Advancing Pedestrian Models: A Comparative Review and Vision for the Future

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PREFACE

Transport models have a fundamental role in transport planning and policy, where they are often used for predicting and assessing modal and route choice in urban areas. Most models and applications have been developed for planning motorised traffic, while those concerning walking have not been widely available and used. Currently there are, however, a few well-established pedestrian models which are available for research, assessments and planning. There is however a need to compare and evaluate pedestrian models in order to e.g., better understand their strengths and potential relevance for capturing modal choice, subjective aspects and walking in special kinds of urban environments, such as informal areas. There is also a research-policy gap when it comes to the use of pedestrian models. Yet to date there have been few efforts to compare and evaluate such models.

The current report by Andres Sevtsuk and colleagues at the Massachusetts Institute of Technology (MIT) focuses on a description and comparative analysis of current pedestrian models. The report draws on insights and findings presented at an "International Research Seminar on Modelling Urban Pedestrian Mobility", organized by Andres Sevtsuk and held on 5–6 October 2023. The purpose of the seminar was to assess the current status of pedestrian modelling and explore future possibilities, while also identifying common challenges and research priorities that can inform urban design, planning, and policy related to pedestrian mobility in cities worldwide. The seminar was attended by leading researchers in pedestrian modelling from both the Global South and the Global North.

The seminar and the current report were commissioned by the Volvo Research and Educational Foundations (VREF) within its "Walking as a mode of transport" program. This program is a VREF-funded initiative that aims to strengthen international research, research capacity, and education on walking in ways that can contribute to more equitable access and sustainable mobility in urban transport, see also www.vref.se.

We hope that this report will be a resource for researchers, educators, policymakers, planners and other stakeholders in their efforts to understand, develop and apply models for walking in urban areas.

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Executive Summary

Pedestrian mobility is increasingly recognized as a cornerstone of sustainable, healthy, and equitable urban environments. Yet, despite the growing policy emphasis on promoting walkable cities, pedestrian modeling has historically received limited attention compared to vehicle-based modeling. This report critically evaluates the current landscape of pedestrian modeling frameworks, identifies methodological gaps, and outlines opportunities to enhance the utility and policy relevance of these tools.

The study is grounded in the proceedings of the *International Research Seminar on Modeling Urban Pedestrian Mobility*, held at Massachusetts Institute of Technology (MIT) in October 2023, which convened global experts to assess the state of the art in pedestrian modeling. Drawing on insights from the seminar and a rigorous comparative analysis, this work first aims to systematically evaluate five prominent pedestrian models—Urban Network Analysis (UNA), Multi-Agent Transport Simulation (MATSim), Model of Pedestrian Demand (MoPeD), Spatial Design Network Analysis (sDNA), and Place Syntax—using the classic four-step transportation modeling framework (trip generation, trip distribution, mode choice, and route choice), and then to highlight how these models can evolve to better inform planning practice and public policy.

Findings reveal substantial diversity across modeling tools in terms of spatial resolution, data needs, behavioral assumptions, and analytical capabilities. UNA and sDNA offer high spatial detail and intuitive visualizations suitable for planners, while MATSim provides robust agent-level simulations across multiple travel modes. MoPeD delivers fine-grained pedestrian demand estimation at the grid-cell level, and Place Syntax offers lightweight spatial accessibility analysis with minimal data requirements.

Despite their strengths, each model also presents specific limitations. Notably, most current models focus heavily on utilitarian walking, often neglecting non-trip-based activities such as leisure, exercise, or social interaction in public spaces. Furthermore, existing models tend to treat pedestrian behavior as homogeneous, failing to capture variations by age, sex, income, or ability—factors that are crucial for inclusive planning.

Another observation lies in the lack of application in informal urban contexts so far, particularly in low- and middle-income countries, where unregistered settlements and informal transport routes shape pedestrian behavior in significant ways. The report also highlights a persistent lack of comprehensive pedestrian count data, which limits the ability to calibrate and validate model outputs. Addressing these issues requires not only improved data collection infrastructure but also deeper community engagement to capture local walking patterns and qualitative insights.

To strengthen the utility and policy impact of pedestrian models, we advocate for a broader, more human-centered, and purpose-driven modeling agenda. This includes developing simple yet powerful metrics that capture the multifaceted benefits of walking, supporting both investment decisions and policy evaluation. We also emphasize the need for models that are adaptable across all stages of planning, including early-phase scenario testing—even in data-limited contexts. Central to this vision is a pluralistic modeling ecosystem that embraces methodological diversity, accommodates varied data environments, and aligns closely with real-world planning and policy priorities. Transitioning from highly specific predictive tools to flexible decision-support systems is essential for adapting to varied planning and policy needs and addressing complex urban challenges such as climate resilience, public health, and social equity. Finally, we underscore the importance of deeper collaboration between researchers and municipal agencies to ensure that models remain grounded in real-world planning practice.

While technical innovation in pedestrian modeling continues to advance, its impact will remain constrained without meaningful integration into policy discourse, the development of responsive metrics, and the creation of accessible tools. Addressing methodological limitations, capturing diverse behavioral patterns, and strengthening connections to planning and policy are essential steps toward maximizing the utility of these models. This report advocates for a paradigm shift in pedestrian modeling—one that embraces modularity, complexity, prioritizes inclusivity, and ensures practical relevance to create walkable, vibrant, and equitable urban environments for all.

Contents

1. Introduction

1.1 What Is a Pedestrian Model?

Pedestrian models are analytical tools designed to estimate how, where, and when people move on foot through urban environments. These models simulate or predict pedestrian flows between locations based on factors such as land use, population and job density, street network characteristics, accessibility to destinations, and, in some cases, individual characteristics and behavioral preferences. Depending on the modeling approach, pedestrian models may estimate the number of people walking along specific streets or sidewalks, identify popular routes, and evaluate how changes in the built environment—such as adding a park, improving sidewalks, or constructing a new transit station—affect foot traffic patterns. Just as traffic models help plan for vehicles, pedestrian models provide essential insights for designing walkable, safe, and accessible urban environments. Models can be developed for specific purposes (e.g., identifying critical walking routes to schools) or for more general purposes (e.g., estimating total foot traffic on a broad range of city streets during a given time period).

The description above primarily refers to macro-scale pedestrian models, which operate at the city and neighborhood levels. Another class of pedestrian modeling tools is micro-simulation software, such as Vissim or Legion. While micro-models are valuable for analyzing detailed pedestrian crowd dynamics in settings such as intersections, transit stations, stadiums, or evacuation scenarios—where the emphasis is on inter-personal interactions, crowding, and congestion—they are not designed to capture broader walking patterns across urban street networks and neighborhoods. Our emphasis in this report is therefore on models that explain how demographics, accessibility, and the built form shape pedestrian flows at neighborhood and city scales. To avoid confusion, this report does not cover micro-level pedestrian simulation tools.

1.2 Why Do Pedestrian Models Matter?

A growing body of research at the nexus of transportation and urban planning indicates that a shift to sustainable modes of urban travel—such as walking, biking, and public transit—is necessary to reduce urban carbon emissions, address public health crises, and make cities more livable for all. Although still in the minority, some municipal and state agencies have begun to address non-motorized travel more rigorously, for example by requiring pedestrian mobility to be included in travel demand models and development impact reviews. However, mainstream transportation modeling approaches have historically focused on capturing the dynamics of vehicles and public transport, and many remain unaware that pedestrian mobility can be modeled with scientific rigor.

While most automobile-oriented travel demand models tend to ignore pedestrian trips, the few that do consider walking as a mode of transport typically focus on aggregate trip generation rather than their geographic distribution along city and local streets. Yet pedestrian flows are highly localized and sensitive to specific features of the built environment. Understanding their spatial distribution—and developing models that explain how the built environment influences foot traffic—is essential for designing policies and plans that support non-automobile travel.

A substantial body of pedestrian planning scholarship has emphasized the importance of mode-specific infrastructure, for instance, building safe and comfortable sidewalks. Albeit important, sidewalk quality alone is often insufficient to increase pedestrian mode share in cities. This is evident in many suburban environments where sidewalks exist and meet design standards, yet the broader built environment fails to generate walking trips. Pedestrian models can help planners and policymakers understand a wider range of factors that influence walking activity beyond route quality. They can estimate and visualize how the availability, proximity, and diversity of destinations affect the likelihood of walking for various trip purposes, and how the relative density and proximity of both origins and destinations are critical in explaining overall pedestrian volumes on city streets. Empirically grounded behavioral assumptions in these models can also describe how trip likelihoods diminish with distance and how convenient access to destinations increases pedestrian trips per capita. The structure of the built environment and the spatial relationship between origins and destinations are often under-examined in sustainable mobility discussions. Pedestrian models can capture such broader influences on walking activity and broaden planning debates from mere sidewalk improvements to more holistic built environment considerations.

A renewed policy emphasis on improving the pedestrian environment has therefore created a need to better understand how pedestrian flows are shaped by urban form in general, and how building and infrastructure developments may affect foot traffic on surrounding streets in particular. This understanding is critical for prioritizing investments in the pedestrian realm and leveraging zoning and urban design to promote walkability and enhance pedestrian experiences.

1.3 Example Applications of Pedestrian Models

Pedestrian models offer powerful analytical capabilities for understanding and improving urban mobility. They can be applied in diverse contexts—from measuring accessibility and forecasting pedestrian flows to evaluating design interventions and identifying critical routes in the walking network. This section presents five illustrative examples that demonstrate the versatility of pedestrian models in real-world settings. Drawing from applications in Munich, Melbourne, Beirut, Cardiff, and London, the figures highlight how these models translate complex urban dynamics into actionable insights for planners, policymakers, and designers aiming to create more walkable and accessible cities.

Pedestrian models are valuable tools for analyzing accessibility across urban neighborhoods. **Figure 1.1** illustrates pedestrian accessibility in the Munich city area (Zhang, Moeckel, and Clifton 2024), visualized at a high-resolution 100 × 100 meter grid known as Pedestrian Analysis Zones

(PAZs). Accessibility is measured by calculating the total number of non-industrial jobs and residents reachable within an 800-meter walking distance from each PAZ, using isochrones generated from the pedestrian street network via OpenStreetMap data. Darker shades represent areas with higher pedestrian accessibility, typically denoting dense, well-connected neighborhoods that facilitate walking. Conversely, lighter shades indicate areas with fewer accessible destinations and lower pedestrian infrastructure quality.

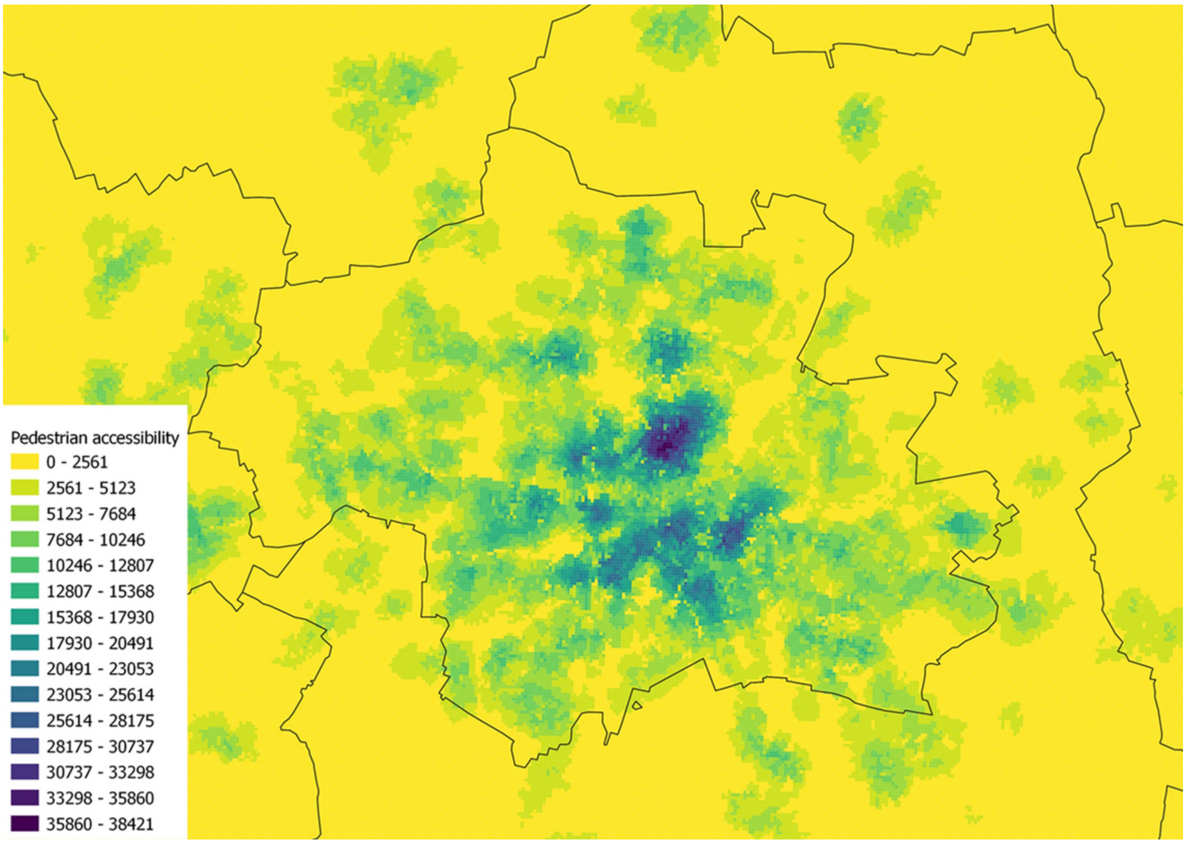

Figure 1.1: Spatial Distribution of Pedestrian Accessibility in Munich City

Pedestrian models are valuable tools for forecasting future pedestrian movement patterns based on past trends and anticipated changes in the built environment. **Figure 1.2** presents an application of such a model in the central business district (CBD) of Melbourne (Sevtsuk, Basu, and Chancey 2021). It shows predicted pedestrian flows during the morning peak hour (8:00–9:00 AM) on a typical workday in June 2015. These forecasts are derived from a model calibrated using 2014 pedestrian count data and updated with 2015 land-use changes. The figure provides a detailed spatial distribution of expected foot traffic across all sidewalk segments and crossings, illustrating how pedestrian activity responds to evolving urban conditions. Policymakers can use this analysis to identify locations where pedestrian flow is projected to exceed existing capacity and prioritize improvements to the walking environment accordingly.

