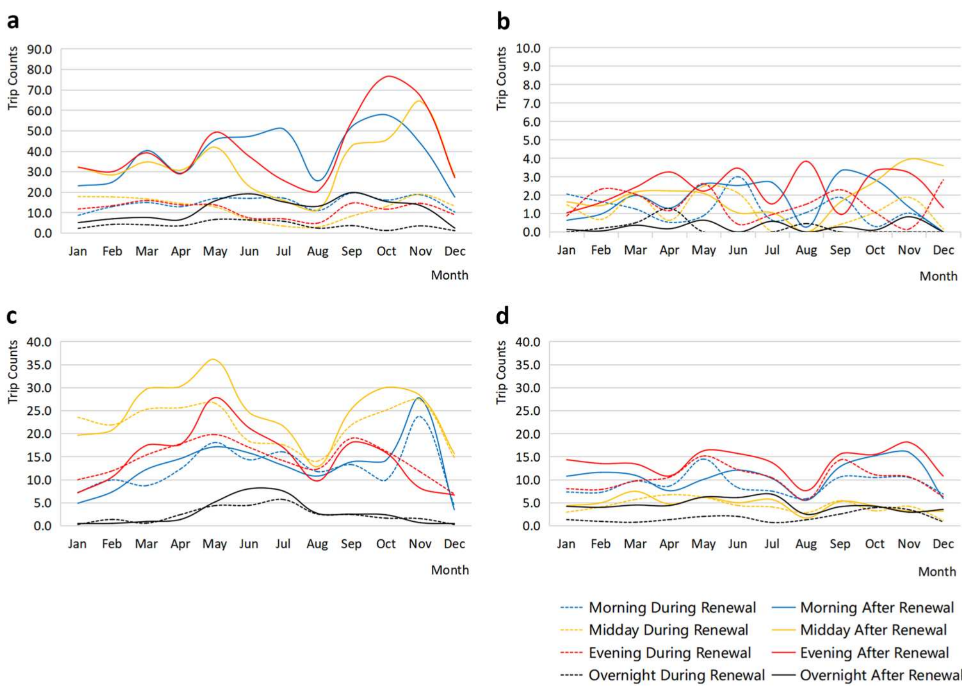

Figure 10. Monthly trip counts by daily time period during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

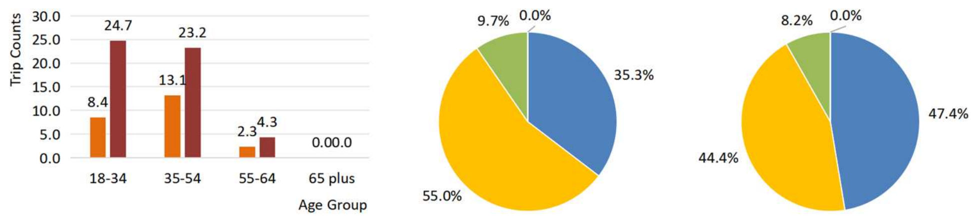

Figure 11. Annual average trip counts: leisure walking by age group during and after the renewal.

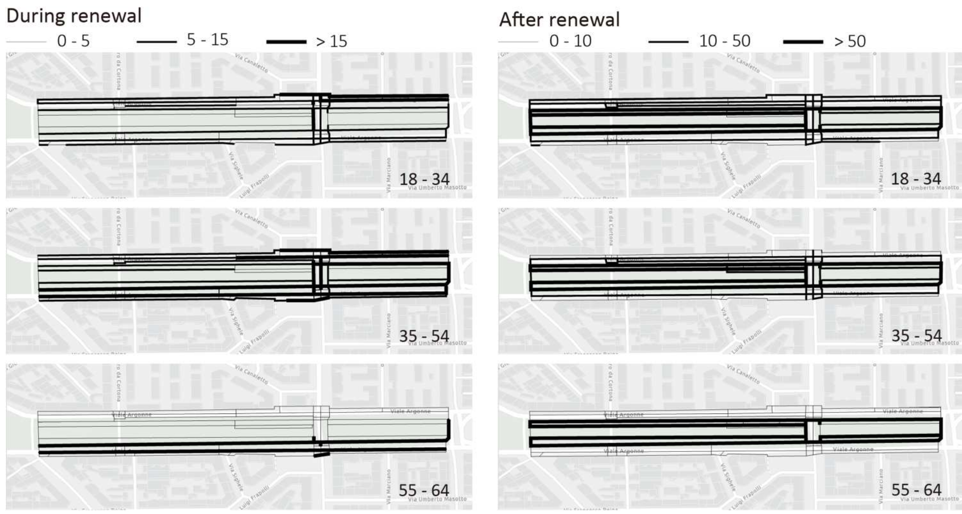

Figure 12. Spatial distribution of average leisure pedestrian trip counts by age group during and after the renewal.

each month after the renewal consistently showing higher trip counts. Specifically, the 18–34 age group saw substantial increases from March to July and September to November, surpassing growth in any other age group during any period. The 35–54 age group displayed major growth during June to July and September to October. The 55–64 age group, except for February and March, showed consistent monthly increases in trip counts, with a fairly even growth rate.

The monthly results of other activity types varied, with some months showing increases and others showing decreases. The growth and decline patterns also varied among the age group. For example, in commute pedestrian activity, the 18–34 age group had a downturn in June, while the 35–54 and 55–64 age group experienced declines in January. In leisure cyclist activities, the 18–34 age group mainly saw increases in May and June, but significant decreases in August and December. The 35–54 age group experienced major growth during June to July and September to October, with noticeable declines in January and August. In commute cyclist activity, the 18–34 age group saw declines in February, August, and November, whereas the 35–54 age group experienced significant declines from April to May, and the decline for the 55–64 age group in April was less severe.

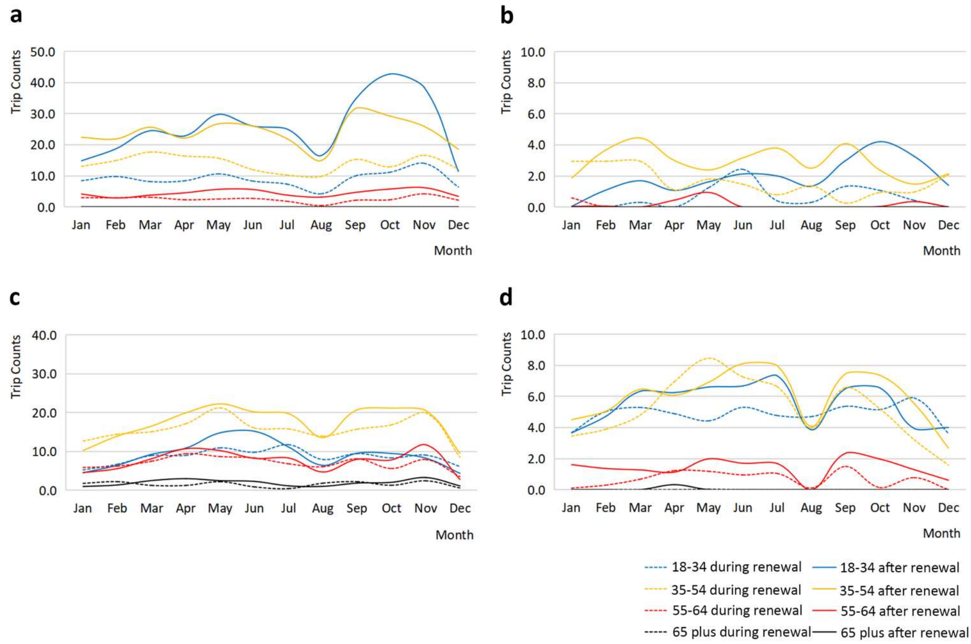

Figure 13. Monthly trip counts by age group during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

