GreenPath SF:

Evaluating and Improving the Suitability of Streets Network for Active Travel in San Francisco Downtown

Lulu Liu (MLA2D)
Instructor: Marta Gonzalez
GSI: Alben Bagabaldo

Abstract

This study presents a comprehensive evaluation of the suitability of the street network for active travel in downtown San Francisco, with a particular emphasis on the role of green canopy and street infrastructure. The primary objective is to assess how these elements contribute to creating an environment conducive to walking and biking, thereby promoting sustainable urban mobility.

To achieve this, the study employs a novel methodology that integrates the Green View Index, derived from Google Street View imagery, with detailed analysis of street infrastructure. This approach offers a unique perspective on the urban landscape, providing insights into how greenery and infrastructure jointly influence the appeal and functionality of active travel routes. The Green View Index serves as a critical measure, offering a quantifiable assessment of street-level greenery, which is directly correlated with the experience and well-being of pedestrians and cyclists.

In evaluating the street network, the study prioritizes routes that are most frequented by active travelers, identifying areas where improvements in greenery and infrastructure could significantly enhance the overall travel experience. This evaluation not only highlights the current state of these routes but also pinpoints potential areas for intervention and improvement.

The findings of this research are expected to contribute significantly to urban planning and design strategies in San Francisco. By focusing on the enhancement of green canopy and infrastructure, the study aims to foster an urban environment that supports active travel, aligns with sustainability goals, and improves the quality of life for city residents and visitors. This research holds the promise of guiding future urban development towards more pedestrian- and cyclist-friendly designs, thereby contributing to the broader vision of creating more livable and environmentally responsible cities.

Key word

Green View Index, Active travel, Streetscape, Urban greenery, Deep learning, Object detection Street-level photography

1 Introduction

This study focuses on downtown San Francisco, a city renowned for its commitment to sustainability and urban livability, to evaluate and enhance the suitability of its street network for active travel. Central to this research is the role of green canopy and street infrastructure in shaping the urban landscape for pedestrians and cyclists.

Active travel is essential for sustainable urban living, offering benefits like reduced emissions, improved public health, and vibrant social spaces. The physical attributes of the urban environment, particularly green canopy and street infrastructure, significantly influence the adoption of these modes of transport. Green canopy, comprising street trees and vegetation, not only enhances aesthetic appeal but also contributes to environmental health, creating inviting spaces for active travelers. Simultaneously, well-designed street infrastructure ensures safety and comfort, encouraging more people to walk or bike.

Employing a novel approach, this research utilizes the Green View Index from Google Street View imagery to quantitatively assess street-level greenery. This is coupled with an in-depth analysis of the street infrastructure to identify areas where enhancements could significantly improve conditions for walking and biking. The study aims to provide a comprehensive assessment of the current state and potential improvements in downtown San Francisco's street network. The findings are intended to inform urban planners and policymakers, guiding the development of more pedestrian- and cyclist-friendly streets.

2 Background

2.1Urban street greenery

Urban street greenery (i.e. street trees, shrubs, lawns, and other forms of vegetation) has long been recognized as critical landscape design elements in urban environments. In summary, the importance of urban street greenery has been long recognized for its diverse benefits in urban environments: carbon sequestration, pollution absorption, and heat island effect mitigation, to sensory and aesthetic enhancements that improve urban attractiveness and walkability.

Using Google Street View to calculate the Green View Index (GVI) offers an objective, scalable, and cost-effective way to assess the visual quality of urban greenery from the street level. By analyzing street view images, it's possible to quantify the amount of greenery visible in urban landscapes, offering a more direct measure of the visual experience of residents and visitors alike.

2.2 Active Travel

Active travel, defined as modes of transport that necessitate sustained physical exertion from the traveler to facilitate movement, becomes the nexus through which this model is conceptualized. The better street greeny environment could encourage active travel and create a better low emission and environmentally-friendly city.

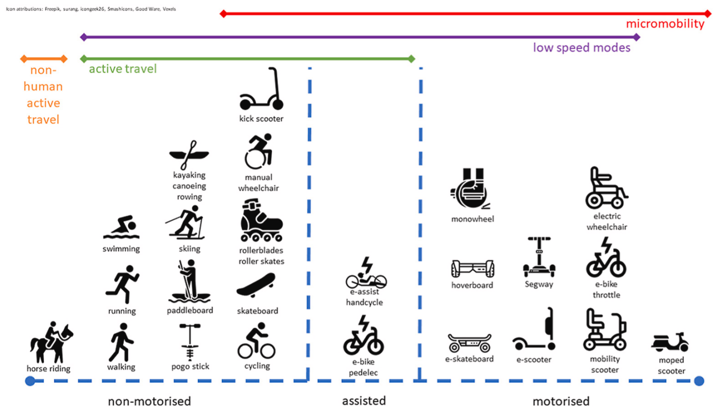


Fig1. Active Travel[1]

Fig2. the Uneven Street Tree Canopy in San Francisco Downtown[2]

2.3 Current Problems and Opportunities

1. The Uneven Street Greenery in San Francisco:
   San Francisco's urban landscape exhibits a noticeable disparity in the distribution of street greenery. Certain areas boast lush, tree-lined streets, while others lack sufficient green spaces. This uneven distribution of street greenery not only affects the aesthetic appeal of the city but also impacts the environmental benefits that these green spaces provide, such as air quality improvement and urban heat island mitigation.

2. Traffic Jam:
   Congestion is a significant issue in San Francisco, with many areas frequently experiencing heavy traffic. This not only leads to increased travel times and frustration for residents but also contributes to higher levels of pollution and greenhouse gas emissions. The city's dense urban layout and high population density exacerbate these traffic-related problems, highlighting the need for alternative transportation solutions.

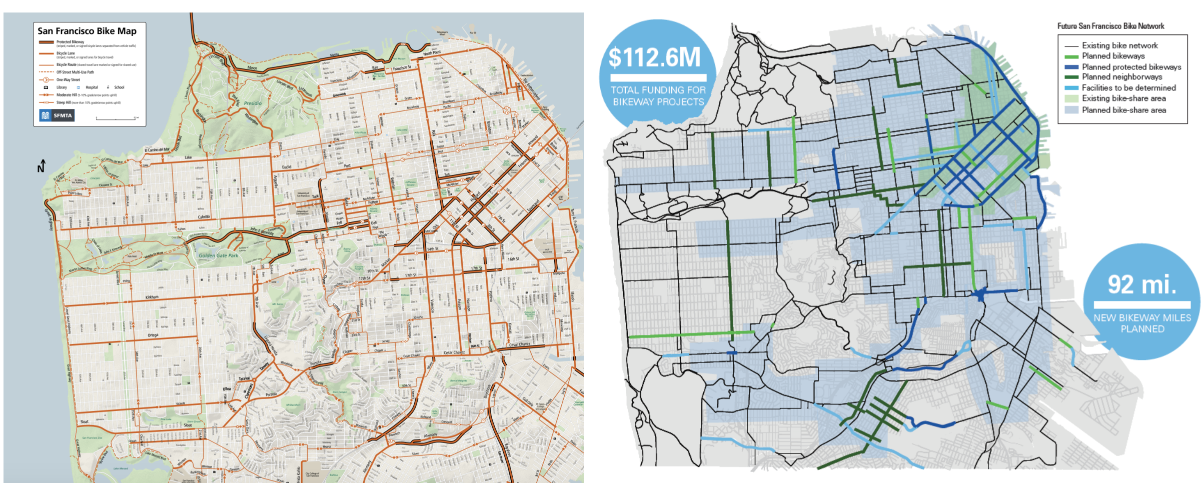


Fig3.San Francisco Bike Map and Bike Network[3]

---

1 Akbarzadeh, Meisam, Sayed Farzin Salehi Reihani, a links of urban networks using cluster detection methods." *Physica A: Statistical Mechanics and Its Applications* 515 (2019): 288-298.
2 https://sfpublicworks.org/services/street-tree-map
3 https://sfpublicworks.org/services/street-tree-map

3 Data Source and Research Area

3.1 Data Source

	Time	Location	Source	Original Format
Residents Walking Biking Data	02/2023-09/2023	San Francisco	Replica	CSV
Residents Biking Data	02/2023-09/2023	San Francisco	Replica	CSV
Street View Image	2021-2023 (not include winter month)	Part of San Francisco (Research Area)	Google API	200*200 jpg
Street Speed Limit		San Francisco	SF Open Data Portal	Shapefile, geojson
Bikeway Infrastructure		San Francisco	SF Open Data Portal	Shapefile, geojson
Sidewalk Width		San Francisco	SF Open Data Portal	Shapefile, geojson

The source of Residents Walking and Biking Data From 02/2023-09/2023 in San Francisco is Replica (a data platform) O-D by Trip Origin Dataset[4].
The weekly O-D pairs table contains information about nationwide hourly origin-destination data for a typical weekday and weekend day with hourly breakdowns and mode breakdowns (including auto, transit, walking, and biking).