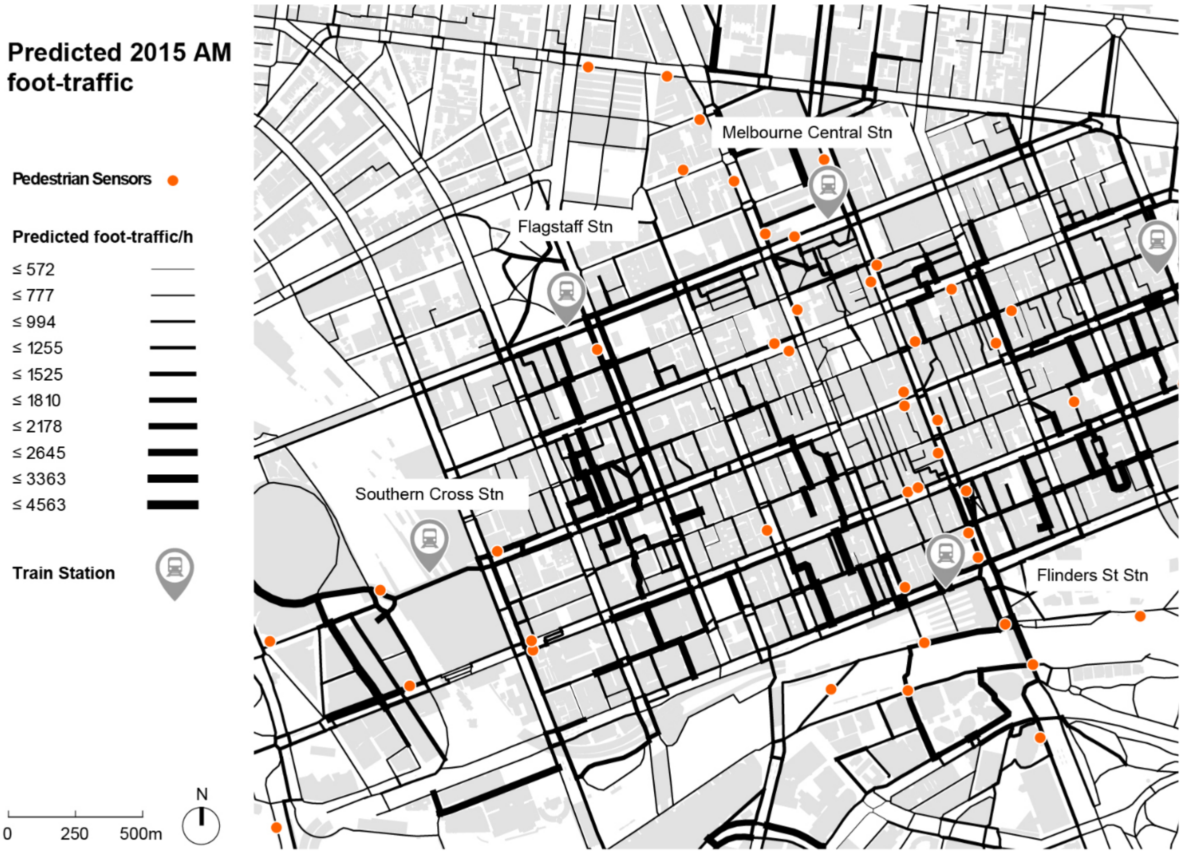

Figure 1.2: Predicted Morning Peak Hour Pedestrian Flows in Melbourne's CBD (June 2015)

Pedestrian models can be used to evaluate how urban design interventions influence pedestrian activity. In Beirut, such a model was applied to project changes in pedestrian activity under different design scenarios (Sevtsuk et al. 2024). **Figure 1.3** presents predicted changes in pedestrian flows during weekday afternoon peak hours (4:30–5:30 PM) across three urban design scenarios. *Scenario 1* involves tactical street upgrades, such as safer crossings and footbridge improvements. *Scenario 2* incorporates permanent infrastructure enhancements, including pedestrianized streets and the opening of parks. *Scenario 3* reflects large-scale urban transformations, such as converting highways into boulevards and introducing new promenades and parks. The figure visually illustrates how each scenario redistributes pedestrian activity geographically compared to the baseline condition, highlighting the potential impact of various design interventions on walkability.

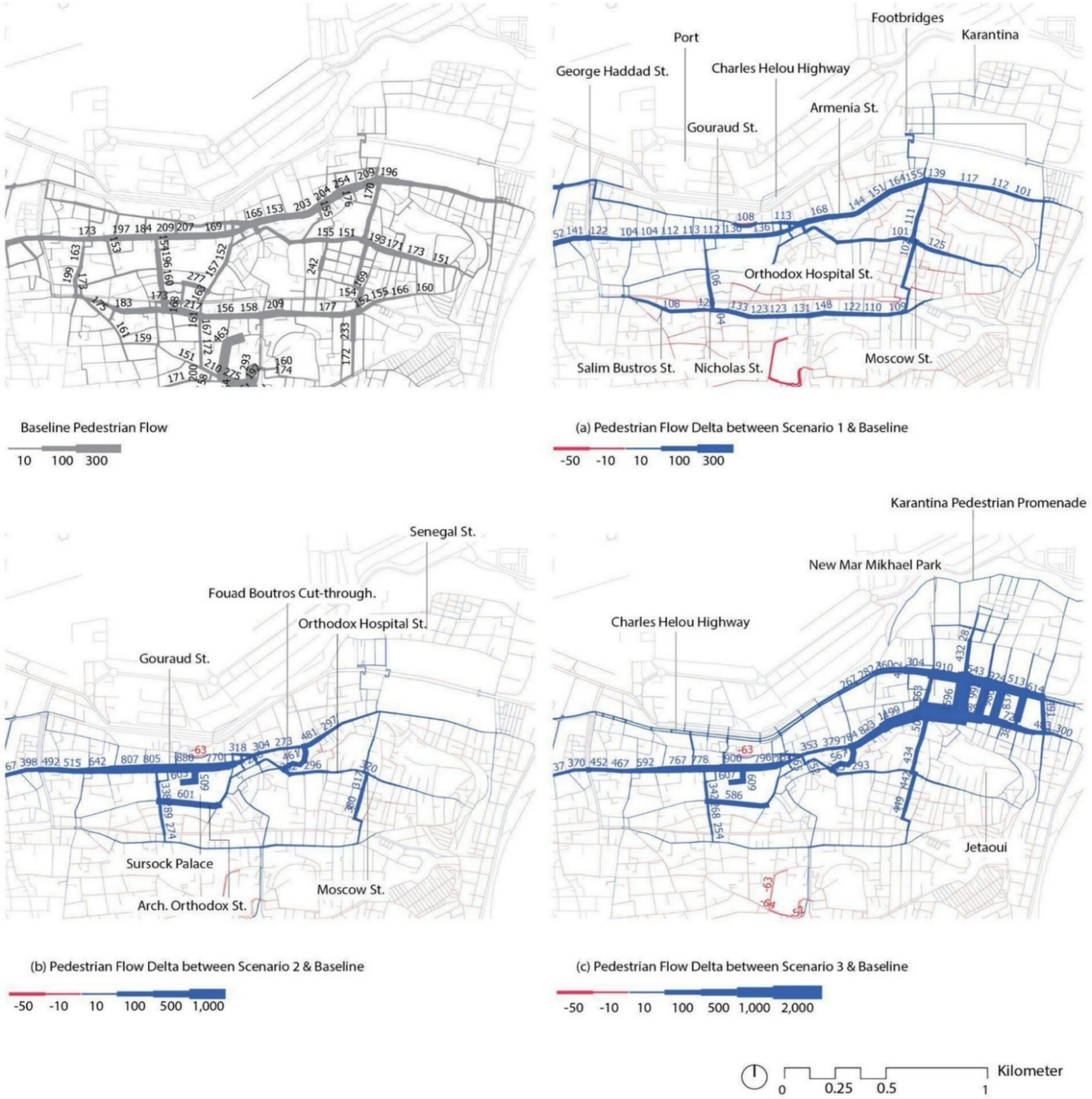

Figure 1.3: Simulated Pedestrian Activity Across Three Urban Design Scenarios in Beirut

Pedestrian models can be used to evaluate the characteristics of pedestrian networks and identify key routes. **Figure 1.4** illustrates this by showing the angular betweenness centrality of Cardiff's road network (Cooper and Chiaradia 2020). This measure highlights road segments that play a critical role in citywide movement. Angular betweenness[1] is calculated using an 8-kilometer network radius and assumes that people prefer to take straighter paths when walking. In the figure, darker lines represent routes with higher betweenness values, indicating they are more frequently used in the shortest paths across the city. Identifying these high-importance routes is essential for planning pedestrian infrastructure, managing traffic, and ensuring accessibility during emergencies.

1 In Space Syntax, angular betweenness is a variation of the standard betweenness measure that uses angular distance instead of topological or metric distance when calculating shortest paths.

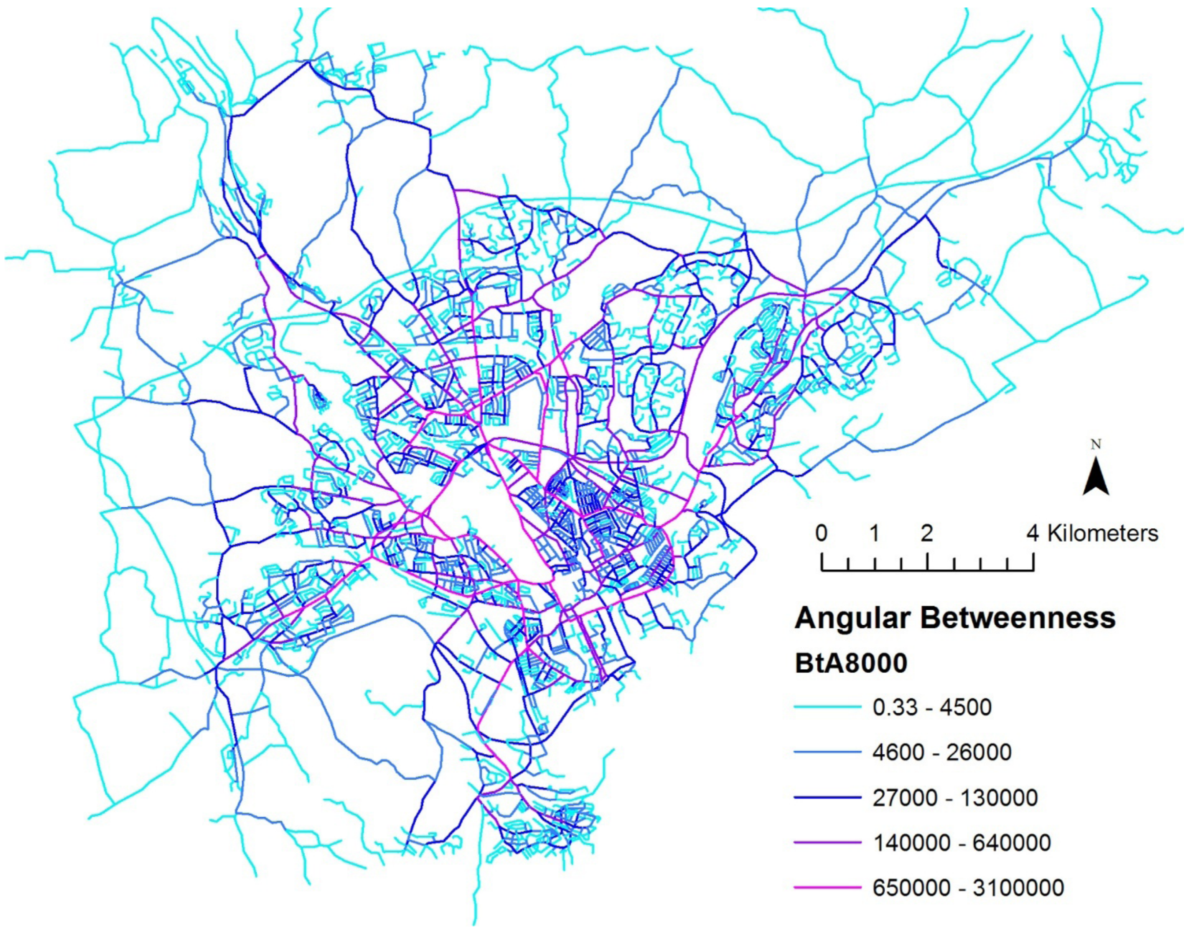

Figure 1.4: Spatial Distribution of Angular Betweenness in Cardiff's Road Network (8 km Radius)

Pedestrian models can also be used to examine spatial relationships between elements of the urban form—such as street network segments and adjacent parcels—rather than directly modeling trips or trip-making behavior, similar to the previous example of angular betweenness. **Figure 1.5** illustrates an example from London's street network, where combined Space Syntax and Place Syntax analyses were used to identify street segments that are both spatially integrated within the network and embedded in dense urban fabric—conditions strongly associated with higher pedestrian activity (Marcus 2025).