4.4. Average trip counts by gender

4.4.1. Annual result

All four activity types – leisure pedestrian, commute pedestrian, leisure cyclist, and commute cyclist – exhibited similar gender-based patterns: male users consistently recorded higher trip counts than females, and the gender ratio remained relatively stable before and after the renewal, as shown in Fig. A4 and Fig. A5. While modest increases were observed across most activity types, leisure pedestrian activities demonstrated the most significant growth and spatial shift. As shown in Figures 14 and 15, average trip counts nearly doubled for male users and increased by approximately 2.5 times for female users. In spatial terms, both genders exhibited a clear transition from using sidewalks along the street edges to clustering around the raised median islands, also in line with observations in Section 4.1.

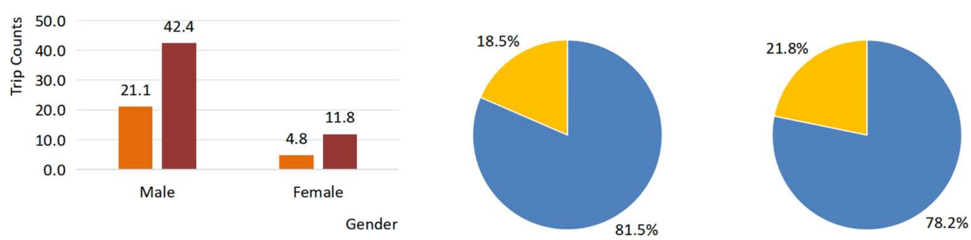

Figure 14. Annual average trip counts: leisure walking by gender during and after the renewal.

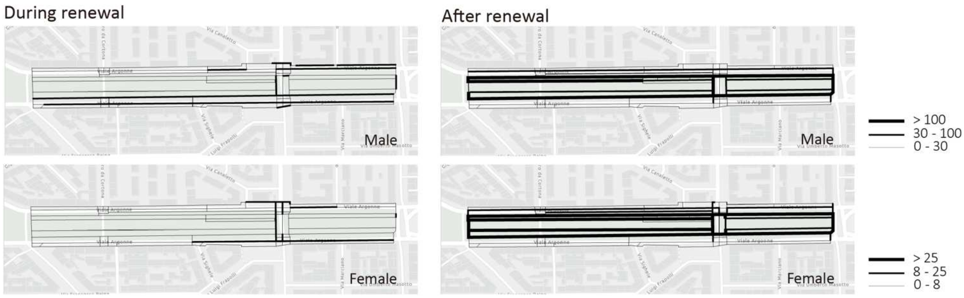

Figure 15. Spatial distribution of average leisure pedestrian trip counts by gender during and after the renewal.

4.4.2. Monthly result

Figure 16 shows monthly variations by gender. Both gender displayed peaks in trip counts during milder months, from March to July and from September to November. Among the four types of activities, leisure pedestrian activity experiencing consistent increases after the renewal for each month. Declines in August and December were observed across almost all activity types, regardless of gender.

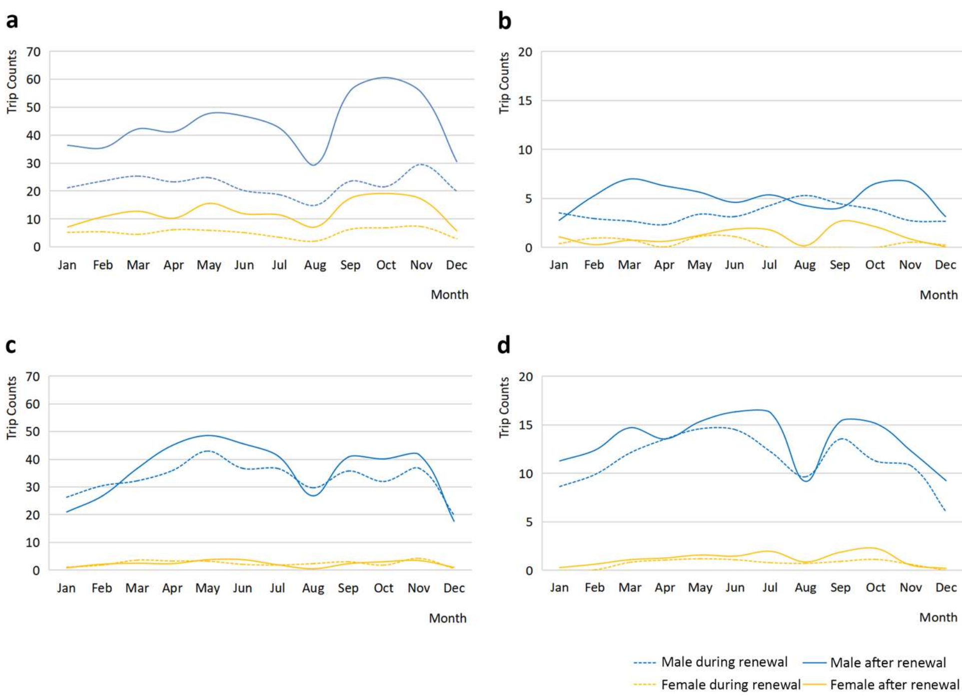

Figure 16. Monthly trip counts by gender during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

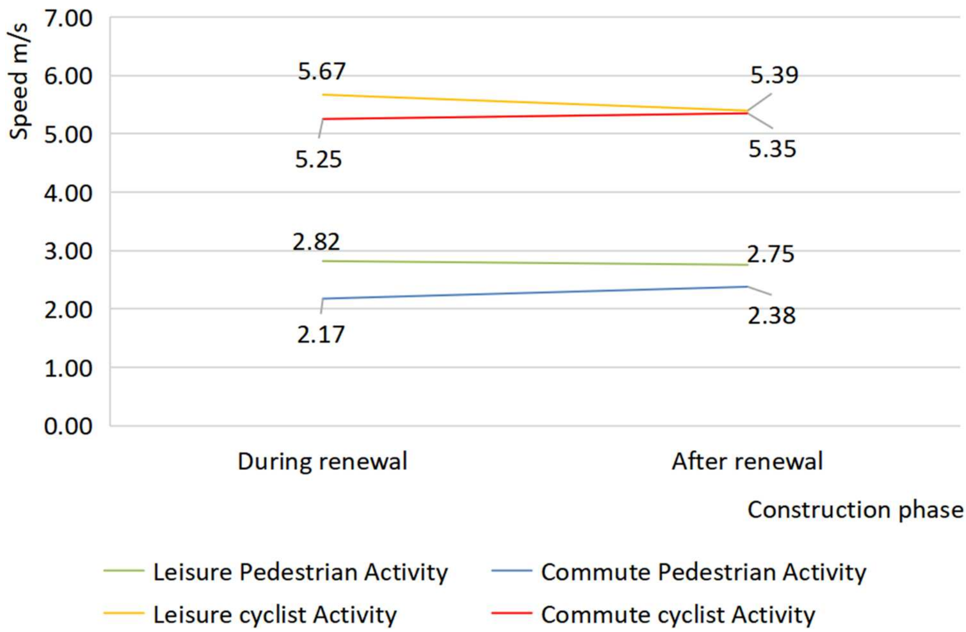

Figure 17. Average speeds during and after the renewal.