3.2 Research Area

The San Francisco downtown area is a place with a high density of active travel. Our research chose the research boundary defined as Divisadero street and 16th st. The research area includes North Beach, China Town, Western Addition and so on.

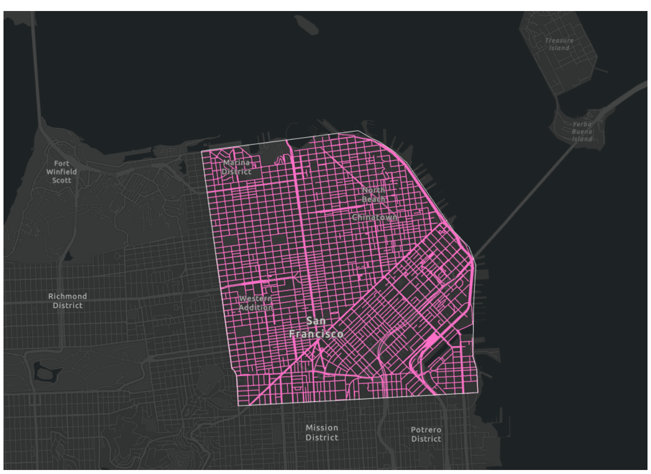


Fig4. Research Area

[4] https://studio.replicahq.com/data/downloads/od-by-origin

4 Methodology

4.1 Network Analysis and model active travel

1. Extended EDA (Exploratory Data Analysis) of Active Travel Data:
   Spatial Analysis: Analyze the geographical distribution of active travel routes.
   Temporal Analysis: Examine the time-based patterns in active travel, like peak hours, seasonal variations, and day-of-week trends.

2. Model Active Travel
   Compare the Constrained Gravity Model and Radiation Model and use CPC, RMSE, R-squared value, Max error to evaluate different models

4.2 Google Street View Perspective Correction

Google Street View provides different zoom values(0-5). The most appropriate zoom level to approximate human eye view would be Zoom Level 2, which offers a 90° field of view. This level provides a balance between a wide perspective and focused detail, aligning more closely with the central focus area of human vision.

4.3 Green View Index Calculation

The calculation of Green View Index (GVI) refers to the Treepedia tool developed by the MIT Senseable City Lab[5]. The process includes point sampling, metadata collection, GVI Calculation and Final Shapefile Generation. The mathematical method for calculating the Green View Index (GVI) in Treepedia involves classifying green vegetation from Google Street View images using object-based segmentation and Otsu's automatic thresholding method. The algorithm also considers the seasonality of the images.

Image Segmentation: The function starts by segmenting the original image using the mean-shift algorithm. This step helps in distinguishing different regions in the image based on color and spatial characteristics.

Color Component Analysis: The segmented image is normalized, and the red, green, and blue color components are extracted.

Green Vegetation Identification: The difference between the green band and the red and blue bands is calculated to highlight areas of vegetation.The algorithm calculates ExG (Excess Green Index) as the sum of these differences.Additional boolean masks are created to identify regions that are unlikely to be vegetation based on their red, green, and blue values. These include thresholds for identifying non-vegetative pixels and shadowed areas.

Threshold Application: A dynamic threshold is applied to the ExG to further refine the identification of green vegetation. This threshold is adjusted within a set range to optimize vegetation detection. Boolean operations combine the results of various thresholding steps to produce a final binary image indicating green vegetation presence.

[5] https://senseable.mit.edu/treepedia

Vegetation Proportion Calculation: The final step involves calculating the percentage of pixels in the image that are classified as green vegetation.This is done by counting the number of green pixels in the processed image and dividing it by the total number of pixels, then converting this ratio into a percentage.

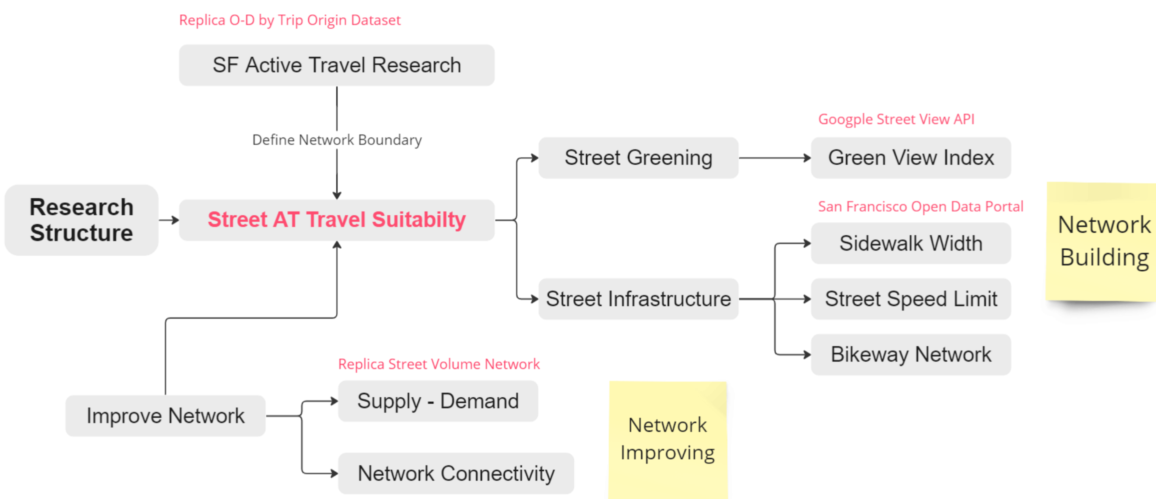


Fig5. Research Framework

4.4 Identify Streets Improvement By Weighted Network Connectivity

To identify the streets that need to be improved, we could compare the active travel suitability of streets (supply) and the active travel volume network (demand) to draw the conclusion. Besides that, we also designed a new structure to evaluate it. We build weighted networks and regard crossroads as nodes, roads as streets and suitability as weight. From the perspective of improving the connectivity of the network, we define a composite metric $M(e)$ to select streets .

Betweenness Centrality Computation:

We begin by calculating the betweenness centrality for all edges in the network. Betweenness centrality () for an edge e is a measure of the edge's influence on the flow efficiency across the entire network and is defined as the number of shortest paths between pairs of nodes that run along it. The centrality is calculated as follows:

$$C_B(e) = \sum_{s \neq e \neq t} \frac{\sigma_{st}(e)}{\sigma_{st}}$$

σst is the total number of shortest paths from node s to node t. $\sigma st(e)$ is the number of those paths passing through edge e.

Inverse Weight Assessment:

Recognizing that higher weights correspond to roads with better suitability for travel, we propose utilizing the inverse of the weight (W) as a proxy for improvement. For an edge e with a weight $W(e)$, the inverse weight is calculated as:

$$IW(e) = \frac{1}{W(e)}$$

This measure inversely correlates with the current suitability, meaning that roads with lower suitability scores are prioritized for upgrades.