The Space Syntax component measures closeness centrality (or "integration"), which evaluates how well-connected each street segment is to others within a 2 km radius based on angular distance. Darker street segments indicate greater spatial integration, which often corresponds to more historic and connected areas. Meanwhile, the Place Syntax analysis assesses accessible density, showing the proximity of parcels to surrounding floor space density (measured by Floor Space Index, or FSI) within a 500-meter walking distance. Darker parcels represent areas with higher surrounding built density, reflecting greater land use accessibility. Together, these methods highlight streets and parcels that are central to both the network and the urban fabric. Details of the Space Syntax and Place Syntax approaches are provided in **Section 3.5.**

Figure 1.5: Spatial Integration and Accessible Density in London

1.4 Modeling Approaches in Pedestrian Mobility

In recent decades, modeling pedestrian mobility as part of land use and transportation systems has gained momentum across academic and professional communities. Three broad categories of modeling approaches can be distinguished:

I. *Sketch Planning, Factoring Methods, and Direct Demand Models:* These approaches estimate pedestrian demand through comparative analysis of various locations and their observed pedestrian activity levels. This typically involves regressing pedestrian counts on variables such as land use mix, density, demographics, street type, and other built environment characteristics, and then applying the resulting regression coefficients to predict pedestrian activity in comparable areas.

II. *Agent-Based Simulations:* These models simulate the movement of individual people—called agents, which are virtual representations of people that follow decision-making rules —along specific routes in space, based on behavioral assumptions and origin–destination pairs. These simulations can produce high-resolution results, where each individual trip is explicitly visualized. However, the high degree of specificity and extensive setup requirements have limited the applicability of agent-based pedestrian models to relatively small-scale environments, such as airports, transit stations, or a few downtown blocks. Multi-Agent Transport Simulation (*MATSim*), an agent-based framework, and Model of Pedestrian Demand (*MoPed*), a pedestrian-specific travel demand model that operates in conjunction with *MATSim*, are notable exceptions that have been applied at the urban scale.

III. *Network-Based Models:* Large-scale pedestrian flow prediction has emerged through network-based models such as PedContext, Urban Network Analysis (*UNA*), Spatial Design Network Analysis (*sDNA*), Depthmap, and Urbano. These models estimate trip-level pedestrian trajectories mathematically, without simulating or visualizing the movements of individual agents. Instead, they calculate the number of trips traversing each network link using graph theory methods, enabling results to be produced more quickly and across significantly larger study areas than agent-based approaches. This makes network analysis an attractive option for planners and urban transportation consultants, particularly those working at the neighborhood scale with high spatial complexity.

1.5 The Need for Comparative Evaluation

While each modeling approach has contributed to advancing the field, their methodological diversity has also made it difficult to compare results or build cumulative knowledge. Differences in assumptions, spatial resolution, and behavioral representation have limited the transferability and policy relevance of many models. This has created a need for a more unified framework to evaluate built environment and walking interactions in a consistent manner and contextualize different modeling strategies.

Additionally, comparing the available models will provide comprehensive insights into their methodological complexity, data requirements, and output characteristics. This will help in selecting the appropriate model for planning purposes that align with the objectives of the plan. It will also highlight the limitations of the models and help identify the type of progress needed in the field and its potential direction.

1.6 Objectives and Working Procedure

This report has two primary objectives. First, it aims to critically evaluate existing pedestrian modeling frameworks in terms of their methodologies, strengths, limitations, data requirements, and input-output characteristics. To achieve this, each model is examined through the lens of the classic four-step transportation modeling framework—trip generation, trip distribution, mode choice, and route choice. This evaluative structure provides a common reference point that aligns pedestrian modeling with traditional transportation modeling, enabling clearer understanding and comparison across models for both researchers and practitioners.

The second objective is to identify methodological and practical gaps in current models and to propose directions for future model development. The goal is to ensure that pedestrian models become more useful, accessible, and policy-relevant, supporting urban planners, designers, and decision-makers in evaluating interventions and guiding sustainable mobility strategies.

To support these aims, this report draws on insights and findings presented during the *International Research Seminar on Modeling Urban Pedestrian Mobility*, held at the Massachusetts Institute of Technology (MIT) on 5–6 October 2023. The seminar was organized by Andres Sevtsuk, Associate Professor of Urban Science and Planning at MIT and Director of the MIT City Form Lab, with financial support from the Volvo Research and Educational Foundations (VREF). The goal of the workshop was to assess the current state and explore future frontiers of pedestrian modeling, while identifying common challenges and research priorities that can inform urban design, planning, and policy related to pedestrian mobility in cities worldwide. Details of the seminar are provided in the *Appendix*.

The two-day seminar brought together researchers, academics, and practitioners from around the world who are engaged in pedestrian mobility, behavior, and modeling. Participants shared state-of-the-art methods in pedestrian modeling and simulation and engaged in structured discussions. The first day featured a series of presentations on leading modeling frameworks—UNA, sDNA, MATSim, MoPed, and Place Syntax—while the second day consisted of workshops that critically examined each model using the four-step framework. This process enabled a comprehensive comparison of modeling techniques and fostered collaborative thinking about future directions for the field.

By synthesizing the seminar outcomes and conducting an in-depth comparative analysis, this report contributes to the growing discourse on pedestrian mobility modeling and its role in evidence-based urban policy and design.

This report is organized in a structured manner. *Section 2* provides a brief overview of the traditional four-step transportation model to familiarize the reader with the basics of this modeling framework. *Section 3* evaluates various pedestrian models using the four-step framework and identifies the key challenges associated with each. *Section 4* summarizes methodological and practice-relevant issues that future models should address to better handle these challenges. Finally, the report concludes with *Section 6*: Conclusion.

2. Four-Stage Transportation Model

The four-stage transportation model is a widely used framework for understanding how people move around cities, with a historical focus on vehicular traffic (Ortúzar and Willumsen 2011). It breaks down the travel decision-making process into four main steps: trip generation, trip distribution, mode choice, and route choice. These steps are described below, and **Table 2.1** provides a summary of the framework.

2.1 Trip Generation

In the first stage, trip generation, the model estimates how many trips are likely to start and end in different parts of a city. This depends on land use and activity levels—for example, residential areas tend to produce more outgoing trips in the morning, while workplaces, schools, and commercial centers attract incoming trips. Importantly, trip generation can also consider household characteristics, such as income level, car ownership, household size, and employment status. These factors influence how frequently different types of trips are made. For example, larger households or those with more working adults may generate more commuting trips, while lower-income households may produce fewer car trips and more walking or transit trips. Trip generation also distinguishes between different trip purposes, such as commuting, education, shopping, and recreation.

2.2 Trip Distribution

Once the number of trips is estimated, the model moves to the second stage: trip distribution, which matches trip origins with likely destinations. It estimates where people go after a trip is generated, based on factors such as travel distance, travel time, and the attractiveness of the destination. Larger or more important destinations—such as major job centers or large shopping areas—tend to attract more trips. A common method used here is the gravity model, which assumes that trip volume increases with destination size and decreases with travel distance.

One widely used method for trip distribution is the **Huff Model**, which helps estimate how people choose among multiple destinations—such as shops, parks, schools, or transit stations—when making a trip (Huff 1963). Unlike simple models that assume everyone goes to the nearest location, the Huff Model takes into account two key factors: (1) how attractive each destination is, and (2) travel impedance—how far away or difficult it is to reach. An example of a Huff Model analysis is presented in **Figure 2.1**. In this example, the model calculates the probability of pedestrians choosing among thirteen different bus stop destinations that are all accessible within a reasonable walking distance from the origin building. Instead of assigning all trips to the nearest one (most likely D10), it distributes foot traffic across all thirteen destinations.

A destination's attractiveness might be based on its size, popularity, or the quality of services it offers—e.g., for example, a bus stop with more frequent service may be a more attractive pedestrian destination than one with infrequent service. Travel impedance might be measured by walking time, slope, or a range of safety, comfort, and preference factors combined into a "generalized cost" of the route. Each destination receives a score based on these two factors. The closer and more attractive a destination is, the higher its score. These scores are then converted into probabilities, which represent the likelihood that a person will choose each destination. All probabilities across the available destinations sum to 100%, allowing the model to distribute trips across multiple locations, rather than assigning all trips to a single place.

For example, imagine someone choosing between two parks: Park A is larger and has more amenities but is a 10-minute walk away, while Park B is smaller but only 5 minutes away. The Huff Model might estimate a 60% chance that the person chooses Park A and a 40% chance they go to Park B. This reflects realistic behavior, where people may prefer a slightly longer walk if the destination offers a better experience.

Figure 2.1: Huff Model for Destination Choice

2.3 Mode Choice

After assigning destinations to trips, the third stage—mode choice—determines what form of transportation people will use for their trips—such as walking, biking, driving, using a bus, or riding a train. This decision is influenced by a variety of factors, including the relative cost, time, convenience, and comfort of each option. For instance, people are more likely to walk or bike if distances are short and safe infrastructure is available, while people with cars may prefer driving if transit is slow or inconvenient.

Personal and household characteristics also play a role: for example, people with access to a private vehicle may prefer driving, while those without a car might rely on public transit or walking. The model may include additional considerations such as parking availability, weather conditions, and service frequency for transit. Mode choice models often use logit models[2] or similar approaches to estimate the probability of choosing each mode.

2.4 Route Choice

Once the mode of travel is chosen, the model proceeds to the final stage: route choice, which determines the specific path a person will take between origin and destination. Travelers are typically assumed to select the route that minimizes perceived travel cost, which may include not just distance or time, but also comfort and safety—collectively measured as "generalized costs". For drivers, this might mean choosing the fastest or least congested route; for pedestrians or cyclists, it may include preferences for safety, shade, sidewalk quality, or pleasant scenery. Advanced models allow for multiple route options and distribute trips across them based on likelihood or performance.

2.5 Conclusion

Together, these four stages form a complete picture of travel behavior—from where and how many trips are made, to where they go, how people get there, and which routes they use. This framework helps planners evaluate the impact of changes in land use, infrastructure, or policy on mobility outcomes. A summary of the framework is provided in **Table 2.1**. Although originally designed for vehicular traffic, the four-step model has also been adapted to model walking and cycling trips, as demonstrated by the pedestrian-specific tools discussed in this report.

2 A logit model in transport is a type of discrete choice model used to predict the probability that an individual will choose a particular alternative among a set of options—such as different travel modes (walk, car, bus, bike, etc.), routes, or destinations.