4.5. Average speed

4.5.1. Annual results

Figure 17 displays changes in average speeds. Leisure activities, both pedestrian and cycling, experienced a reduction in speed after the renewal. In contrast, commute activities experienced modest speed increases, indicating improved travel efficiency.

Figure 18 presents the spatial distribution of speeds.[3] For leisure pedestrians and cyclists activities after the renewal, speed reductions were concentrated around the raised median islands. In contrast, speed of commute walking activity increased around the raised median islands, while decreased on the sidewalk at southeast. Conversely, the commute cycling speeds increased on the sidewalk in the southeast and northeast corner.

4.5.2. Monthly results

Figure 19 presents the monthly fluctuation of speed throughout the year. Leisure cyclist's activity presents the greatest degree of decrease in speed, especially between March and July. The speed of other three modes are more stable with their curves 'under renewal' and 'after renewal' closely intertwined, especially for leisure pedestrian speed. Comparing the change of speed during and after the renewal considering travel purpose, the months where speeds of leisure activities slowed down after the renewal are concentrated from February to July and September to November, with a speed increase observed in August. For speed of commute activities, the months with increased speeds are mainly from February to May, and a slowdown occurs in November.

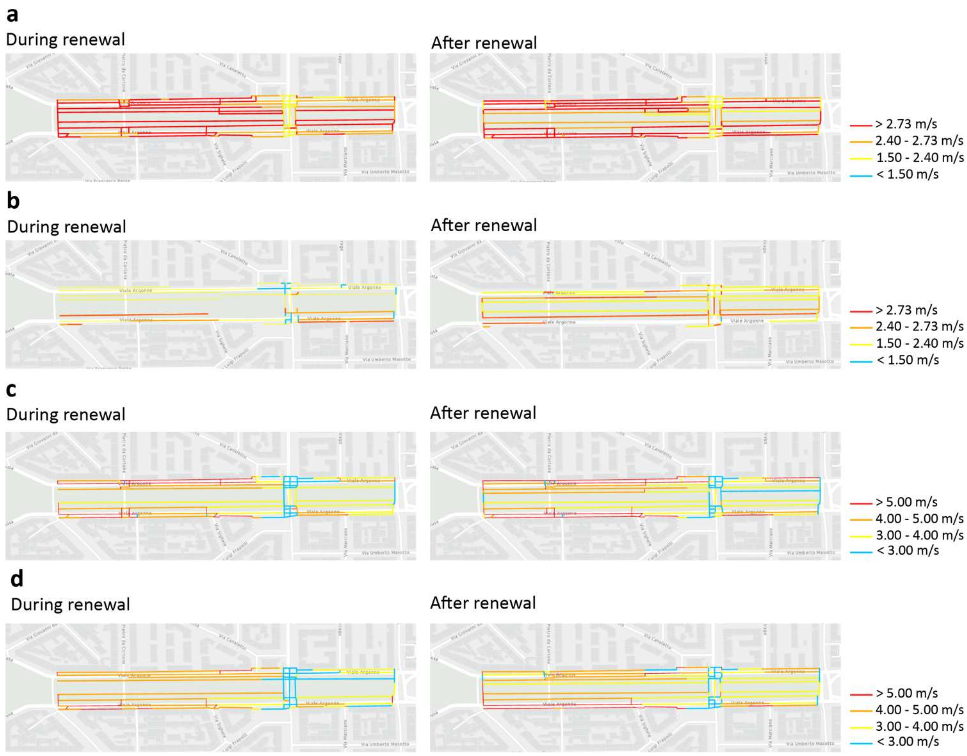

Figure 18. Spatial distribution of average speed during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

4.6. Summary for the results

The renewal project notably increased leisure pedestrian activity, with a significant rise in trip counts and a shift toward the newly developed raised median islands. These spaces, equipped with urban furniture and recreational facilities, became key attractions, particularly for evening leisure walks. In contrast, commute activities showed more modest growth, with only slight increases in trip counts and speeds. Seasonal trends indicated that leisure activities were more sensitive to changes in weather, with peaks in spring and autumn.

Younger age group (18-34 and 35-54) showed the most significant increases in leisure pedestrian activity, while leisure cycling also saw moderate growth. In terms of gender, both males and females demonstrated similar trends, with more pronounced increases in leisure pedestrian activity. The renewal project led to a decrease in leisure activity speeds, especially for cyclists, while commute activity speeds slightly increased.

5. Discussion

5.1. Implications for urban design and active mobility

The findings of Viale Argonne renewal project suggest that, in this case, well-designed urban spaces may encourage shifts in active mobility, particularly leisure activities.

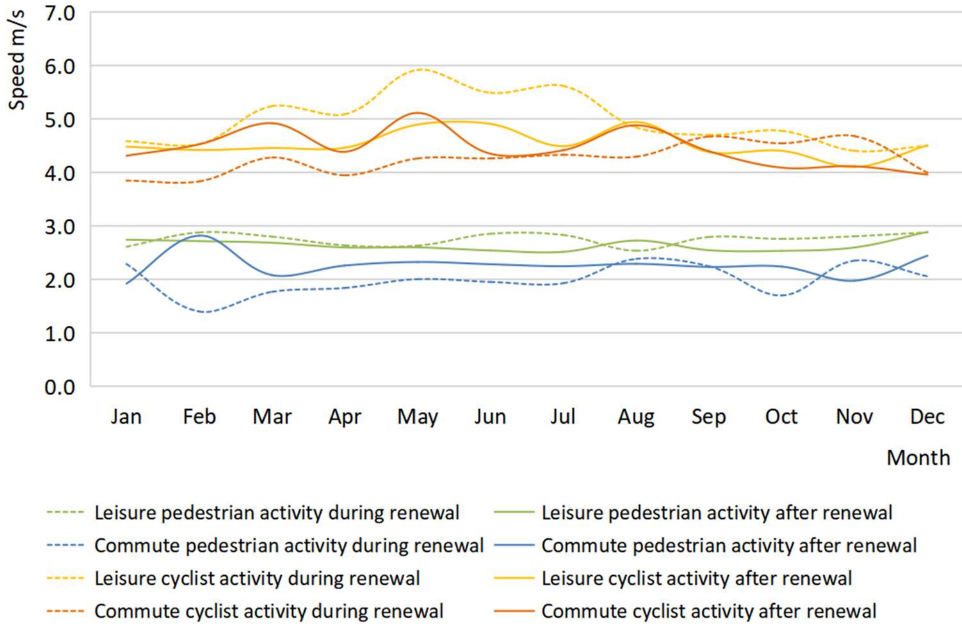

Figure 19. Monthly average speed during and after the renewal.