Composite Metric for Road Improvement Prioritization:

To determine the priority for road improvements, we amalgamate the betweenness centrality and the inverse weight into a single composite metric (M). The edges are then scored based on this metric, which balances the importance of an edge in the network's connectivity with the urgency for its improvement. The composite metric for an edge e is given by:

$$M(e) = C_B(e) \cdot IW(e)$$

Edges with the highest $M(e)$ scores are identified as the most beneficial targets for improvement interventions. These edges are critical for connectivity and have significant room for enhancement in terms of their suitability for active travel.

5 Result

5.1 Active Travel Behavior

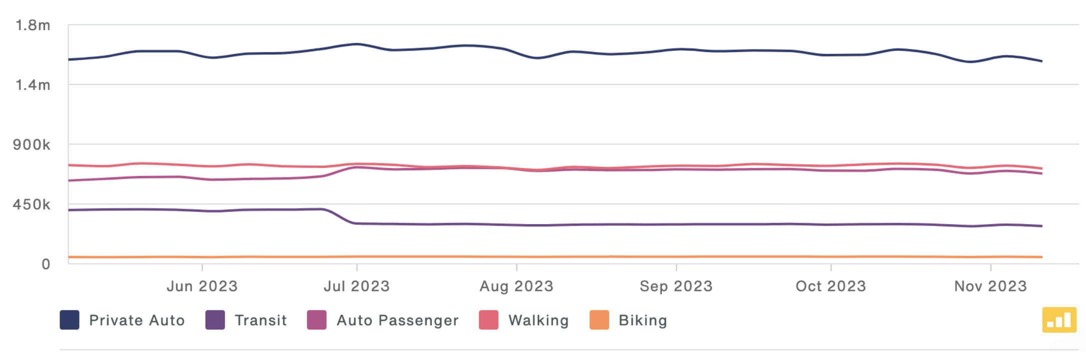
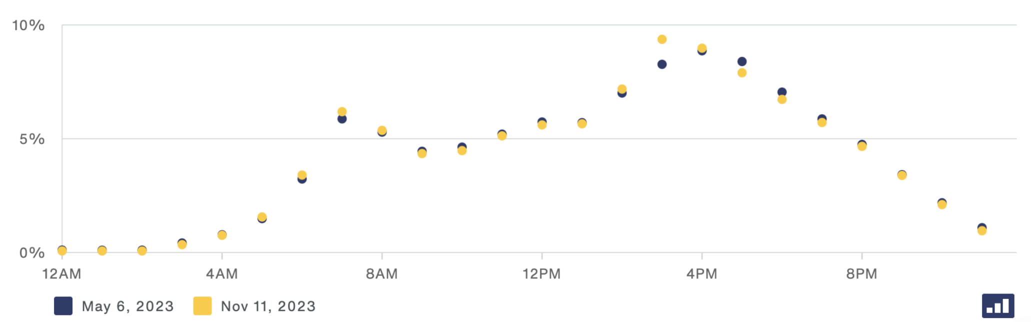


Fig6. Mode Split Trip volume



Fi7. Trip Start Time

The plots show private autos as the dominant transportation mode over several months, with stable transit use and minimal walking and biking. Morning and evening peaks suggest rush hours, with an evening spike on November 11 indicating a possible special event or seasonal behavior. Walking and biking are least used.

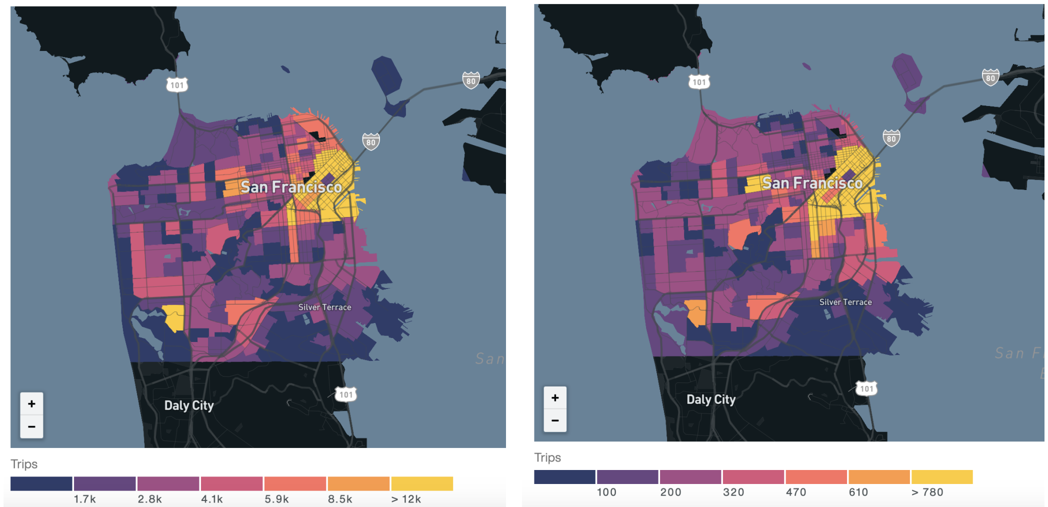


Fig8. Walking and Biking Trip volume by Destination

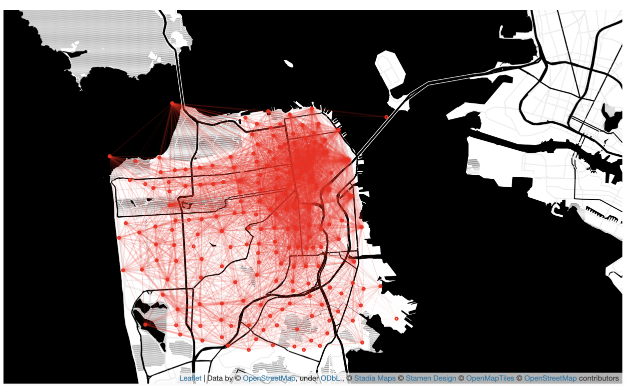


Fig9. Biking Travel Plot

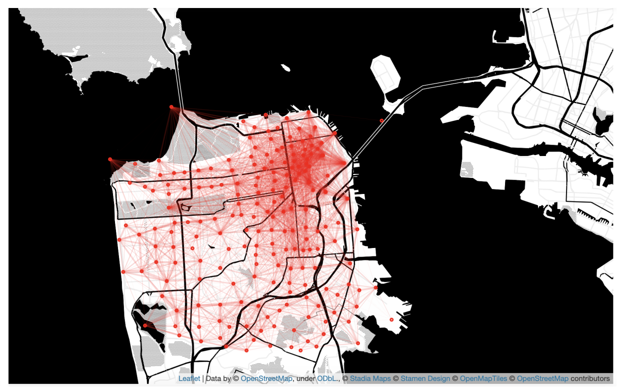


Fig10. Walking Travel Plot

Biking Travel Plot: The densest biking activity appears to be concentrated in what could be the downtown area, with heavy lines possibly indicating major thoroughfares or bike-friendly routes. If this is San Francisco, such areas could correspond to Market Street or the Embarcadero, known for their bike lanes.

Walking Travel Plot: The walking activity is widespread, with denser nodes that might represent areas like Union Square, the Financial District, or other downtown streets where pedestrian traffic is typically high. The spread of the red dots across the map suggests that walking is a common mode of travel throughout various neighborhoods.