Table 2.1: Summary of the Four-Stage Transportation Model

Stage	Purpose	Key Inputs	Outputs / Feeds Into
Trip Generation	Estimate how many trips originate in or end in each area	Land use, population, employment, household characteristics, trip purposes, trip production and attraction rates	Number of trips per zone (zones can vary from zip codes down to individual address points) ››› feeds into Trip Distribution
Trip Distribution	Link origins to likely destinations	Travel time, distance, destination attractiveness (size, function), accessibility	Origin–destination trip pairs ››› feeds into Mode Choice
Mode Choice	Determine which transportation mode is used	Available modes, travel time/cost per mode, personal factors (e.g., income, car ownership)	Mode selected per trip ››› feeds into Route Choice
Route Choice	Identify the specific path taken for each trip	Road/transport network data, perceived travel cost (distance, time, comfort)	Final route taken on network ››› trip assignment & flows

3. Comparative Analysis of Pedestrian Models

This chapter evaluates five prominent pedestrian modeling frameworks—Urban Network Analysis (UNA), Multi-Agent Transport Simulation (MATSim), Model of Pedestrian Demand (MoPeD), Spatial Design Network Analysis (sDNA), and Place Syntax—through the lens of the traditional four-step transportation model: trip generation, trip distribution, mode choice, and route choice. These models vary significantly in their underlying assumptions, data requirements, analytical capabilities, and intended applications. While some simulate individual pedestrian behavior with high spatial and temporal resolution, others emphasize network-level accessibility or spatial centrality. By systematically comparing their methodologies, inputs, and policy relevance, we highlight each model's unique contributions and limitations, identify key gaps in current practice, and outline opportunities to advance pedestrian modeling for evidence-based urban planning and design.

3. Urban Network Analysis (UNA)

Urban Network Analysis (UNA) is a network-based modeling framework that helps us understand how people move through cities on foot or by bike. It models the city as a network of streets or walking paths, where edges represent the paths people can take (such as streets or sidewalks), and origin and destination nodes are places where trips start or end (like homes, schools, or shops). Instead of simulating individual travelers as agents, UNA estimates how many walking trips pass through each edge of the street network for specific trip types (e.g., walks from home or job locations to transit stops) or within a specific time period (e.g., total foot traffic during the PM peak hour). It covers the four classic steps of travel demand modeling—trip generation, trip distribution, mode choice, and route choice—though the mode choice step is handled in a simplified way.

Trip Generation

In UNA, trips are generated from specific locations known as origins—typically mapped as point objects—which can be individual addresses, block frontages, city blocks, or other units of analysis chosen by the user. These origins may include residential buildings, employment locations, schools, or other places where walking trips commonly begin. Each origin is assigned a weight based on its attributes—such as the number of residents, employees, or the type of land use (e.g., residential, commercial, institutional)—which informs the expected volume of trip generation from that location.

Trip generation is also influenced by the accessibility of surrounding destinations. Areas with a higher density of destinations within walking distance—such as parks, schools, transit stops, or retail areas—can generate more pedestrian trips to such destinations. This reflects the principle of elasticity to destination accessibility, wherein greater proximity and ease of access to destinations result in a higher number of trips per capita.

The model further accounts for the temporal distribution of trip purposes, incorporating assumptions about when specific types of trips typically occur. For instance, commuting and school trips are more likely in the morning, while shopping or leisure trips tend to occur in the afternoon and evening. To support these estimates, UNA utilizes a variety of data sources, including population and employment data from census blocks, school locations, transit stops, and points of interest (POI) such as parks and tourist attractions. These datasets help identify where trips are likely to originate and quantify the relative weight of each origin based on its functional role and level of activity.

For example, consider a site with three key trip origins: a residential building with 50 residents, an office building with 100 employees, and a school with 200 students. Assuming trip rates of 1.2 walking trips per resident, 0.5 per employee, and 1.0 per student during weekday afternoon (school to home), the model would estimate 60 trips from the residential building (50 × 1.2), 50 trips from the office (100 × 0.5), and 200 trips from the school (200 × 1.0). This example demonstrates how trip generation varies by land use type and trip purpose, and how the time of day plays a critical role in modeling pedestrian activity using UNA.

Individual-level demographic characteristics—such as age, gender, or income—can also be factored into the trip generation process when such data is available. Incorporating demographic variation can enhance model accuracy, particularly in contexts where trip-making behavior differs significantly across population groups.

Trip destinations are also represented as point objects—similar to trip origins—and can optionally be attributed with numeric weights that reflect their attractiveness for different trip purposes. For instance, transit stations can be represented as points with weights indicating the number of daily departures, the number of lines served, or the number of jobs reachable from the station within a 30-minute window, based on GTFS[3] and job distribution data.

As shown in **Figure 3.1**, different types of land use are assigned specific weights to reflect their expected trip generation and attraction rates. The model uses these weights to construct a trip-based Origin-Destination (OD) matrix, which serves as the foundation for the analysis. For example, a residential land use may generate trips based on the number of residents as weights, while a commercial area may attract trips based on their weight like number of employees or retail floor area.

3 GTFS stands for General Transit Feed Specification and is a standardized data format used to share public transport information.

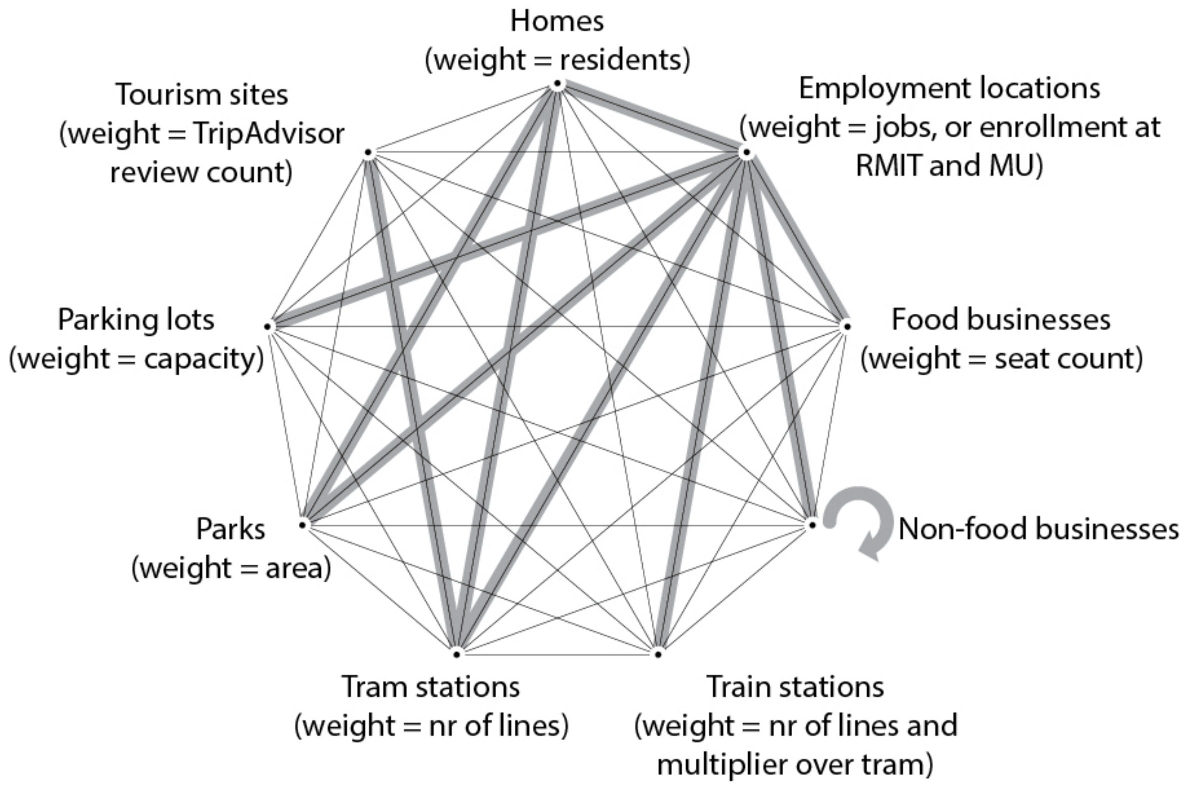

Figure 3.1: Indicators Used as Weights for Different Types of Land Use and Frequency of Trip between Origin-Destination as Expressed by Linewidth

Trip Distribution

The UNA framework uses the Huff destination choice model to decide where walking trips go. Instead of sending all trips to the closest destination, the Huff model assigns a probability to each available destination within a given catchment radius (e.g., within a 10-minute walkshed) based on two key factors:

- *Destination weight*: How attractive the destination is. Bigger, more useful, or more popular places (like a major train station or a busy school) get higher weights.
- *Travel cost*: How easy it is to get there. This could refer to distance, travel time, slope, or discomfort (such as heavy traffic or lack of sidewalks, accounted for in generalized segment costs).

These two factors are combined to give each destination an accessibility score. Destinations that are both attractive and easy to reach get higher probabilities, while those that are less appealing or harder to access get lower ones. The set of destinations considered can be limited to a given walking range, and all the probabilities sum to 1. That means trips are spread across multiple destinations, not just assigned to one, as illustrated in **Figure 2.1**. For example, if someone lives at an equal distance from a small local park and a large waterfront park, the model might assign 30% of the person's home-to-park trips to the local park and 70% to the larger, more attractive one.

Unlike more complex models that simulate full daily activity patterns (such as going from home to work, then to a store, and then back home), UNA treats individual trips separately. For instance, a trip from home to the metro is modeled independently from the metro-to-work trip. Because of this, the model does not automatically guarantee that people return home after each trip, nor does it simulate chains of activities. However, users who wish to model tour-based trips can estimate daily activity schedules elsewhere, break them into discrete travel legs, and use these as starting estimates for pedestrian trip routing in UNA.

Mode Choice

In UNA, the model is designed specifically to simulate pedestrian or cycling trips, and it does not include a separate process to decide which mode of travel a person will use. That means UNA does not ask whether someone will walk, bike, or take a car—it simply assumes that the person is already walking or biking. Instead of predicting mode choice directly, UNA adjusts its results during the calibration phase, which is when the model is fine-tuned to match real-world data. This means it uses actual pedestrian counts collected from streets to make sure its predictions are realistic. For example, if many people are seen walking on a street, the model will adjust its results to show a similar number of walking trips at that time. In this way, mode choice is indirectly reflected in the model through the calibration process, even though it is not modeled as a separate decision-making step.

Route Choice

In the UNA model, route choice refers to how the model determines which paths people are likely to take from their origins to various destinations. Unlike traditional models that assign each trip to a single shortest route, UNA takes a more rigorous approach. It simultaneously assigns all plausible routes for each origin-destination pair, not just the shortest or lowest-cost route. A plausible route is defined as one that is reasonably efficient—within a certain percentage (e.g., 10% or 20%) of the lowest-cost route in terms of travel effort or time. This allows the model to represent a diversity of paths people might actually take, rather than assuming uniform behavior.

For example, in the case of a "home-to-school" trip, multiple reasonable routes from the same origin to the same destination may be found. As shown in **Figure 3.2**, the model identifies several plausible routes from the same origin to the same destination. Each of these routes is assigned an equal probability, effectively splitting the trip into fractions that traverse the network in different ways and converge back at the destination. If route qualities are incorporated into generalized costs, the route assignment probabilities can also account for differences in route quality, allocating more trips to more pleasant or safer paths.

UNA can measure route "cost" in two main ways. The first is geometric length, which is simply the physical distance between origin and destination and does not require any additional data about street quality. The second—and more advanced—method is "perceived length", where each street segment is assigned a generalized cost based on how people experience walking there. For example, a narrow sidewalk beside heavy traffic might feel more exhausting than a tree-lined, quieter street of the same distance. These perceived costs are calculated using estimated Value-of-Distance or Willingness-to-Walk coefficients derived from pedestrian route choice analyses, including factors such as sidewalk width, greenery, shade, traffic volume, and other characteristics influencing walkability. All these factors are combined into a single "perceived length" score for each segment using a linear equation, which can be either longer or shorter than the geometric length of the segment depending on its qualities. UNA can also be used to assign different route choice preferences through different perceived costs for different demographic groups of pedestrians.

Figure 3.2: Multiple Plausible Routes between a Single Origin-Destination pair

Challenges

While UNA is a useful and efficient tool, it has limitations. One key challenge is that it currently models only functional trips—such as walking to school or work—but does not include leisure walking or movements in public spaces, like strolling in a park or hanging out in a plaza. These non-trip activities are common in cities but are difficult to model and remain absent from all pedestrian models to date.

Another limitation is the lack of a built-in mode choice step. The model does not ask whether people prefer walking over biking or driving—it assumes walking or biking from the start and uses real-world data to adjust the numbers at the end.

Finally, UNA can use detailed, fine-grained data (i.e., high spatial resolution). When modeling trips at the address level and considering factors like street characteristics, detailed geospatial data inputs are required to distinguish origins, destinations, and network characteristics. While such data are generally publicly available in the U.S., they can be difficult to obtain in other parts of the world. Collecting detailed geospatial input data takes time and resources, which may not be feasible in every city. However, UNA is generally considered relatively easy to set up, even with limited data, especially given the detailed flow outputs it can generate.

Using the Model

UNA is freely available as a Python Madina Package on GitHub with supporting documentation at madinadocs.readthedocs.io. It is also available as a plug-in for Rhinoceros 3D, with resources accessible via the user manual. The Rhino version offers an interactive experience with a user-friendly visual interface, making it well-suited for small-scale analyses and educational use. In contrast, the Python version is optimized for developing reusable scripts and conducting large-scale, automated analyses.