The wide and continuous pedestrian paths, integration of recreational and social amenities (benches, ping-pong tables, playgrounds), physical separation from vehicular traffic, and improved spatial accessibility are closely associated with the observed shift of active travels from sidewalks to the raised median islands.

The seasonal patterns observed in the study also offer valuable insights into the effectiveness of urban design in promoting year-round mobility. While the observed peak activity periods in spring and autumn suggest a strong responsiveness to favorable weather, it highlights the need for design solutions that can mitigate the influence of less favorable conditions, such as winter or intense heat (Batur et al. 2024; Kajosaari, Ramezani, and Rinne 2022). Future design improvements could consider features that provide weather protection or enhance comfort during colder or hotter months.

One possible explanation for the observed reduction in leisure speeds is that the redesigned median islands offer a more attractive and comfortable environment, encouraging slower, more relaxed movement (Franěk and Režný 2021; Gehl 2011). Alternatively, this reduction may be a consequence of increased user density. According to the classic Greenshields model (Greenshields et al. 1933; Gupta and Pundir 2015), higher pedestrian flows lead to lower speeds due to spatial constraints and user interaction. Without complementary evidence from on-site observations or user surveys, it remains unclear whether the reduced speed reflects voluntary behavioral change or crowding effects. Future research should employ user perception surveys to clarify these causal mechanisms.

Interestingly, although leisure activities are typically expected to occur at slower speeds than commute trips, our findings show the opposite: average leisure speeds exceeded those of commuting, as presented in Figure 17. This counterintuitive result may be explained by the behavioral characteristics of Strava users, who are predominantly younger and more physically active. As a result, many 'leisure' trips likely reflect exercise-oriented activities (such as fitness cycling or brisk walking) rather than casual strolling, leading to higher recorded speeds. In addition, leisure trips are more likely to occur during off-peak times on less congested routes. However, commuting trips are more likely to occur during peak congestion periods, including more frequent stops, or follow less optimal routes, all of which may reduce their average speed. These factors related to behavior and data-source help contextualize why leisure speeds may, in certain cases, exceed those of commute travel.

5.2. Advantages and limitations of Strava Metro data

The use of Strava Metro data in our research offered valuable insights into how pedestrian and cyclist behaviors have adapted to urban design changes over time. One of the key strengths of Strava Metro data is its granularity. The data allows for precise tracking of movement patterns down to specific times of day and specific street segments (Lee and Sener 2021). This level of detail is essential for understanding not just the volume of activity in an area but also the specific patterns and flows of movement.

In addition, as it collects data continuously, it allows for longitudinal studies that can track changes over longer periods (Lee and Sener 2020). This capability is especially important for assessing the lasting influence of urban changes. Moreover, unlike surveys or observational studies, which can be subject to biases and inaccuracies, Strava Metro data is collected through GPS tracking, offering objective and highly accurate measurements of trip counts, mobility speed, and spatial distribution (Lee and Sener 2020). Finally, using Strava Metro data can be more cost-effective compared to traditional investigation methods, which is time-consuming and labor-intensive.

However, the reliance on Strava Metro data comes with inherent limitations. The primary concern is the demographic bias associated with Strava users, who are typically more likely to be younger, male, proficient in technology, and engaged in higher levels of physical activity compared to the general population (De Cock et al. 2023; Lee and Sener 2021). This sample bias raises concerns about under- and over-representation of specific population groups, limiting the generalisability of findings. For instance, older adults or those from lower socio-economic backgrounds might not be adequately represented in the data, potentially overlooking their mobility needs and preferences. In addition, aggregation the traveler data makes it unavoidable that details on individual travel activity will be lost, such as person-level user profiles and individual full-route traces (Lee and Sener 2021).

5.3. Future research directions

While this study provides case-based empirical evidence, suggesting a positive role of urban renewal in promoting leisure-oriented active travel, it also raises important questions regarding the long-term sustainability of such interventions. Existing research suggests that improvements to walking and cycling infrastructure do not universally result in lasting increases in active mobility. For example, during the COVID-19 pandemic, many cities (including Milan) introduced temporary 'pop-up' measures to promote walking and cycling, such as provisional bike lanes and restricted motorized traffic (Creutzig, Lohrey, and Franza 2022). These measures were associated with short-term increases in active travel and air quality improvements. However, researchers have noted that such changes were likely to diminish once lockdowns were lifted, and their long-term effectiveness remains uncertain (Creutzig, Lohrey, and Franza 2022). In this context, future studies should evaluate whether the observed increase in leisure walking following the Viale Argonne renewal can be maintained over time, or whether it may plateau as the novelty of the redesigned space fades. In light of this, it is necessary for future studies to assess whether the observed increase in leisure walking following the Viale Argonne renewal can be sustained over time, or whether it may plateau as the novelty of the redesigned space diminishes.

While the literature tends to emphasize successful outcomes following walkability and bikeability improvements, less attention has been paid to cases where interventions fell short of expectations, and the reasons behind such failures deserve further exploration. For instance, a painted curb extension in Los Angeles, designed to enhance pedestrian safety and comfort, did not lead to a measurable increase in pedestrian volumes. Post-intervention assessments revealed that users misunderstood the markings, thereby undermining the intervention's intended effect (Green et al. 2019). Similarly, the Oakland Slow Streets program, which restricted vehicle access on 21 miles of local roads to encourage walking and cycling, indicates that while some streets showed notable increases in activity, others did not differ from control streets. Research suggests that this variability was largely influenced by differences in community engagement and communication strategies. Positive outcomes were more common in neighborhoods where residents were actively involved and clearly understood the purpose of the intervention. In contrast, where outreach was limited, residents were often unaware of the program's intent, leading to minimal behavioral change. Beyond issues of awareness and communication, some intervention failed to meet local mobility and recreational needs, or lacked a sufficient user base, indicating a mismatch between the intervention and the spatial distribution of potential users (Douglas and Moore 2022, pp. 14, 19). Taken together, these examples highlight the importance of examining not only what types of interventions are effective, but also the contextual conditions under which they may fail to achieve their intended outcomes. Future research should place greater emphasis on identifying the factors that differentiate successful from unsuccessful interventions, incorporating contextual, perceptual, and behavioral dimensions into evaluation frameworks.

Furthermore, to build on the findings from this study, future research should incorporate a broader array of data sources to capture a more representative cross-section of the population. Qualitative methods, such as surveys or interviews, could be employed to gather insights on the subjective experiences of different demographic groups, including those less likely to use apps like Strava. Furthermore, exploring the economic and social impacts of urban renewal projects, such as changes in local business activity or community cohesion, could provide a fuller picture of the benefits and challenges associated with such interventions. Lastly, it would be valuable to expand the focus of future research to include the impacts of extreme weather conditions on active mobility. As urban areas face increasing climate challenges, understanding how weather influences mobility patterns will be crucial for designing resilient cities that can support sustainable transport in the face of climate change.