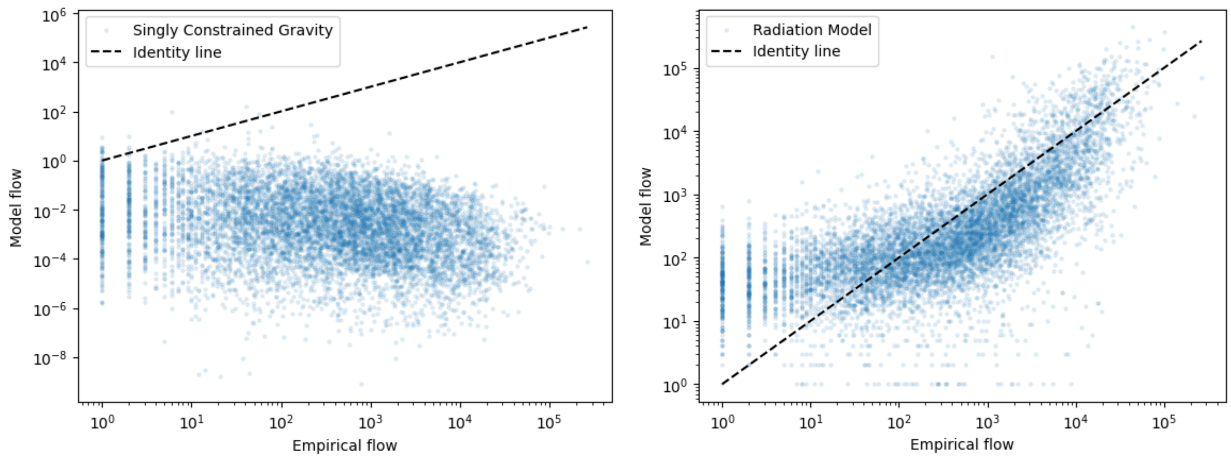


Fig11. Singly Constrained Gravity Model and Radiation Model

5.2 Green View Index

The Calculation of green view index (GVI) includes 3 steps: point sampling on the street network of San Francisco City, metadata containing GSV panoID and GVI calculation of sampling points.[6] Based on the open source code of the treepedia project, we improved and changed the process of calculation: setting zoom level equals to 2, filter out non winter months (January and December) and mean value of 6 different directions with dropping 2 minimum values. For each sample point, we calculated 6 images of 6 different directions (0, 60, 120, 180, 240, 300). For most of the street sample points, there will be 2 directions facing the building instead of street trees. So the 2 minimums should be filtered out before calculating the final mean value.

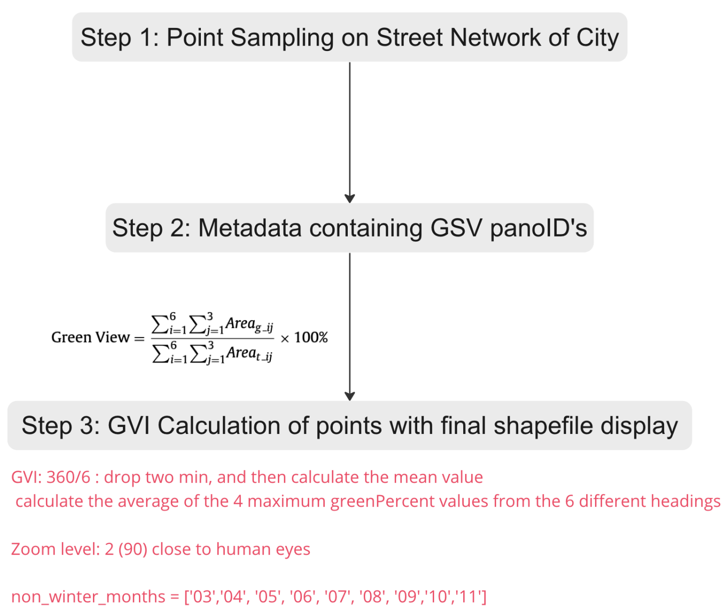


Fig12. Process of Calculating GVI

[6] https://github.com/mittrees/Treepedia_Public

We used 50m as the sampling interval to collect points from the street shapefile. The number of final GVI points in the San Francisco downtown area is 7055. The average GVI is 8.2%. The GVI assessment of San Francisco reveals the distribution of urban canopy greenery. The green dots that are likely representing trees or vegetation patches are not uniformly distributed across the city.

Fig13 Sample Points (50 Meters Interval)

Fig14 Distribution of GVI Value

We then add normalized GVI and other normalized features which are about street infrastructure: Speed limit, bikeway infrastructure and sidewalk width. Each feature is from 0 to 1. The final result is the indicator of active travel suitability of the streets.

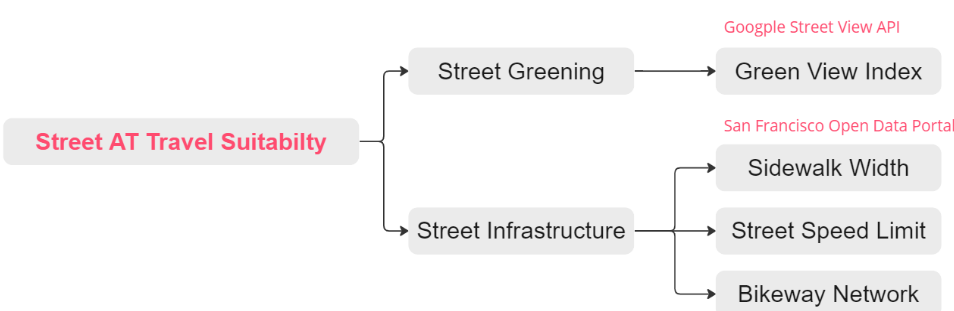


Fig15. Calculation of Street Active Travel Suitability

5.3 Suitability Evaluation

Fig16. Evaluation of Active Travel Suitability Network

Fig17. Improvement Suggestion Map

According to the suitability result and the active travel volume, we can conclude the streets that have lower suitability grade but have higher value of active travel volume. This means that these streets need to be reconstructed and improved to build a better active travel environment. These highlighted streets are Market Street (NE), Mission Street (NE), California St, Post St, 6th St, 7th St and so on.

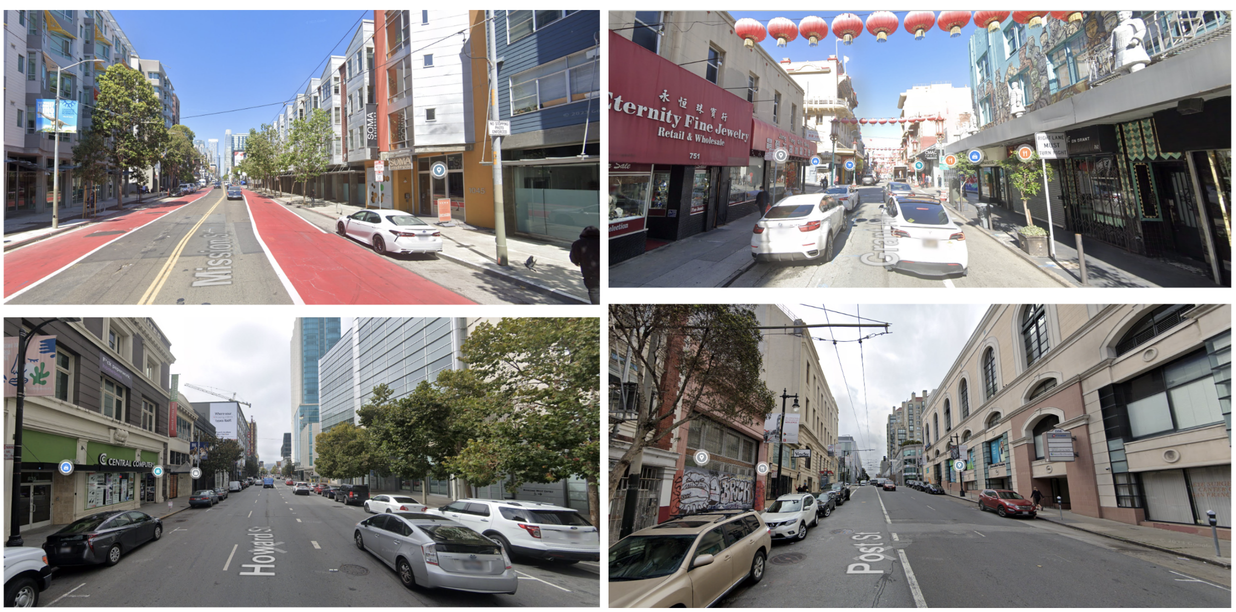
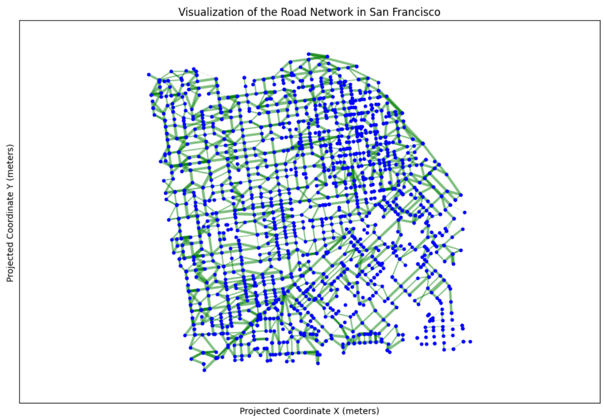