Selected case studies demonstrating the application of UNA include: Sevtsuk et al. 2021; Sevtsuk et al. 2024; Sevtsuk 2021a.

3.2 Multi-Agent Transport Simulation (MATSim)

Multi-Agent Transport Simulation (MATSim) is an agent-based transportation modeling framework that generates synthetic populations of travelers based on travel and time-use diary data. It is designed to simulate a wide range of transportation modes, including vehicular traffic, cycling, walking, and public transit, making it a versatile tool for analyzing multimodal mobility patterns. However, due to its broader aims, implementing a MATSim model requires considerably more input data and more detailed user specifications than any of the other models described here.

Trip Generation

In MATSim, trips are generated from the daily activity schedules of individual agents. These schedules—called activity chains—are built using data from time-use surveys and travel diaries, which are then expanded to represent a synthetic population—a statistically representative, anonymized version of the actual population. Each agent follows a sequence of activities (such as home, work, or shopping), and trips are generated whenever the agent moves from one activity location to the next. For example, if a person's diary shows they leave home at 8 a.m. for work, go to the grocery store at 5 p.m., and return home at 6 p.m., MATSim will simulate these three trips as part of their day. These activity schedules need to be prepared in advance and are not generated by MATSim itself.

The locations of activities can be defined at a fine spatial scale, depending on the resolution of the input data. For instance, with high-resolution geographic data, an agent's home might be mapped to a specific address rather than just a general neighborhood. Unlike models that assign weights to origin points based on population or land use, MATSim does not explicitly assign origin weights. Instead, trip intensity at a given location naturally emerges when multiple agents begin their trips from the same place. A large residential complex might show high trip volumes simply because many agents are assigned to start there.

Trip generation in MATSim is not elastic to destination accessibility—agents follow their pre-defined activity plans regardless of how close or far their destinations are. Additionally, like many other models, MATSim does not generate recreational or spontaneous trips unless they are explicitly included in the travel diaries. For example, if a park is listed as a destination in the activity data, MATSim can simulate trips to and from the park. However, it does not simulate free-form movement within the park itself. Thus, setting public spaces as destinations allows the model to include trips to and from these areas, but intra-space movement is not captured.

Trip Distribution

In MATSim, trip distribution refers to how the model determines the destination of each trip—that is, where an individual (or "agent") travels after leaving their starting point. The model can handle this in two main ways. The classical approach uses geospatial fitting to match destination patterns based on observed geographic trends. The advanced approach relies on a discrete choice model—typically a multinomial logit model—which selects a destination based on its attractiveness and accessibility.

Each trip is assigned a single destination, not a set of options or probabilities. The decision is based on factors like travel time, distance, or destination quality. Once selected, that destination becomes the fixed endpoint of the trip. Trips in MATSim are also unimodal, meaning they use only one mode of transport per trip leg. Destinations are closely tied to the agent's daily activity chain. For example, if someone's schedule includes going from home to work, then to a store, and finally back home, MATSim will assign one specific location for each of these activity legs. If a person plans to shop after work, the model might assign a nearby supermarket as the destination—based on proximity, popularity, or behavioral data—depending on how the model is configured.

Mode Choice

MATSim is a multi-modal simulation framework capable of modeling various modes of transportation, including walking, cycling, driving, and public transit. To determine which mode an agent chooses for a given trip, MATSim employs a discrete choice model, typically a multinomial logit model. This model evaluates all available transportation options and selects the one that offers the highest perceived utility to the agent—considering factors such as travel time, cost, convenience, and personal preferences.

For example, if an agent needs to travel to work, they might have three options: walk for 20 minutes, bike for 10 minutes, or take a bus for 15 minutes with a fare. The model weighs each alternative based on its characteristics and selects the one that is most appealing or practical for that agent—such as the least costly or fastest option.

It is important to note that MATSim treats walking and cycling separately from vehicular modes. While the model supports all these modes, pedestrian and cycling trips are often simulated separately from vehicular traffic. This modular approach allows for greater specificity but may limit the integration of mode-switching within a single trip.

Route Choice

In MATSim, route choice refers to how the model determines the specific path an agent takes to reach their destination. At present, the basic version of MATSim handles pedestrian journeys simplistically, with limited explicit modeling of destination or route choice. It uses a least-cost path routing approach, where each trip is assigned a single route that minimizes an overall cost value. This "cost" is not limited to distance alone; rather, it is a flexible measure that can be customized based on the available data and specific goals of the model. For example, the cost function can incorporate network-level attributes such as travel distance, slope or elevation changes, surface quality, the number of turns or stairs, traffic volume, lighting, and the presence of amenities like benches or greenery. These elements can help reflect how pleasant, safe, or convenient a route is.

In addition to network attributes, the model can also include agent-specific characteristics that influence route preference. For instance, the cost calculation can be adjusted based on whether the agent is elderly, pushing a stroller, accompanied by children or pets, or has mobility limitations. This allows for more nuanced modeling of pedestrian behavior across diverse population groups. Once the cost function is defined, MATSim identifies the single route that offers the lowest overall cost for each trip and travel mode.

Currently, the model selects only a single optimal path per trip, without incorporating variability or probabilistic route selection. However, ongoing development aims to integrate a discrete route choice model, which would allow for more realistic simulation of alternative route choices based on perceived trade-offs. Extensions such as MoPeD—a pedestrian-specific module—enhance this capability by incorporating logit-based destination choice and hierarchical trip distribution. MoPeD is described in **Section 3.3**.

Challenges

One of the biggest challenges in using MATSim is that it requires extensive detailed data and significant technical expertise to set up and operate effectively. The accuracy of the model depends heavily on how much data you have, how good that data is, and how detailed it is in both space (e.g., exact locations) and time (e.g., specific times of day). A key input is travel diaries—records of when, where, and how people travel throughout the day. But these diaries are often formatted differently in different regions, which can make it hard to prepare them correctly for the model. On top of that, travel diary data can be difficult to find or may not exist at all in many places.

When it comes to walking trips, MATSim handles them in a fairly simple way. The model does not fully simulate how people choose destinations or which walking routes they take. Instead, it relies on pre-defined activity schedules and chooses only one route per trip, without accounting for how people might choose between different destinations or routes based on their preferences or surroundings.

Using the Model

Documentation, resources, and instructions for obtaining and using MATSim are available on the project's website: https://www.matsim.org. The site also features a list of case studies spanning multiple modes and geographic contexts. Further details can be found in Axhausen et al. 2010; Dobler and Lämmel 2014; Dobler and Lämmel 2016.

3.3 Model of Pedestrian Demand (MoPeD)

MoPeD is a four-step travel demand model designed specifically for predicting pedestrian trips. It works within small grid cells (80m x 80m), called Pedestrian Analysis Zones (PAZs). These are much smaller than the typical zones used in car-based models, which allows for more detailed analysis of walking behavior.

Unlike traditional four-step models, MoPeD flips the order of two steps: it first decides if a person walks or not (mode choice) and then decides where they are going (trip distribution). This change makes sense because walking depends heavily on short distances—so whether a person is willing to walk often comes before knowing exactly where they are going.

Also, MoPeD does not include route choice, meaning it does not calculate the exact path people take to get somewhere. That step can be added with tools like MATSim or UNA.

Trip Generation

Trip generation in MoPeD follows principles similar to those used in traditional travel demand models. It applies a linear regression model to estimate the number of trips originating from each PAZ, using input from household travel surveys. These surveys capture detailed information about household characteristics—such as size, income, vehicle ownership—as well as trip frequency and characteristics. For example, Clifton et al. (2016) present PAZ-based trip production (home-based other trips), as shown in (**Figure 3.3**).

Unlike vehicular models that typically use large traffic analysis zones, MoPeD operates at a much finer spatial resolution, allowing it to capture more localized differences in travel behavior. Based on the survey data, MoPeD constructs a synthetic population to realistically simulate trip-making patterns at the PAZ level. The model is calibrated using observed survey data on trip rates across different household types and locations.

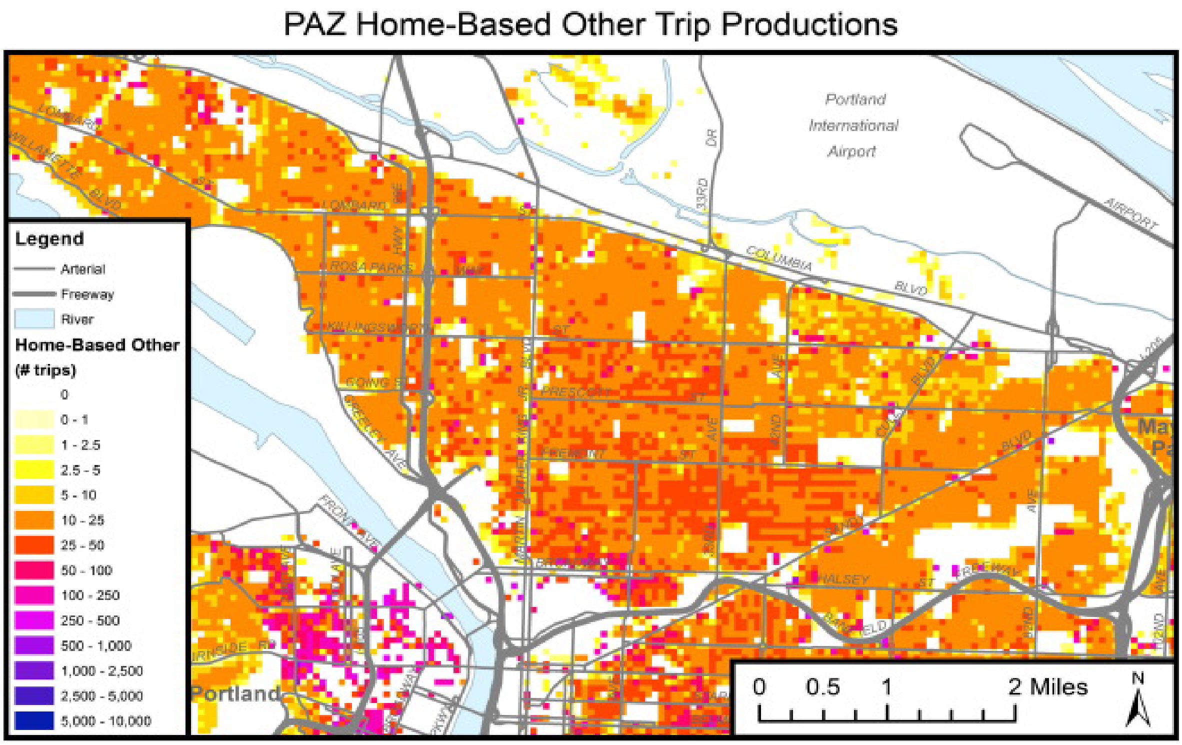

Figure 3.3: PAZ-Based Trip Production

Mode Choice

MoPeD focuses on modeling pedestrian travel by simplifying mode choice into a binary decision: walking or using a non-pedestrian mode, such as a car. This decision is made using a binary logit model that accounts for several factors related to pedestrian access, including travel time, distance, individual and household characteristics (such as car ownership, income, and age), and area-specific attributes like sidewalk density. These variables are evaluated within a defined distance threshold, which typically reflects how far individuals are realistically willing to walk.

For example, if a destination such as a school or grocery store is located within a specified distance threshold—say, 1.5 kilometers—and is accessible via walkable routes, the model calculates the probability of walking based on a set of attributes such as travel distance, car ownership, individual age, and household income. If the estimated probability exceeds a defined threshold, the trip is classified as a walking trip.

However, MoPeD does not incorporate detailed behavioral or perceptual factors—such as how safe, pleasant, or comfortable a route feels. Instead, it primarily relies on objective measures of accessibility and basic demographic and spatial characteristics to predict whether a trip will be made on foot.

Trip Distribution

Once MoPeD identifies that a trip will be made on foot, it uses a logit-based destination choice model to determine where that trip will go. This model focuses on destinations within a reasonable walking distance—typically around 1.5 kilometers.

To structure this process, MoPeD organizes the analysis into two levels of spatial units. Small PAZs are grouped into larger areas called Super PAZs, each consisting of a 5×5 cluster of PAZs. Trip distribution occurs hierarchically in two steps: first, the model assigns a trip from the origin Super PAZ to a destination Super PAZ; second, the trip is directed to a specific PAZ within the destination Super PAZ. The selection of the destination PAZ is based on its relative attractiveness and accessibility.

Each PAZ aggregates destination attributes that contribute to its overall attractiveness—such as the amount of park space, the number of retail and employment opportunities, the availability of schools, and other key amenities. Accessibility is evaluated using a *Pedestrian Index of the Environment*, which quantifies how many attractive destinations—such as jobs, households, or educational institutions—can be reached from the origin within a walkable network distance.