6. Conclusion

This study examined the influence of the renewal project on pedestrian and cyclist activity along Viale Argonne, employing a longitudinal approach that integrated both temporal and demographic factors. The findings reveal increased levels of activity, particularly for leisure trips during evening hours and in milder months, alongside a spatial shift of use toward the renovated median island. These results suggest that redesigned street environments can create more attractive settings for active mobility and foster more social and leisurely forms of use.

Beyond the case-specific outcomes, the study contributes to the broader discussion on sustainable urban design in three ways. Methodologically, By utilizing Strava Metro data, the study provided a detailed, data-driven analysis of mobility patterns during and after the renewal project. Empirically, it provides rare longitudinal evidence from a European context, addressing a gap in current research. Practically, it identifies design features, such as wide pedestrian paths, recreational amenities, and separation from traffic, that appear associated with shifts in active mobility.

While bounded by the limitations of the dataset, these contributions highlight the potential of combining digital mobility data with urban design analysis to enrich our understanding of how renewal projects shape active mobility. Future research should continue to test the durability of such effects over time, incorporate additional data sources to capture underrepresented groups, and explore how contextual factors influence the success or failure of interventions.

Notes

1. Strava Metro dataset does not provide breakdowns of speed data by time or demographic categories.
2. Data for the age group over 65 was negligible.
3. Walking speed is influenced by factors such as age, gender, and physical health. In this study, the speed thresholds for walking are set at 1.5 m/s for general walking (U.S. Department of Health and Human Services 2018), 2.4 and 2.73 m/s are respectively the fastest 50% and 30% of 5km running speeds as reported by RunRepeat data (Barraclough 2023). Bicycling speeds cover a broader range, with significant differences between urban and rural spaces (Glenton 2024). Data from Milan show that the average speed of cycling is approximately 6 m/s (Wecity 2016). Based on this and the data distribution in this study, reference points for data segmentation are set at 5, 4, and 3 m/s to present the data effectively.

Disclosure statement

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ORCID

Yang Liang http://orcid.org/0000-0003-1114-2875
Andrea Rolando http://orcid.org/0000-0001-9998-1731
Stefan van der Spek http://orcid.org/0000-0003-1258-0527

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Appendix

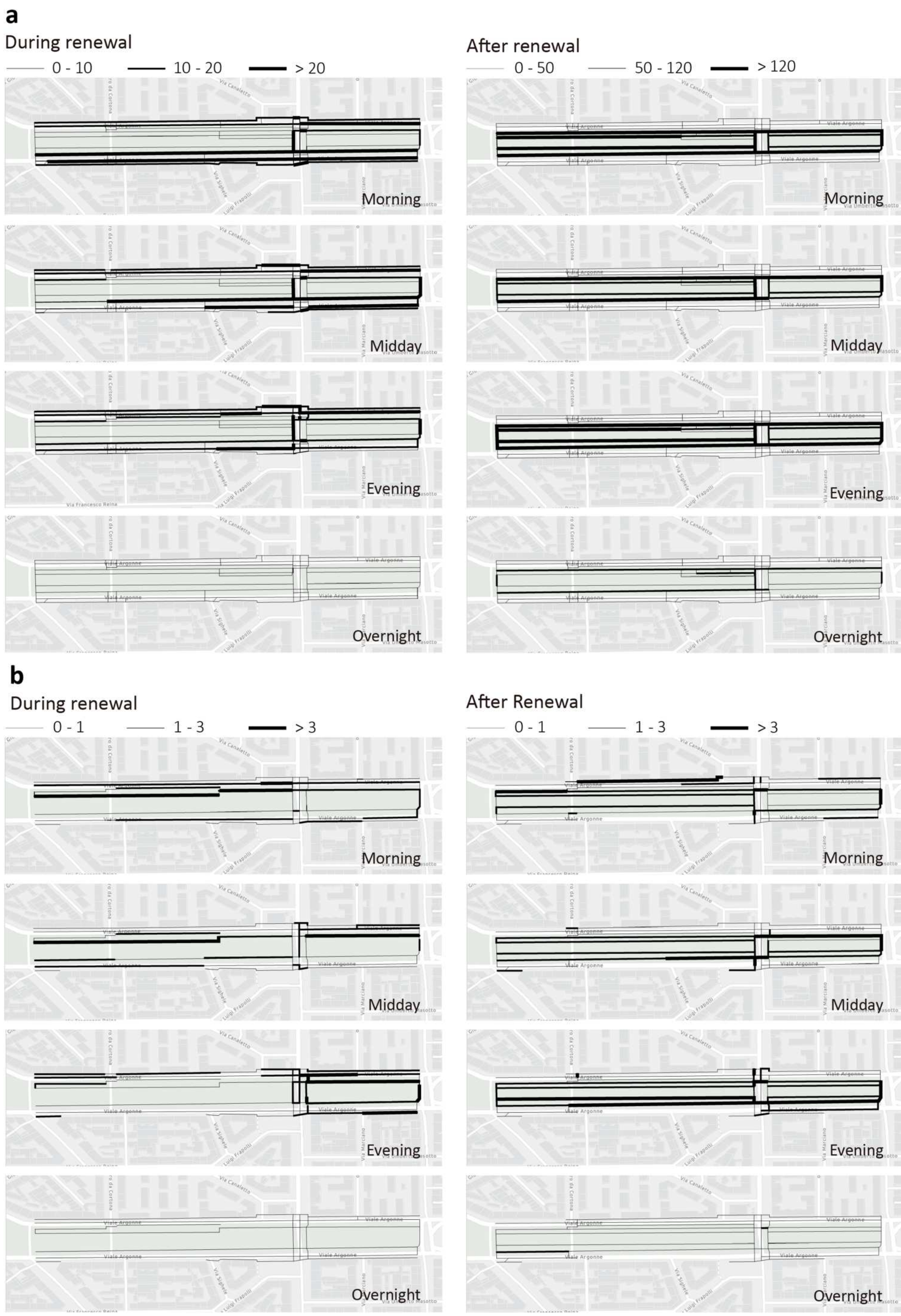

Figure A1. Spatial distribution of average trip counts by daily time periods during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b). (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