Fig18. Current Street View (Google Map)

5.3 Weighted Network Evaluation



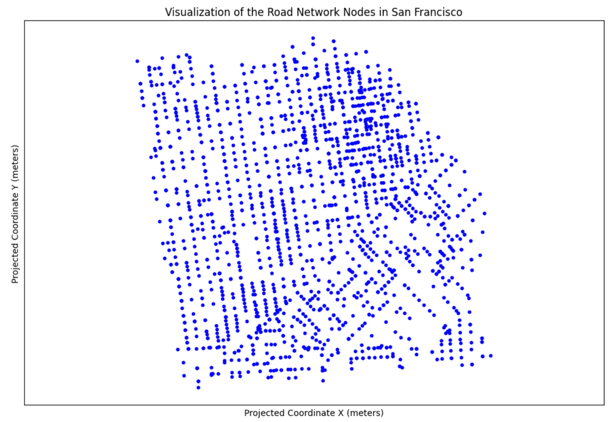


Fig19. Street Network Visualization (weighted link) Fig20. Street Network Visualization (without link)

Incorporating weights into the analysis to improve connectivity can be approached by considering the suitability of each road for active travel. The higher weight indicates better suitability. So we prioritize improving roads with lower weights, as these are less suitable in their current state. However, simply improving the least suitable roads doesn't ensure maximum connectivity, we also improve roads that would most benefit the overall connectivity of the network. We sort streets according to M(e) because edges with the highest M(e) scores are identified as the most beneficial targets for improvement interventions. Then select the streets with the defined limited budget to draw the final conclusion.

PROGRAMS/PROJECTS (Dollars in Thousands)	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023 - 2027	Plan Total	Backlog
SPENDING PLAN								**DEFERRED**
Streets & ROW								
State of Good Repair Renewal - Streets & ROW	93,329	98,669	105,066	113,007	119,144	707,320	1,236,535	809,042
Public Right-of-Way Transition Plan Improvements	10,299	10,379	10,803	11,330	11,863	68,078	122,751	-
Enhancements - Streets & ROW	54,500	7,000	82,150	57,250	-	128,082	328,982	2,563,075
SUBTOTAL	**158,128**	**116,048**	**198,018**	**181,587**	**131,007**	**903,481**	**1,688,268**	**3,372,116**

Fig21. San Francisco City Financial Summary (For Infrastructure and Streets)[7]

For the financial year 2023-2027, the investment on the state of Good Repair Renewal - Streets & ROW is about 707,320,000. We assume that 20% money will be spent on street renewal. After calculating, the budget of renewal street in San Francisco downtown in the future 5 years is about 23,577,000. The raw cost estimate of renewal streets is about $5000 per meter and the length of streets is about 11,788 meters.

[7] San Francisco Capital Plan https://onesanfrancisco.org/

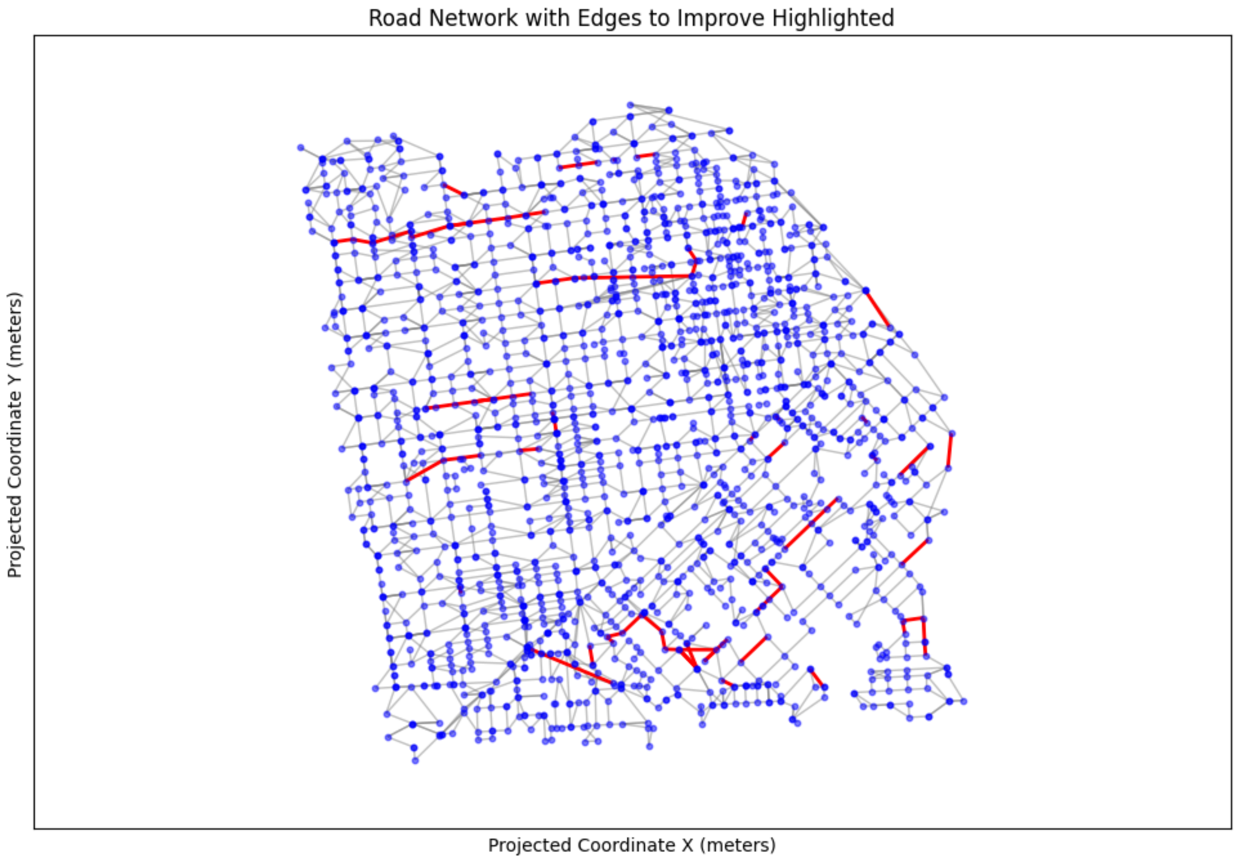


Fig22. Selected Streets (Red Highlighted)

6 Limitation and Future Work

Firstly, the use of Google's API poses constraints, including a limited number of requests that can be made, and the fact that many images are captured during winter, potentially skewing the representation of greenery. Secondly, the travel data used has its own limitations. The origin-destination dataset lacks specific travel trajectories, and the data on the active travel network is incomplete. Lastly, the classification algorithm used to analyze greenery has its shortcomings, as it equates all green items to tree canopy or greening, which might not always be accurate.