For example, if a person lives in a Super PAZ surrounded by several shops, schools, and green spaces, the model assesses which of these options are not only nearby but also functionally appealing. If a particular park is within walking distance and has enough amenities to make it attractive, MoPeD is more likely to assign it as the trip destination.

It is important to note that MoPeD treats each trip independently. Like UNA, it does not simulate chained activities or complete daily schedules, and it does not ensure that agents return to their origin location (e.g., home) by the end of the day. To operate the destination choice module effectively, MoPeD requires detailed data inputs, including household travel surveys, a high-resolution pedestrian network, land use and employment data, and information on topographic features such as slope.

Route Choice

MoPeD does not calculate which exact path people take on the street network. It only says, for example, "a person walks from PAZ 1 to PAZ 10". To assign specific walking routes, users need to combine MoPeD with other tools like MATSim or UNA.

Challenges

The MoPeD framework relies heavily on large volumes of input data, particularly household travel surveys, which may be difficult to obtain or standardize across different regions. Like other models, it does not account for trips made primarily for recreational purposes—such as walking for exercise or for social purposes in public spaces—and does not represent access or egress trips associated with other modes of transport (e.g., walking to or from a bus stop).

While the use of PAZs as analysis zones can make urban or metropolitan-scale modeling more computationally manageable, it may lack precision for district- or neighborhood-level analysis, where trips start and end at specific addresses, stations, or locations. In sum, MoPeD offers more precise trip generation, destination choice, and mode choice methodologies for pedestrian journeys than MATSim, and it can be combined with the latter to achieve full flow prediction, including route assignment.

Using the Model

Selected case studies demonstrating the application of MoPeD include: Clifton et al. 2016; Zhang, Moeckel, and Clifton 2022; Zhang et al. 2024.

3.4 Spatial Design Network Analysis (sDNA)

Spatial Design Network Analysis (sDNA) is a pedestrian modeling framework that uses graph theory—a mathematical approach to understanding how things are connected through networks. To handle pedestrian trips, it uses the "betweenness algorithm", which measures how often a street segment is likely to be used when people travel through origins and destinations in an area. While it is inspired by the traditional four-step travel demand model, it adapts those steps to a simpler, network-based approach specifically for walking trips, similar to UNA.

Trip Generation

In sDNA, trip generation is highly flexible and can be modeled in several ways depending on data availability. Unlike traditional models that rely on zones, sDNA generates trips using four main approaches: (a) Link-based – trips originate from entire street segments, with busier streets typically assigned more trips; (b) Sub-link-based – street segments are divided into smaller parts to provide finer spatial detail; (c) POI-based – trips generate at specific address-level points like schools, shops, or homes; and (d) Land-use-based – trips are generated from parcels categorized by land use, such as residential or commercial areas.

Each origin—whether a street segment, sub-link, POI, or land-use parcel—can be weighted based on its trip-generating potential. These weights might reflect population, employment, building function, or land use intensity. For example, a large apartment complex would typically generate more trips than a single-family home, and sDNA can capture that difference in its origin weighting. Trip generation procedures are therefore similar in both sDNA and UNA.

However, trip generation is not influenced by the proximity or accessibility of destinations—meaning it is not elastic to destination accessibility. This limitation can be important in predictive scenario modeling, where adding new pedestrian-oriented land uses or improving street qualities increases accessibility and should, in theory, lead to higher trip generation. Additionally, sDNA has not yet been used to incorporate demographic characteristics such as age, income, or gender when estimating trip generation, though these could potentially be adapted as trip generation weighting factors.

Trip Distribution

In sDNA, destinations—such as stores, schools, offices, or parks—can be represented with high spatial detail, even down to specific buildings or address points. When the model looks for possible destinations for a trip, it considers all destinations of a particular type within a certain walking distance. However, a key difference from UNA is that sDNA does not use a destination choice model to assign probabilities to different destination options—it does not weigh how attractive, useful, or close one destination is compared to another. Instead, it treats all available destinations equally. For example, if there are three grocery stores within a specified walking distance, sDNA does not weigh which one is more attractive or more likely to be chosen; it simply counts all three as equal.

Also, like other platforms, sDNA does not support modeling pedestrian tour patterns. It models trips one by one in sequence, which means if someone starts a trip from work to a store, the model does not automatically create a return trip home. Unlike MATSim, the simulation does not guarantee that all trips eventually bring people back to their starting location.

Mode Choice

sDNA is designed specifically for pedestrian trips, so it does not include a mode choice model—in other words, it does not simulate people choosing between walking, biking, driving, or taking transit. It assumes that all trips being modeled are already walking trips.

However, similar to UNA, during the calibration phase—when the model is adjusted to match real-world data—it is possible to estimate how many pedestrian trips should be generated by comparing the model's output to actual pedestrian counts (such as those from street observations or sensors). This helps fine-tune the model so that the number of simulated trips more closely aligns with observed real-world behavior.

Route Choice

sDNA assigns one route between each origin and destination pair using a graph-based approach. It can calculate the shortest route (Euclidean distance), the most direct route (which minimizes angular changes or turns), or a hybrid that balances both distance and directness (**Figure 3.4**). These calculations can be applied in both 2D and 3D networks, allowing the model to incorporate slope—so uphill or downhill paths can influence the route choice.

The model can identify potential high-traffic pedestrian corridors using betweenness centrality—a graph theory concept that measures how often street segments fall on the shortest paths between many pairs of points. However, unlike UNA, sDNA so far does not account for other route characteristics such as sidewalk conditions, lighting, amenities, or perceived safety. Each trip is assigned a single path, with no alternative or probabilistic routing.

Challenges

There is no destination choice component to weigh preferences—sDNA treats all destinations within a walkable distance as equally likely, without assigning probabilities based on attractiveness or utility. It also uses simplified route choice assumptions, offering routes based on least distance, least turns, or a combination of both, without incorporating more comprehensive generalized costs such as sidewalk width, street amenities, or lighting. This limits its ability to reflect real-world pedestrian preferences. Additionally, it identifies a single most likely route rather than a range of concurrent route options.

Using the Model

Documentation and instructions on how to use the framework is available in the project's website: https://sdna.cardiff.ac.uk/sdna/. Selected case studies include: Cooper et al. 2021; Cooper and Chiaradia 2020.

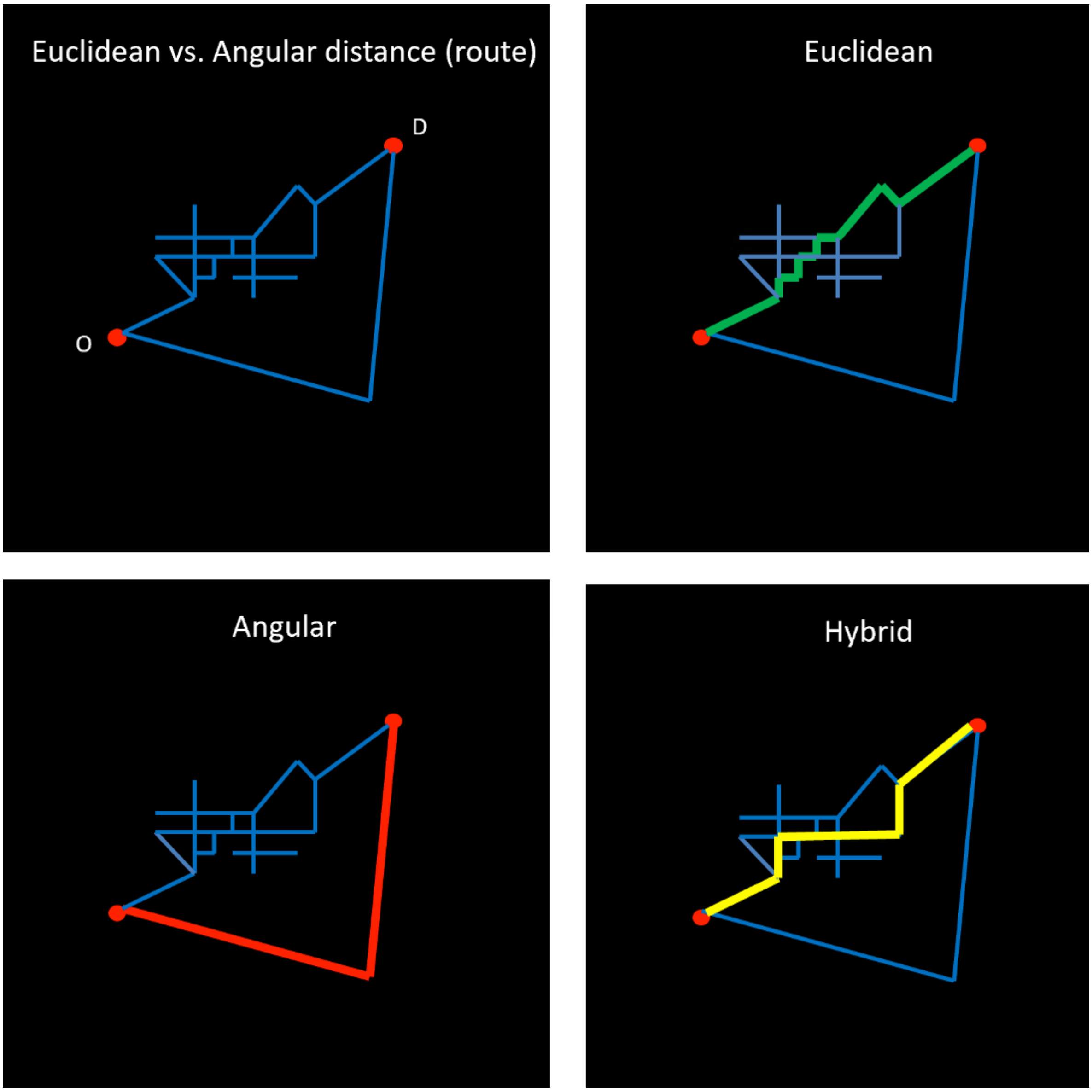

Figure 3.4: Example of Three Methods for Route Choice

3.5 Place Syntax

Place Syntax is a derivative of the more well-known Space Syntax approach (Hillier 1996; Marcus 2025). It is a graph theory–based model that analyzes how central different street segments are within a city's street network. In this context, centrality refers to how well-connected a street is to all other streets—essentially, how easily people can reach it from different parts of the city. This centrality is calculated mathematically by looking at the structure of the street network, rather than actual travel behavior. Research has shown that higher centrality scores often correlate with higher pedestrian and vehicle traffic, especially in cities with dense and mixed-use development. That means the streets that are more "central" in this network sense tend to attract more movement in real life. Such analyses can help identify street segments that are most central, frequently encountered, or most visible or accessible to different user groups.

However, Place Syntax is not a travel demand model—it does not simulate individual trips or estimate how many people will travel from point A to point B. Instead, it functions as a spatial centrality or accessibility model, illustrating how easily different areas of a city can be reached from a given street segment or location. The model can optionally incorporate land use weighting, allowing destination streets to be weighted by factors such as population or employment levels to make accessibility measures more meaningful.

Because Place Syntax does not simulate trip generation, distribution, mode choice, or route choice within a four-step structure, it does not fit neatly into our discussion framework used so far. Applying the four steps to Place Syntax is therefore more of a conceptual exercise than a literal one.

Trip Generation

In Place Syntax, every street segment in the study area is treated as a potential origin. But instead of modeling trips, it measures how central each street segment is within the entire street network. This centrality is calculated using methods similar to Space Syntax, a well-known approach in urban design. For each street segment, the model computes each segment's spatial relationship to all other segments in the city. This is done by drawing the shortest path (either in terms of physical distance or how straight the route is—called *angular deviation*) from that segment to every other segment. If there are *n* total segments in the network, then each segment is connected to *n-1* others through these shortest or straightest paths.

The street segments used in this model have historically not been typical road segments. Instead, they are *axial lines*—the longest straight lines of sight that pass between buildings along the street grid. In other words, they represent uninterrupted straight paths through the urban environment. Unlike conventional segments that are broken at intersections, axial lines remain continuous and are treated as single units throughout the analysis. However, in more recent years, road centerlines have also been commonly used in addition to axial lines. At the end of the process, the model assigns each axial line or segment a centrality score based on how directly and easily it connects to all other lines in the system.

A key feature of the Place Syntax add-on to Space Syntax is its additional focus on land parcels. Place Syntax measures the accessibility of individual parcels to surrounding parcels, using destination weights such as floor area density or land use identifiers to capture land use accessibility.

Trip Distribution

In the Space Syntax model, every axial line within a specified radius is considered a possible destination. These destinations can optionally be weighted based on land use characteristics—for example, streets with more shops, offices, or housing may be considered more attractive or important, as determined by Place Syntax analysis. Space Syntax and Place Syntax provide static measures of how central or accessible each street is, without explicitly modeling trips or pedestrian activities.