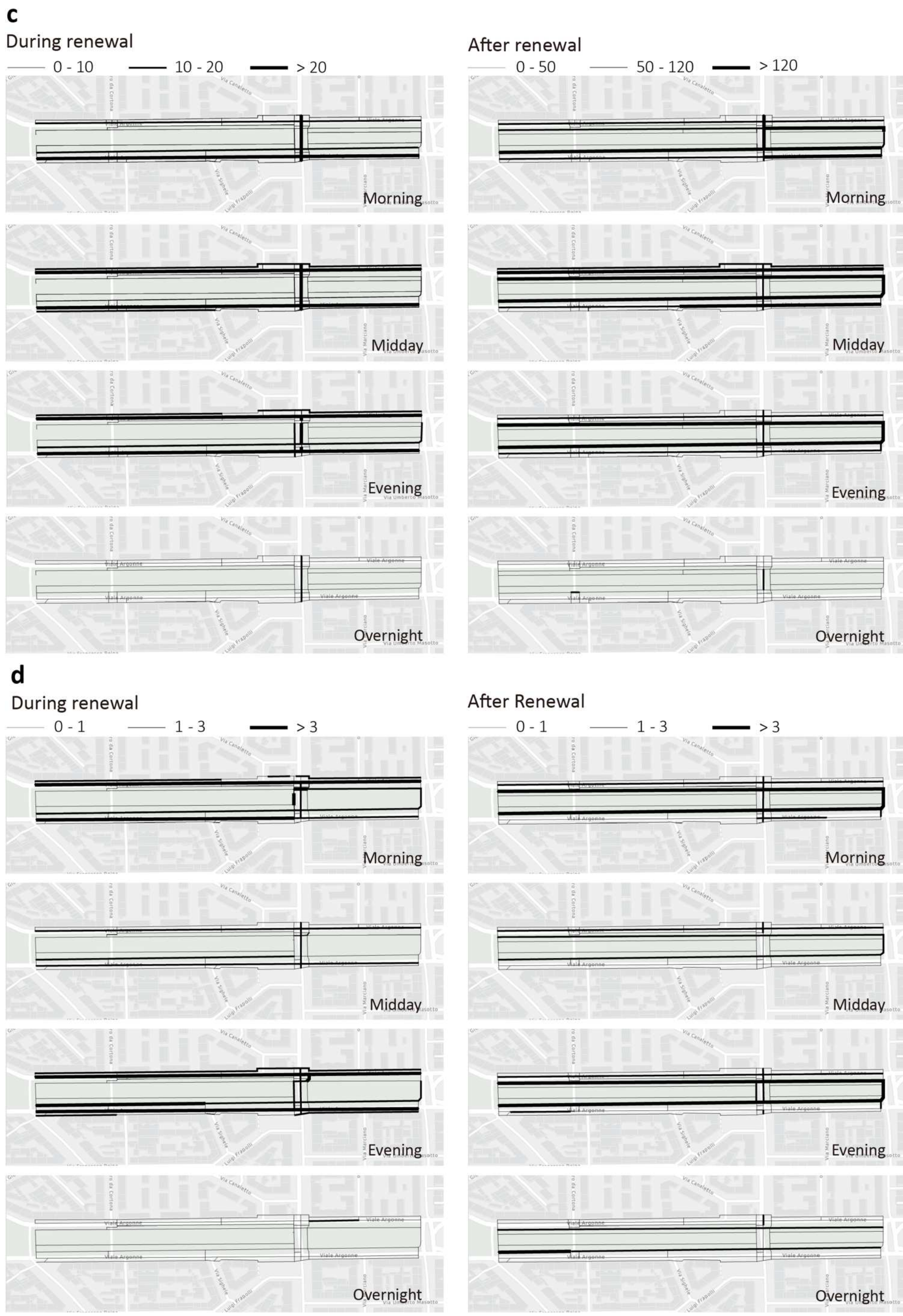

Figure A1. *Continued*

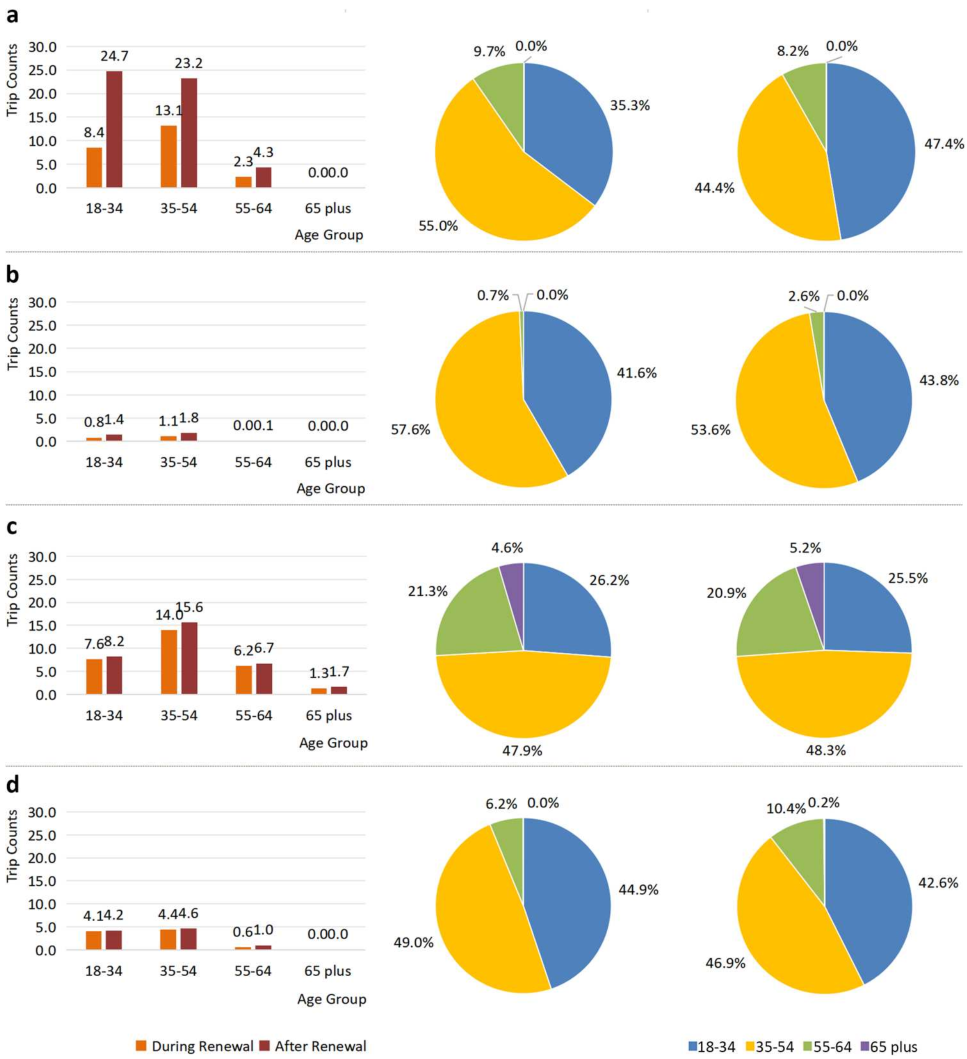

Figure A2. Annual average trip counts by age group during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