Future work:

Evaluating Green Justice: Investigate disparities in green space distribution and active travel facilities across different neighborhoods.Examine the correlation between socio-economic factors and access to green spaces. Propose policy recommendations to address any identified inequities in green space distribution.

7 Reference

Li, Xiaojiang, et al. "Assessing street-level urban greenery using Google Street View and a modified green view index." Urban Forestry & Urban Greening 14.3 (2015): 675-685.

Aric A. Hagberg, Daniel A. Schult and Pieter J. Swart, "Exploring network structure, dynamics, and function using NetworkX", in Proceedings of the 7th Python in Science Conference (SciPy2008), Gäel Varoquaux, Travis Vaught, and Jarrod Millman (Eds), (Pasadena, CA USA), pp. 11–15, Aug 2008

Berland, Adam, and Daniel A. Lange. "Google Street View shows promise for virtual street tree surveys." Urban Forestry & Urban Greening 21 (2017): 11-15.

Berland, Adam, and Daniel A. Lange. "Google Street View shows promise for virtual street tree surveys." Urban Forestry & Urban Greening 21 (2017): 11-15.

Tanhuanpää, Topi, et al. "Mapping of urban roadside trees–A case study in the tree register update process in Helsinki City." Urban forestry & urban greening 13.3 (2014): 562-570.

Anguelov, Dragomir, et al. "Google street view: Capturing the world at street level." Computer 43.6 (2010): 32-38.

Ki, Donghwan, and Sugie Lee. "Analyzing the effects of Green View Index of neighborhood streets on walking time using Google Street View and deep learning." Landscape and Urban Planning 205 (2021): 103920.

Ki, Donghwan, and Sugie Lee. "Analyzing the effects of Green View Index of neighborhood streets on walking time using Google Street View and deep learning." Landscape and Urban Planning 205 (2021): 103920.

Cook, Simon, et al. "More than walking and cycling: What is 'active travel'?." Transport Policy 126 (2022): 151-161.