Mode Choice

Place Syntax does not simulate trips or mode choice. Instead, it measures how central and accessible different street segments are, without estimating how people travel or how many trips occur.

Route Choice

In Place Syntax, the centrality of a street segment is calculated based on the lowest-cost path connecting it to all other segments in the network. This "cost" can be defined in different ways depending on the analysis: geometric distance (the shortest physical route), angular distance (the straightest path with the fewest turns), or topological distance (the path involving the least number of axial line crossings). For each origin segment, the model computes one lowest-cost route to every other segment using the selected definition of distance. These routes are then used to evaluate how central or accessible a segment is within the street network. This method helps identify which streets are most likely to attract movement based on their spatial connectedness.

Challenges

Place Syntax is a model that measures how central each street segment is in the overall network, based on how easily it connects to other streets. Because it does not simulate actual pedestrian trips, it requires much less data than traditional pedestrian travel demand models. This makes it relatively easy to apply in many city contexts to get a quick sense of which streets are likely to be more or less active based on their network position (**See Figure 1.5**).

However, there are important limitations to keep in mind:

- It does not predict actual pedestrian movements. Space Syntax and Place Syntax only produce a centrality score for each street segment, not a pedestrian count. While this score may correlate with how many people use a street, it is not the same as a direct estimate. In existing cities, this score can sometimes be adjusted using real pedestrian count data, but in newly planned areas where no such data exists, this kind of calibration is not possible.
- It works better in dense, mixed-use urban areas. Research has shown that centrality scores tend to align well with pedestrian activity in dense city environments. But in low-density suburbs or edge-of-city developments, where built densities and street hierarchies are less pronounced, this relationship weakens.
- It favors long and straight streets. Because the model is based on axial lines and measures angular distance between these lines (or centerlines) (or centerlines), it naturally assigns higher centrality to longer, straighter streets. However, in reality, shorter streets can sometimes be more pedestrian-friendly and better used, especially if they are surrounded by active land uses or well-designed public space. So, the model may overestimate the importance of certain streets just because of their shape, not because of actual usage.

In summary, Space Syntax and Place Syntax can be useful for quickly identifying spatial patterns in the street network, particularly the more central places within a city. However, they should be used cautiously with respect to pedestrian activity. Although correlations exist, these models do not simulate pedestrian trips or behavior and therefore should not be used to understand pedestrian trip-making in a city.

Using the Model

The Place Syntax tool is provided as a QGIS plugin. The download, documentation, and sample data are available on the project's website: https://smog.chalmers.se/projects/pst-plugin-for-qgis/. For more, see: Berghauser Pont, Stavroulaki, and Marcus 2019; Ståhle, Marcus, and Karlström 2007.

3.6 Conclusion

In summary, each pedestrian model reviewed in this chapter brings a distinct perspective to the challenge of analyzing walking behavior in urban environments. While an agent-based model like MATSim excels in simulating detailed, individual-level movements across different modes of transportation, it has so far focused more on vehicular and public transportation trips, implying simplified assumptions regarding pedestrian mobility. The MoPeD methodology has been combined with MATSim to improve pedestrian mobility estimation using PAZs.

The UNA approach offers a detailed, address-level method for modeling pedestrian trips in built environments and has been shown to scale to detailed foot-traffic estimation across entire cities. However, UNA handles mode choice in a simplified manner, relying on a model calibration phase with observed pedestrian counts. Modes beyond active modes (walking or cycling) are not modeled.

sDNA offers similar functionality to UNA, with some key differences. It does not use a destination choice model, and for route assignment, a single route is chosen for each trip, instead of the probabilistic assignment of multiple route options used in UNA. It also does not incorporate generalized segment costs, which would enable accounting for street characteristics in pedestrian flow modeling.

Place Syntax and Space Syntax provide insights into spatial accessibility and structural connectedness of places or streets without simulating individual trips. This can help highlight where the densest and connected places are in a network, which has implications for pedestrian activity.

Choosing the most appropriate model depends on the intended application, available data, desired level of detail, and geographic context. **Table 3.1** provides a comparative summary of the key features, data requirements, outputs, and limitations of each model. By understanding the strengths and constraints of these frameworks, urban planners and researchers can more effectively leverage pedestrian modeling to support walkability, equity, and sustainable mobility goals.

Table 3.1: Comparison of Five Pedestrian Modeling Frameworks

Model	UNA	MATSim	MoPeD	sDNA	Place Syntax
Type	Network-based pedestrian model	Agent-based multimodal simulation model	Modified four-step model with pedestrian focus	Graph theory-based (betweenness centrality)	Graph theory-based (spatial centrality)
Spatial Scale	Address points, POIs, land parcels, blocks or zones	Individual agents with activities and locations	Grid-based (PAZ, Super PAZ)	Address points, POIs, land parcels, blocks or zones	Axial-line segments
Trip Generation	Address-level origins weighted by land use/population; Can be elastic to destination accessibility	Agent-based activity chains from synthetic population; Not elastic to destination accessibility	Regression model using household travel survey with synthetic population at PAZ-level; Not elastic to destination accessibility	Multiple approaches (link, sub-link, POI, land use); Not elastic to destination accessibility	Not modeled; Focuses on centrality of axial lines
Trip Distribution	Huff model with probabilistic destination choice based on attractiveness and cost	Discrete choice or geospatial fitting; Single destination per trip	Hierarchical: Super PAZ ››› PAZ using logit model based on attractiveness	Equal probability for all destinations within walkable range; No attractiveness weighting	Not true trip distribution; Static accessibility representation; All axial lines within range considered destinations, weighted optionally by land use
Mode Choice	Not explicitly modeled; Walking assumed	Multinomial logit model for mode choice	Binary choice (walk or non-walk) based on access and demographics	Not modeled; Walking assumed	Not modeled
Route Choice	Multiple plausible paths based on perceived or geometric cost	Single least-cost path based on customizable cost functions	Not included (external tools like UNA or MATSim required)	Single path using angular or geometric shortest route	Shortest, straightest, or topological path used for centrality

Data Requirements	Land use; POIs (schools, transit); Street network attributes (sidewalks, amenities); Demographics data (optional); Pedestrian counts; Slope/topography data (optional)	Detailed travel/time-use diaries (activity schedule); Data of synthetic populations; High-resolution land use; Multimodal network data; Mode attributes	Household travel surveys; Topography; PAZ-level demographics/land use data; Pedestrian network	Street network (2D/3D); Land use/POIs (optional); Slope/topography data	Low data requirements; Axial line network (GIS); Optional land use weights
Model Output	Trip volumes per link; Accessibility surfaces; Probabilistic OD matrices; Route maps	Individual-level activity chains; Route assignments; Network load; Mode shares; Flow visualizations	Predicted pedestrian volumes per PAZ; Mode shares; Estimated OD matrices (based on PAZ flows)	Betweenness centrality scores; Predicted pedestrian corridors	Street centrality heatmaps; Accessibility rankings
Key Strengths	High spatial detail; Flexible routing and destination choice; Intuitive visualizations; easy setup	Highly customizable; Agent-level realism; Multimodal integration	High resolution; Calibrated for pedestrian mode; Modular integration	Strong spatial analytics; 2D/3D support; Lightweight	Minimal data needs; Strong for spatial structure analysis
Key Limitations	No recreational trips; Needs high-resolution data; No mode choice model; No tour modeling	High data needs; Weak for recreational trips; Complex setup; Simplified pedestrian routing	No tour modeling; Mode choice before destination; High data demand; Ignores recreational trips	No attractiveness in destination choice; No mode choice; Limited route realism	Does not simulate trips; Centrality ≠ demand; Only centrality; Overemphasizes long streets

4. Future Research and Implementation Priorities

4.1 Critical Gaps and Opportunities in Pedestrian Modeling

This section explores critical gaps and opportunities in pedestrian modeling to better capture the full richness and complexity of walking—both as a mode of transport and as a lived urban experience. It highlights the need to move beyond utilitarian assumptions, address demographic and spatial inequalities, incorporate informal settings, strengthen validation through data and community engagement, and rethink performance metrics. Together, these themes underscore the importance of inclusive, context-sensitive, and human-centered approaches to pedestrian modeling. **Figure 4.1** provides a visual summary of the key messages presented throughout the section.

Beyond Utilitarian Walking	• Expand models to include recreational, social, and health-oriented walking. • Treat walking as a lived experience, not just a transport mode.
Representing Demographic Heterogeneity	• Move beyond homogeneous assumptions to capture age, income, gender and ability differences. • Reflect walking differences between necessity and choice. • Address context-specific needs across neighborhoods.
Integrating Informality	• Apply models in the contexts of informal housing, roads, and street life. • Recognize informal settings as legitimate parts of urban mobility. • Address data gaps through local knowledge and nontraditional data sources.
Validation & Community Engagement	• Deploy pedestrian counting infrastructure. • Validate models with community input. • Capture experiential dimensions of walking.
Rethinking Pedestrian Metrics	• Need for simple yet robust metrics to guide investment decisions. • Measure experiential quality: social interaction, aesthetics, thermal comfort. • Quantify latent walking demand and enviromental gaps.
Embracing Complexity	• Accept diverse and modular modeling approaches and avoid one-size-fits-all. • Reflect critically on model assumptions and limitations. • See modeling as an evolving tool for representing diverse knowledge about pedestrian mobility and for asking new questions.

Figure 4.1: Key Directions for Advancing Pedestrian Modeling Practice

4.1.1 Beyond Utilitarian Walking: Accounting for Leisure, Health, and Social Walking

Conventional travel demand models tend to focus narrowly on walking as a utilitarian mode of transport—primarily capturing movements between home, work, school, and other functional destinations. Yet research in the United States has shown that recreational walking can constitute roughly half of all walking trips in some parts of the country (Carlson et al. 2018). Such trips are particularly common during non-work hours and weekends. However, these non-trip-based pedestrian activities—such as walking for exercise, strolling, people-watching, meeting friends, or simply spending time in civic spaces like parks, plazas, and town squares—are largely absent from mainstream pedestrian modeling frameworks. Walking is more than just a way to travel from one place to another; it is a fundamental human activity, deeply connected to our natural need for daily movement. It is also a key enabler of physical and mental health, social interaction, cultural expression, and local economic vitality.

In this report, when we note that most models do not include recreational trips, we specifically refer to trips that begin and end at the same location (e.g., a circular walk for exercise or leisure). Many trips with distinct origins and destinations—such as to parks, cafés, or shopping areas—may also contain recreational dimensions in addition to utilitarian purposes; therefore, recreational and utilitarian walking should be seen as overlapping rather than strictly separate categories.

Incorporating these experiential dimensions into pedestrian models is challenging but feasible. Creative and interdisciplinary approaches can help bridge the gap, enhancing the ability of models to support more holistic urban planning. As cities increasingly rely on quantifiable evidence to justify investments and policies, it is important that pedestrian models do not overlook the recreational, qualitative, and humanistic dimensions of walking. Embracing walking not only as a mode of transport, but also as a lived experience ("walking as an experience"), can lead to more equitable, inclusive, and vibrant urban spaces.

4.1.2 Representing Demographic Heterogeneity in Pedestrian Models

Pedestrian behavior is inherently heterogeneous, shaped by a broader set of factors than vehicular travel. However, most current models still rely on frameworks rooted in car-based mobility—such as the conventional four-step model—which are often ill-suited to capture the complexity of walking. While progress has been made, existing models rarely reflect the diverse decision-making processes, behavioral patterns, and physical capabilities that characterize real-world pedestrian activity.

A critical gap lies in the lack of demographic sensitivity. Pedestrian models generally treat walkers as a homogeneous group, disregarding variations in age, income, gender, and ability. For instance, the walking needs of an older adult in a dense Asian city may differ sharply from those of a young commuter in a Western suburb. Similarly, walking trips of many adults in African cities are substantially longer (e.g., >5 km) than those commonly considered "long" in the Global North (Odhiambo 2022). Therefore, it is important to incorporate context-specific and demographic behaviors into model design.

Walking behavior also differs by trip purpose. For some, walking is a leisure activity; for others, it is a daily necessity. Understanding these variations—such as the difference between recreational walking as a luxury and time-constrained walking out of economic need—requires more fine-grained empirical research. Future models must account for how local environmental conditions and access to infrastructure shape walking behavior across different populations. Without this, pedestrian models risk overlooking key populations—particularly vulnerable groups—and misrepresenting travel demand in urban neighborhoods.

4.1.3 Integrating Informality in Pedestrian Modeling

In many cities, particularly across the Global South, informality plays a central role in shaping pedestrian behavior. Yet current pedestrian models have rarely been implemented in informal environments, including unregistered housing areas, informal paths and roads, street vending zones, and non-formal transit systems (Sevtsuk 2021b). These models often fail to recognize the spatial and social dynamics present in informal settings, which limit their relevance in large portions of the urban world.