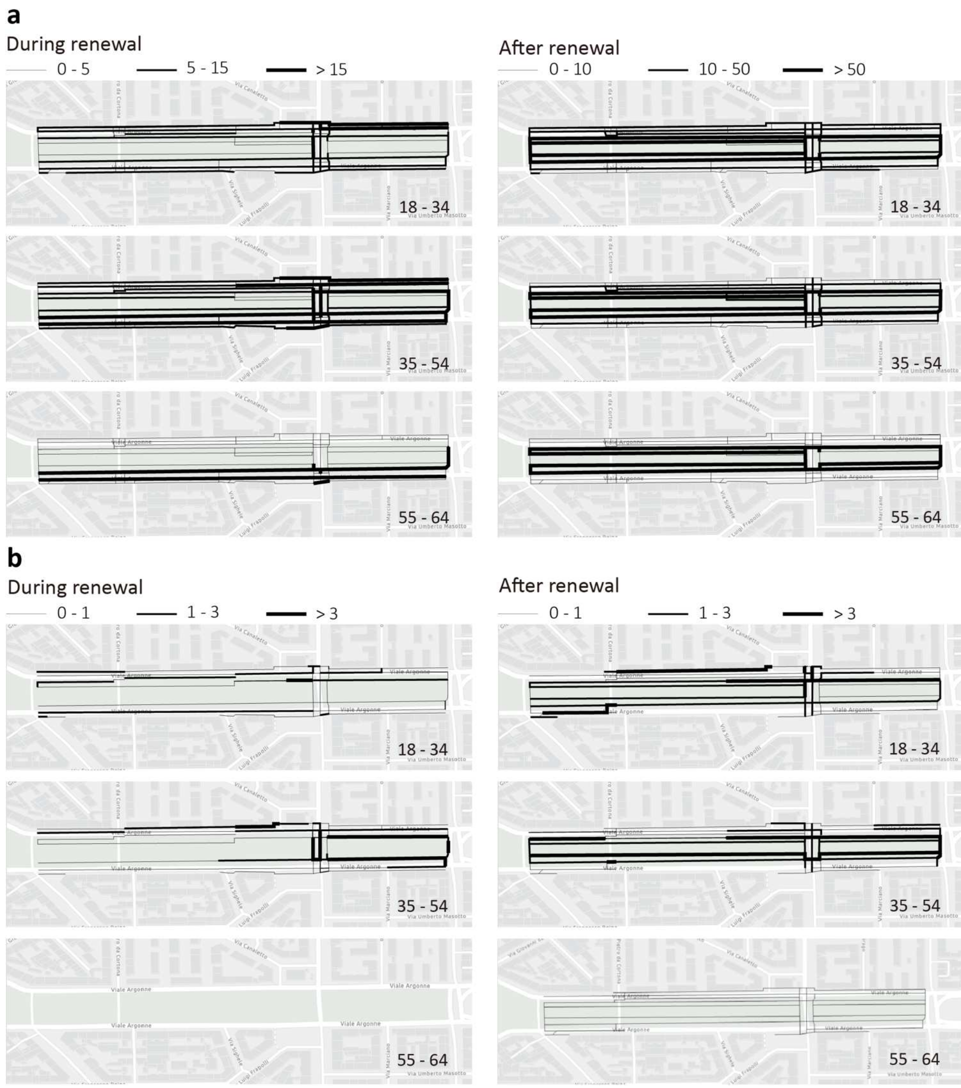

Figure A3. Spatial distribution of average trip counts by age group during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b). (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