8 Appendix

8.1 Active Travel Origin-Destination Data Analysis

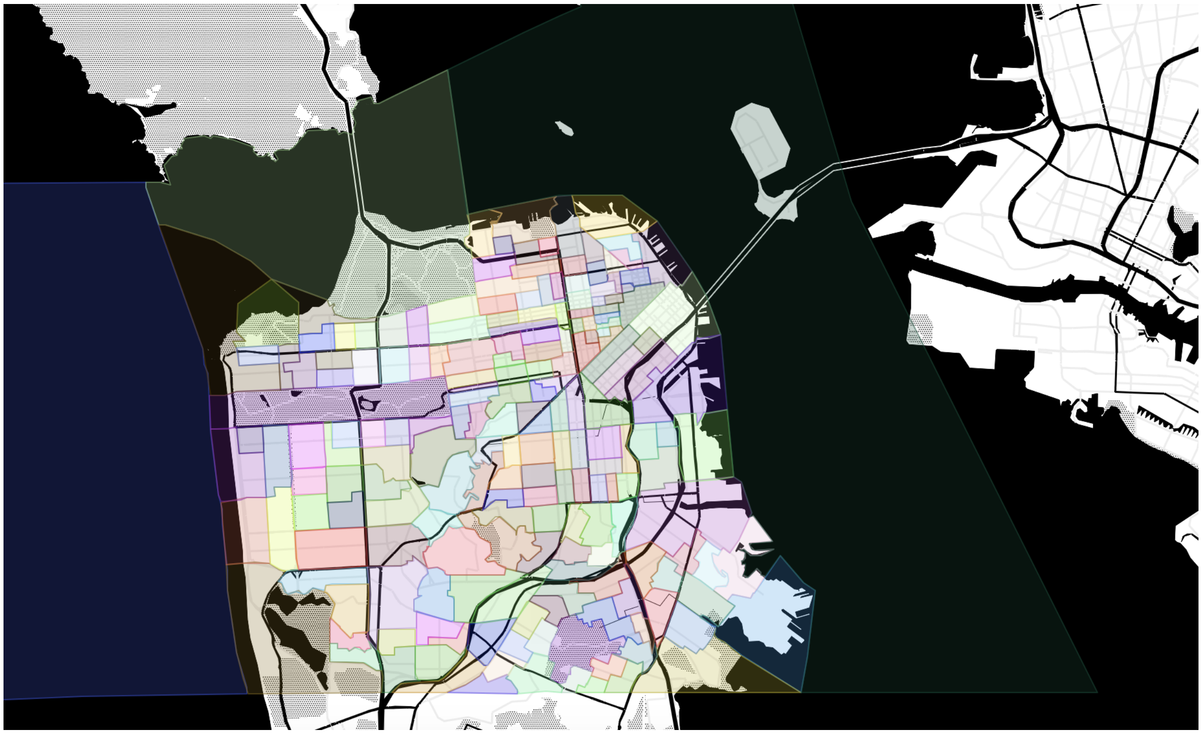


Fig. Census Tracts in SF

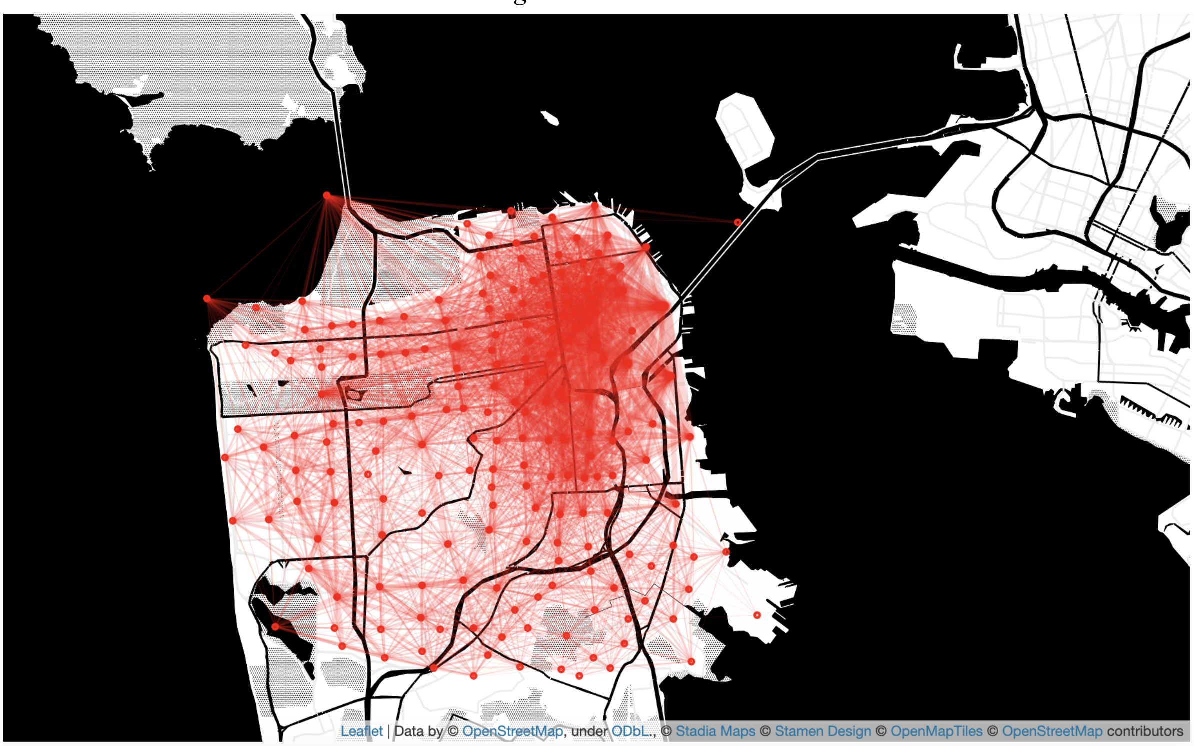


Fig. Biking Travel Plot

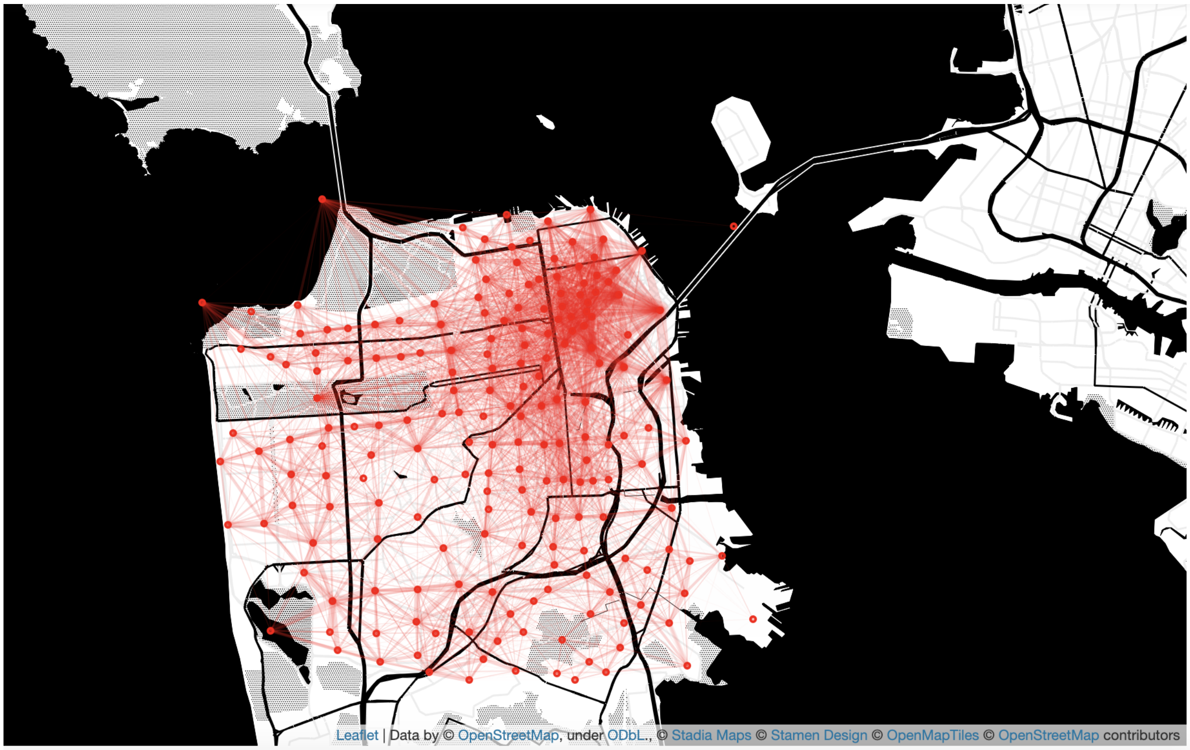


Fig. Walking Travel Plot

8.2 Street Infrastructure Situation

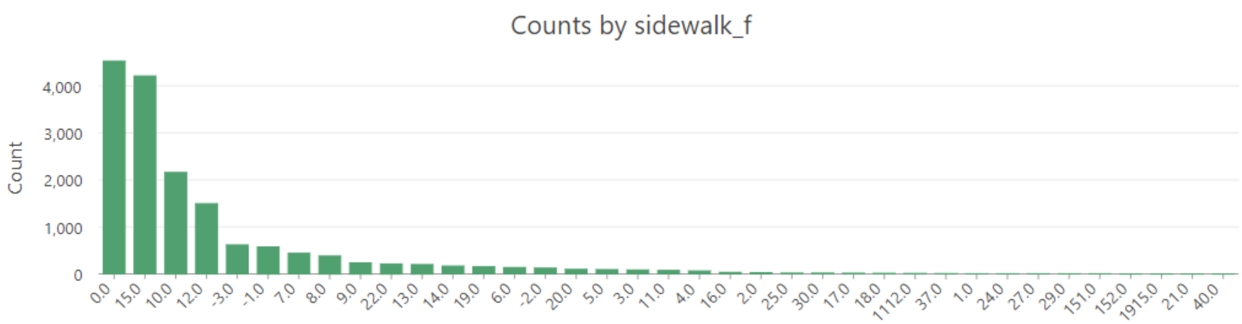


Fig. Distribution of Sidewalk Width

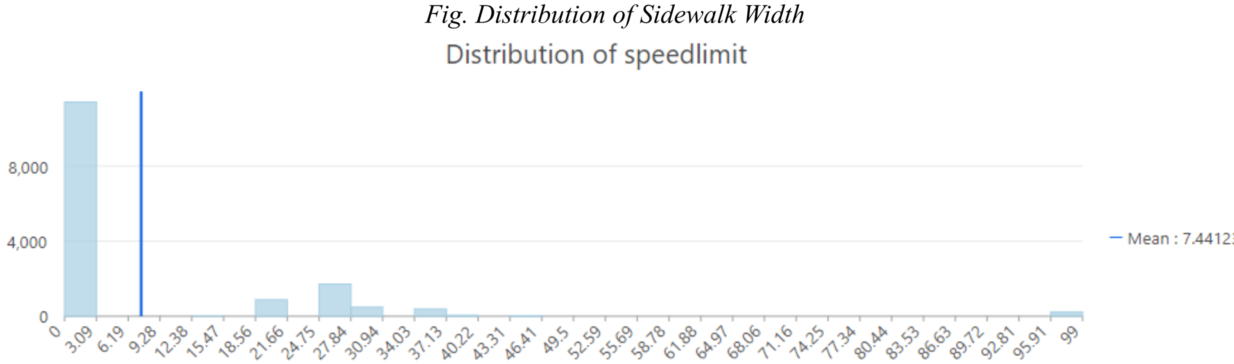


Fig. Distribution of Street Speed Limit

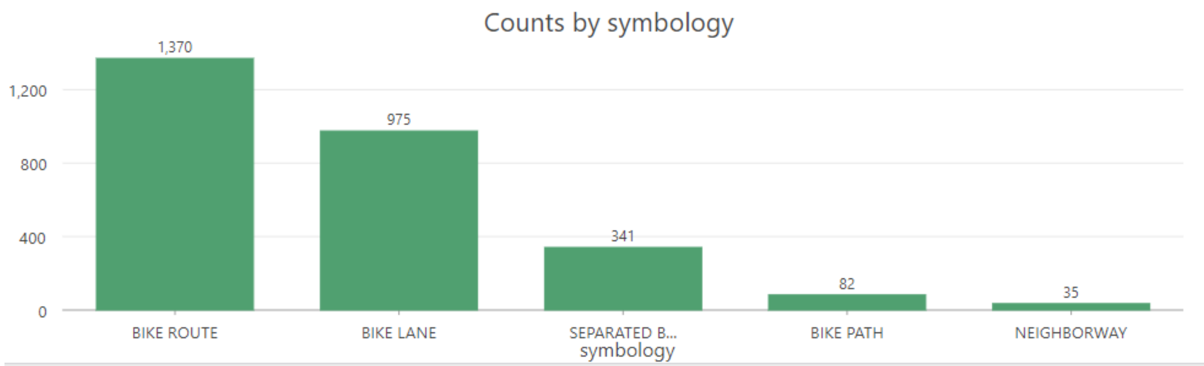


Fig. Bike Infrastructure Statistic

8.3 Sample Classified Images

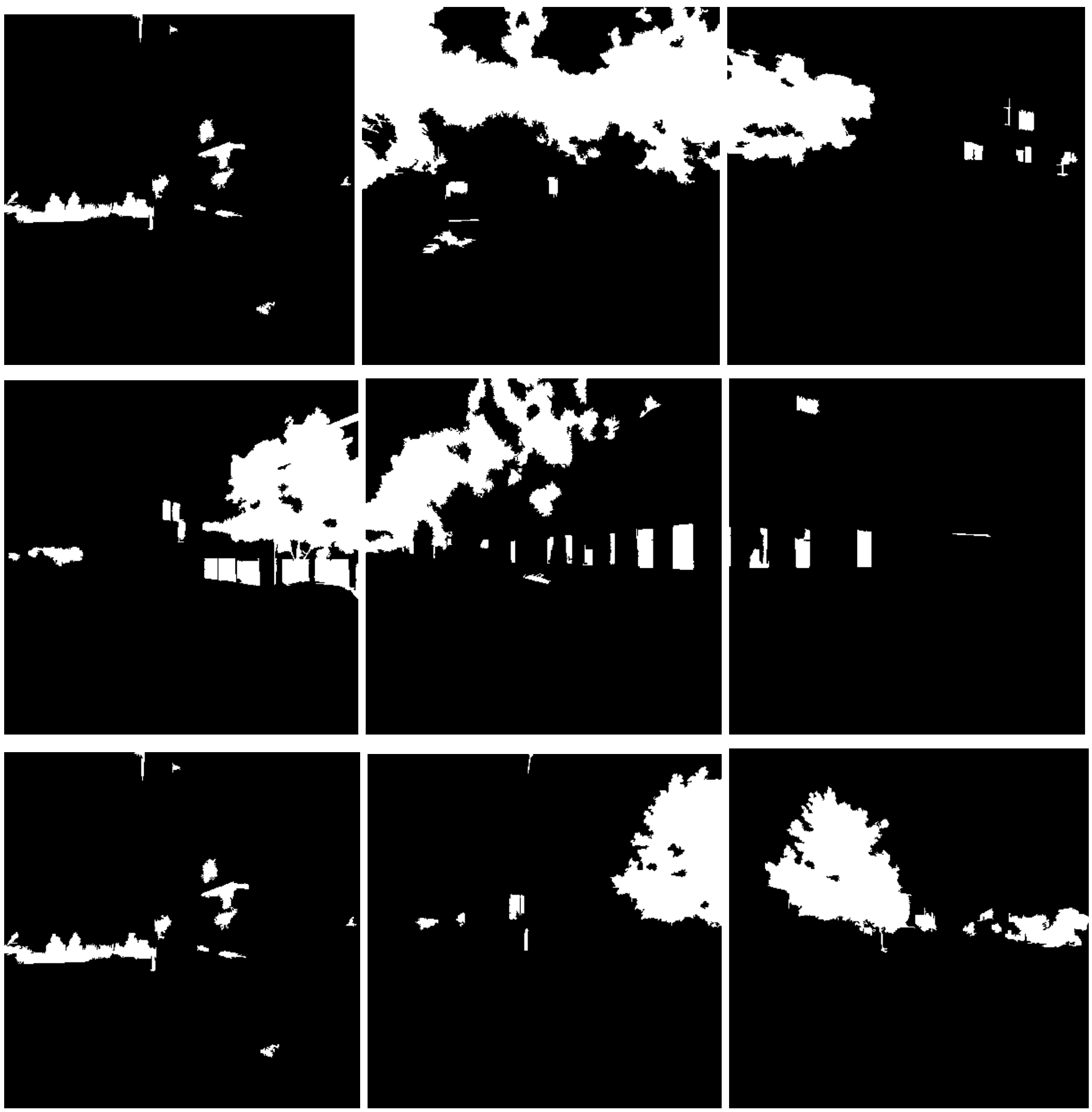


Fig. Sample Classified Images (White = Green View Pixel)

8.4 Distribution of Green View Index

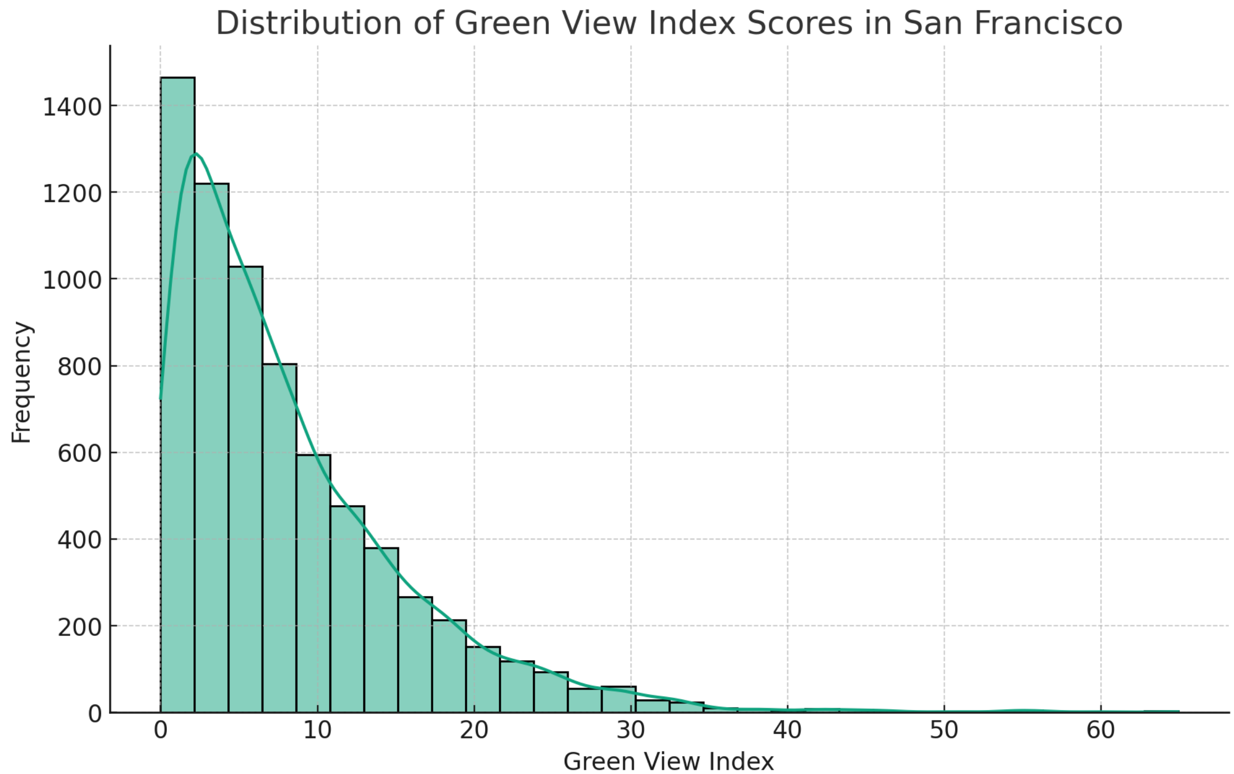


Fig. Distribution of GVI

Count: There are 7,037 observations in the dataset.
Mean: The average Green View Index score is approximately 8.19, indicating a moderate level of greenery visibility on average.
Standard Deviation: The standard deviation is about 7.59, suggesting a wide range of greenery visibility across different locations.
Minimum: The minimum score is 0, which indicates locations with no visible greenery.
25th Percentile (Q1): 25% of the locations have a Green View Index of 2.60 or less.
Median (50th Percentile): The median score is around 6.05, which means that half of the locations have a Green View Index below this value and half above.
75th Percentile (Q3): 75% of the locations have a Green View Index of 11.60 or less.
Maximum: The maximum score observed is 64.90, suggesting some locations with very high visibility of greenery.

8.5 Python Script

Notebook link:
https://drive.google.com/drive/folders/1Neti9u1YIQ4ZrUGPaxZOuTr7rkt-0Mii?usp=drive_link

Data Link:
https://drive.google.com/drive/folders/13b320rcssYIMNwduIlc6J6FWPPgMOPz_?usp=drive_link