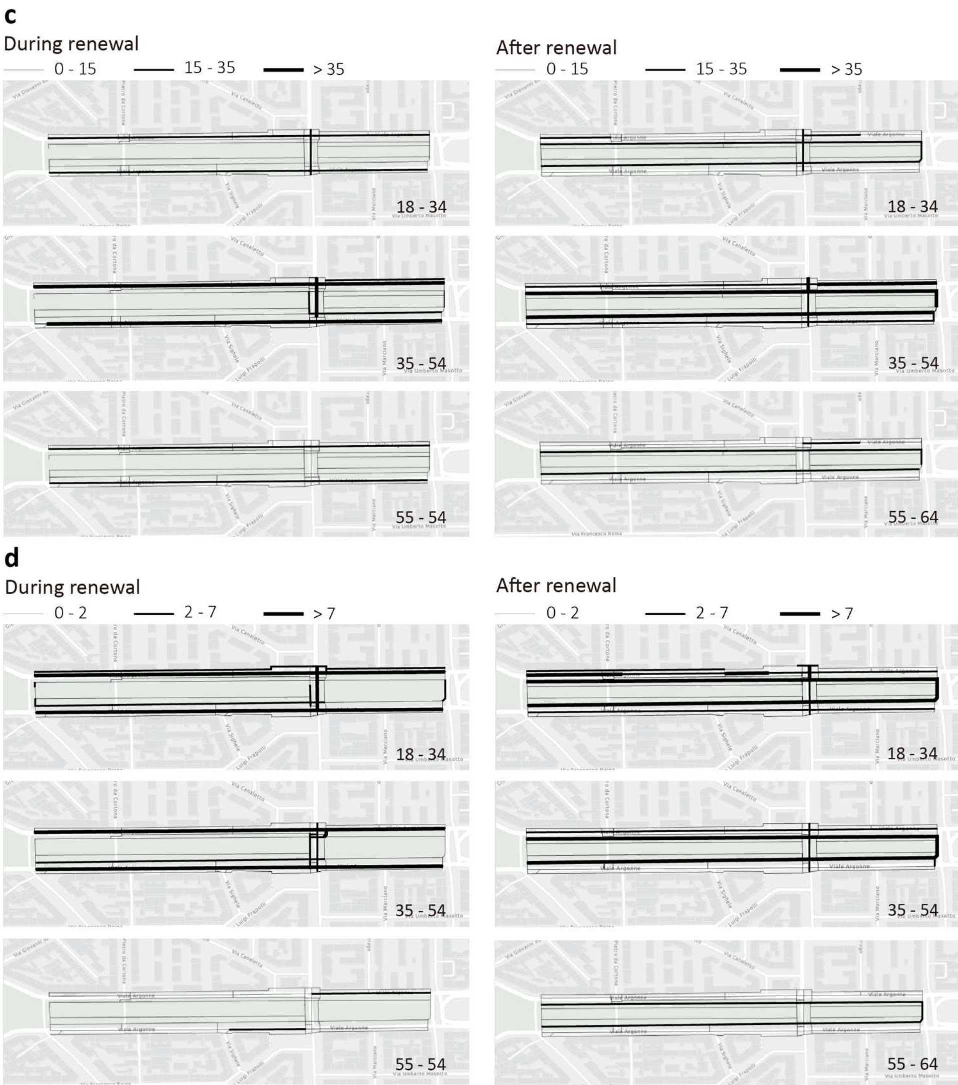

Figure A3. *Continued*

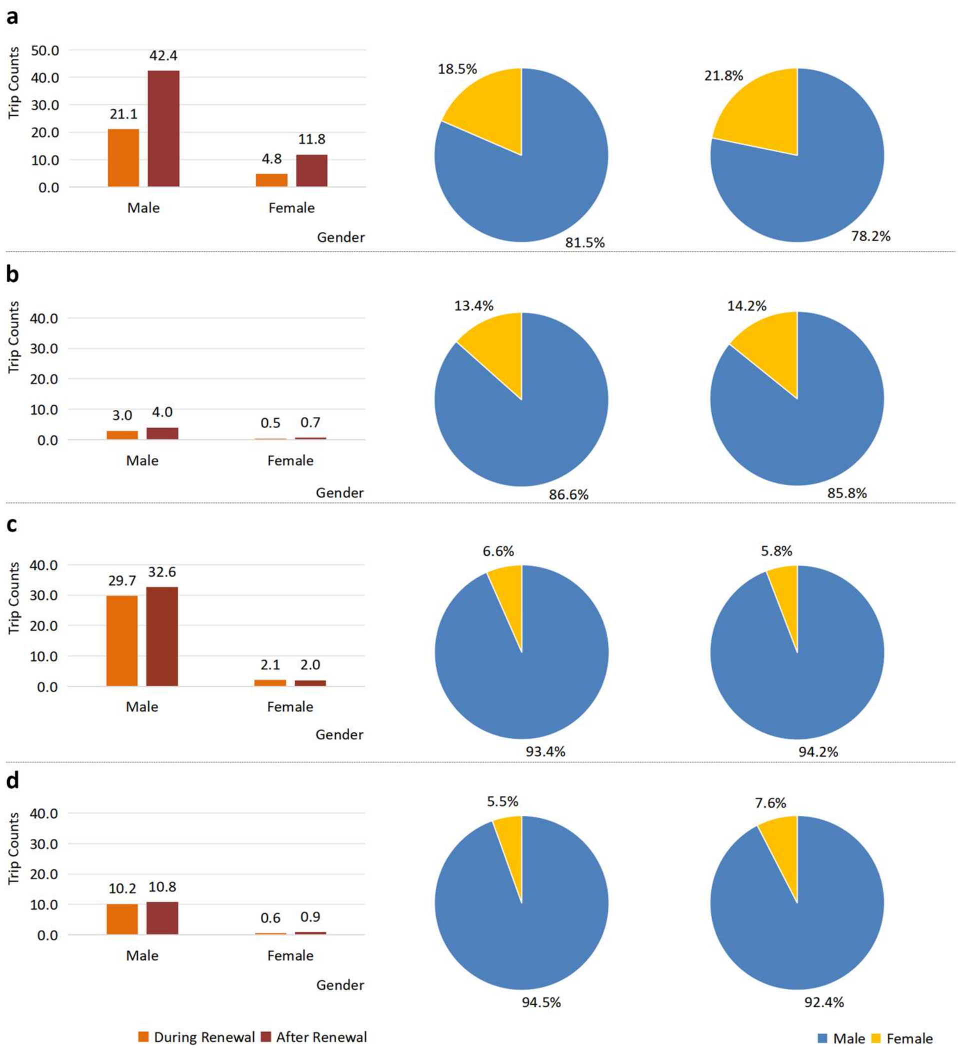

Figure A4. Annual average trip counts by gender during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).

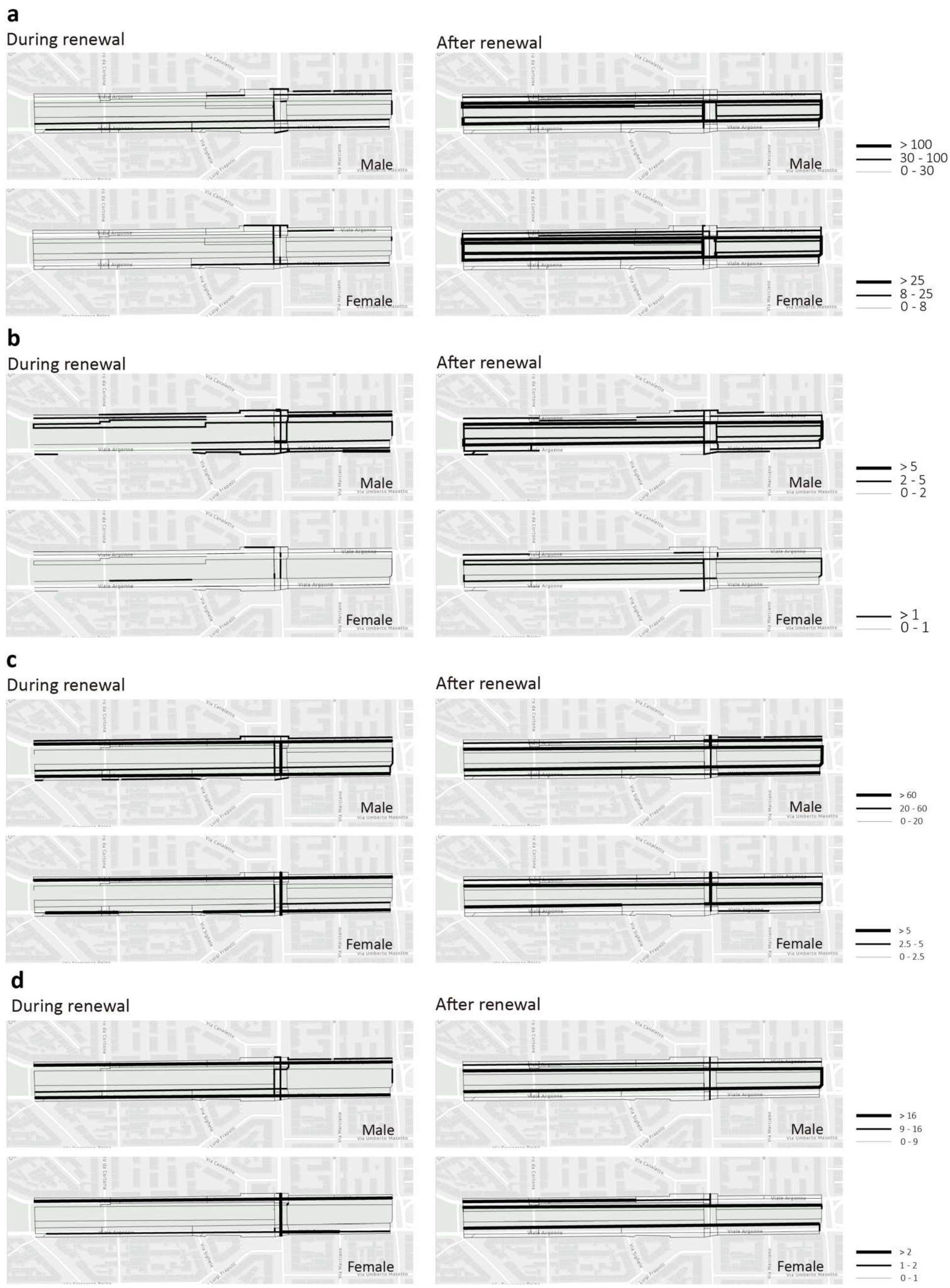

Figure A5. Spatial distribution of average trip counts by gender during and after the renewal: (a) leisure pedestrian activity (Group 1a and 1b); (b) commute pedestrian activity (Group 2a and 2b); (c) leisure cyclist activity (Group 3a and 3b); (d) commute cyclist activity (Group 4a and 4b).