One of the major barriers is data. Representing origins, destinations, and walking routes in informal contexts can be methodologically challenging due to the fluidity and lack of formal records. However, thinking around informality is evolving. Rather than viewing it as a temporary or "undeveloped" condition, emerging perspectives recognize informality as a legitimate and adaptive form of urban life—one that actively shapes how cities function and how people move within them. Novel data sources—such as global building footprint data (Microsoft 2023), global population density data (Meta 2025), and global open-access street view data (Mapillary 2025)—combined with available local data sources, are making model implementation in diverse global contexts less challenging each year.

For pedestrian modeling to be globally applicable and equitable, it must evolve to incorporate informal urban dynamics. This includes developing new methods for capturing informal mobility data, engaging with local knowledge systems, and shifting the narrative to embrace informality as a legitimate and influential form of urban organization.

4.1.4 Need for Enhanced Validation Data and Community Engagement

Robust validation using empirical pedestrian count data is essential to ensure that pedestrian models accurately reflect real-world walking patterns across urban environments. Validation counts from a small number of monitoring locations are often used to calibrate and validate model performance across a much broader network of streets, extending far beyond the areas where counts are actually conducted. However, such data remains limited and is infrequently collected by most municipal authorities. While many developed cities maintain extensive infrastructure for monitoring vehicular traffic—using technologies such as loop detectors, road tubes, and surveillance cameras—equivalent systems for pedestrian counting are far less common. A notable exception is Melbourne, Australia, where the Victorian Government operates and publicly shares hourly pedestrian count data through an automated counting network, accessible via a dedicated website (https://www.pedestrian.melbourne.vic.gov.au/).

Maps of estimated pedestrian flows for city streets are still relatively uncommon. As more of these maps become available, it will be important to incorporate community input to help assess their accuracy. Engaging local residents to compare modeled flow patterns with their lived experience can provide valuable insights. This feedback can also guide the strategic placement of pedestrian counters in areas where validation is most needed, thereby improving model calibration. The current shortage of pedestrian counting infrastructure underscores the urgent need for broader deployment to enhance the reliability and accuracy of pedestrian modeling.

Beyond data validation, it is important to engage with communities in ways that allow modelers to capture context-specific issues that influence walking behavior. For example, individuals may choose to spend extra time in a plaza during a trip to take a short break to clear their mind. From the perspective of a purely utilitarian model, such time may appear as inefficiency or "wasted" time. However, this behavior reflects the broader experiential and emotional dimensions of walking—elements that are often overlooked in traditional modeling. Recognizing and incorporating these qualitative aspects of walking underscores the broader value of pedestrian activity, supporting a more comprehensive and human-centered approach to modeling.

4.1.5 Rethinking Pedestrian Metrics: Guiding Infrastructure Investment

A key issue is the need for better, more comprehensive metrics to represent pedestrian experiences and the benefits of walking to policy makers and infrastructure funders. Traditional measures like travel time, shortest path, or monetary value of time fail to capture the full spectrum of walking's benefits. To better advocate for pedestrian infrastructure, cities need intuitive yet powerful metrics that reflect not only the functional but also the experiential quality of walking.

The COVID-19 pandemic led to the rapid implementation of *open-street initiatives*—temporary or permanent closures of streets to vehicles to prioritize walking, cycling, and public space use—which prompted broader exploration of walking metrics beyond speed or efficiency. Some cities tried to evaluate impacts of pedestrian-focused interventions through economic indicators such as changes in consumer spending or sales tax revenue. However, such efforts were often hindered by data limitations and the methodological difficulty of isolating causal impacts. Capturing qualitative aspects of walking poses an even greater challenge.

Effective cost-benefit analysis should incorporate social and environmental benefits and communicate these clearly to the public for creating positive public opinion. In vehicular planning, the value of travel time (VOT) is a key metric used to justify infrastructure projects—such as highways—by highlighting time savings, even if temporary due to induced demand. This simple, widely accepted metric has long guided funding decisions. Similarly, pedestrian infrastructure needs clear, easy-to-communicate metrics to capture its benefits and support investment.

Another example from vehicular traffic is Level of Service (LOS), which rates road performance based on capacity and flow. Ironically, high LOS scores reflect empty, fast-moving roads. This logic does not translate well to pedestrian contexts. Instead, a Pedestrian Level of Service (PLOS) must capture not only ease of movement across streets, sidewalks, and crossings but also the quality of the experience: opportunities for social interaction, access to shops and amenities, environmental comfort (e.g., through the Universal Thermal Climate Index), and aesthetic appeal. Research on pedestrian route choice highlights how street characteristics influence preferences, offering a data-driven basis for such metrics.

There is also a pressing need for metrics that capture how urban environments suppress latent—or unrealized—walking trips. This suppression often branches from two primary environmental deficiencies: (1) a lack of destinations within a reasonable walking distance, and (2) poor pedestrian infrastructure connecting people to existing destinations. While the distribution of destinations can be more difficult to influence directly through pedestrian design and planning efforts—since land use patterns and economic activity are shaped by broader market forces and often reinforce spatial inequalities (as critics of the 15-minute city concept have noted)—the quality of pedestrian routes is far more amenable to improvement. Enhancing the walkability of these routes through targeted planning, policy, and design interventions offers a tangible and equitable pathway to unlock suppressed walking demand.

This recognition of latent demand invites rethinking conventional trip generation methods. Traditional models, like those based on Institute of Transportation Engineers (ITE)[4] trip generation tables, often mix observed trip frequency with true demand. Yet trip counts are context-sensitive, influenced by destination availability, environmental quality, demographics, and even weather. Using data from one location as input for another can misrepresent potential walking demand, even when density and land use appear similar. Therefore, pedestrian models must better reflect the complex, context-dependent nature of walking, emphasizing actual demand over observed behavior.

4 Institute of Transportation Engineers (ITE). (2016). *Trip Generation Handbook, 3rd Edition* (Third Edit). Institute of Transportation Engineers. https://ecommerce.ite.org/IMIS/ItemDetail?iProductCode=RP-028D-E

4.1.6 Embracing Complexity, Diversity, and Modularity in Walkability Modeling

Modeling walkability reveals the complex interplay between daily life, activity patterns, and travel decisions in ways that traditional motorized transportation models have often overlooked. While this added complexity may be perceived as a challenge—risking models that become too complicated or unable to fully capture real-world conditions—it also presents a valuable opportunity. It allows transportation researchers to explore questions and dimensions of mobility that were historically marginalized or ignored.

The diversity of policy- and design-relevant questions and challenges in cities and communities around the world requires that pedestrian models be modular and adaptable. Policy-makers interested in quantifying pedestrian accessibility to different types of destinations should be able to do so without needing to use more complex modeling methodologies. Decision-makers seeking to identify critical routes to destinations (e.g., safe routes to school) should be able to do so without preparing a more comprehensive pedestrian flow model. And technical personnel seeking to model all dominant types of pedestrian flows for a representative period should be able to do so withing the constraints of data inputs and calibration coefficients available to them. This underscores the value of modular model structures, where only parts of a more comprehensive pedestrian model can be used independently of other model components, depending on the task at hand and the data available.

The diversity of modeling approaches, perspectives, and tools can serve as a safeguard against the limitations of a single dominant framework. In contrast, the widespread adoption of vehicle miles traveled (VMT)-oriented traffic models in the 1960s has contributed to many of the shortcomings in today's urban transportation systems. A pluralistic modeling landscape, where different methods and paradigms coexist, may offer more robust and nuanced insights than relying solely on a singular viewpoint—or none at all.

As modelers, it is essential to recognize and reflect on our own assumptions and biases. Modeling is not a neutral process; the choices we make—what data to include, what assumptions to apply, and what outcomes to prioritize—reflect particular worldviews. Therefore, when engaging with models and their results, we must critically ask: What is the model omitting? Which perspectives are being privileged or downplayed? And how might the model be improved to offer a more inclusive and realistic representation of walkability and mobility?

4.2 Enhancing Policy Relevance of Pedestrian Modeling

This section examines the evolving role of pedestrian modeling in supporting urban policy and planning. While modeling tools have grown increasingly sophisticated, their practical influence on decision-making often remains limited. The chapter is organized into three subsections: expanding the purpose of pedestrian models beyond forecasting, strengthening collaboration with public agencies, and addressing the persistent gap between modeling outputs and real-world policy implementation. Together, these discussions underscore the need for models that are flexible, inclusive, and better aligned with planning practice. A visual summary of the key points is provided in **Figure 4.2**.

Expanding the Role of Models	• Shift from pure forecasting to supporting design and planning decisions. • Allow modeling with limited or early-stage data to inform concept plans. • Reverse-engineer urban form from policy goals.
Engaging Public Agencies	• Strengthen collaboration to ensure models are practical and policy-relevant. • Design accesible and adaptive modeling tools aligned with real-world needs. • Develop tools usable in both data-rich and data-scarce settings.
Bridging Policy Gaps	• Avoid overly complex models disconnected from real-world applications. • Translate modeling outputs into practical, actionable strategies.

Figure 4.2: Key Strategies for Enhancing the Policy Relevance of Pedestrian Modeling

4.2.1 Beyond Forecasting: Expanding the Purpose and Potential of Pedestrian Modeling

As urban challenges grow more complex, the purpose of pedestrian modeling must expand beyond traditional demand forecasting to serve a broader range of planning, policy, and design needs. Although pedestrian modeling has made a great deal of progress, future pedestrian models must be capable of capturing not only how many people walk and where—but also *why*, *under what conditions*, and *for what purposes* they do so. This requires advancing both the technical and conceptual scope of modeling to align with evolving goals and diverse objectives of modeling.

A key challenge in pedestrian modeling lies in its need for detailed environmental data, often at a much finer spatial resolution than traditional models—potentially down to the address or parcel level. This requirement creates difficulties when evaluating early-stage design and development proposals, which are typically conceptual and lack the detailed spatial information necessary for modeling. Ironically, these early phases are when modeling could be most influential in shaping planning decisions. However, by the time proposals are fully developed and the needed data becomes available—after significant investments of time and resources—there may be limited opportunity to reconsider or revise design alternatives based on model insights. To address this gap, pedestrian models must develop the capacity to operate with approximate, fuzzy, or high-level representations of the built environment, enabling iterative evaluation of alternative urban scenarios even when data is incomplete or evolving. This flexibility would allow for their application during the formative stages of planning, where their impact on guiding decision-making can be most meaningful and far-reaching.

Modelers should use models to help solve real-world problems. Pedestrian models should go beyond simply forecasting travel demand—they should serve as tools to understand how land use, infrastructure, and urban design decisions interact to shape walkability. In urban design, project proposals often include visual renderings that suggest the implementation of the proposal will lead to lively, pedestrian-friendly spaces filled with active and happy pedestrians. However, these depictions are rarely grounded in analytical evidence. A well-informed spatial analysis can help assess whether such outcomes are realistic. Pedestrian models can fill this gap by evaluating whether proposed design features, policies, and land use patterns are likely to support the envisioned outcomes. When used as decision-support tools, these models enable planners and designers to test whether their interventions will realistically contribute to healthier, more vibrant, low-carbon urban environments.

In addition, there is growing value in using reverse-engineered pedestrian models to work backward from established policy targets—such as mode-share goals—to identify the urban form and land use configurations required to achieve them. For instance, if a city aims to double its walking mode share by a specific year, modeling can help determine the necessary combinations of density, land use mix, and street network quality needed to meet that objective. Many cities have already set ambitious mobility targets without concrete pathways for achieving them. Boston's 2030 Sustainable Mobility Plan aims to reduce personal vehicle travel by 50%[5]; New York City seeks a 20% reduction[6]; and Los Angeles has committed to ensuring that 50% of all trips occur via walking, cycling, or public transit by 2035[7]. In such cases, pedestrian models can be instrumental in testing different scenarios, identifying feasible land use and design interventions, and articulating the costs, trade-offs, and co-benefits of various development strategies.

4.2.2 Strengthening Collaboration with Public Agencies

Modelers often operate within their own disciplinary frameworks, which can result in narrowly focused outputs centered on traffic efficiency. However, transportation is fundamentally a tool for enabling broader societal goals, and modeling practices must reflect this larger context. To achieve this, a stronger alignment between modeling efforts and the policy priorities of municipal agencies is essential. Despite this need, a noticeable gap persists—many modeling initiatives remain primarily researcher-driven, with limited direct engagement with public-sector stakeholders. Acknowledging this disconnect is the first step toward redefining the relationship

5 https://www.boston.gov/sites/default/files/file/document_files/2019/08/reducing_commuters_driving_alone_to_work_1.pdf

6 https://www.nyc.gov/assets/sustainability/downloads/pdf/publications/New%20York%20City%27s%20Roadmap%20to%2080%20x%2050_Final.pdf

7 https://www.dropbox.com/scl/fi/3ri83j36w0kybsv716vzc/the-plan.pdf?rlkey=f611qb0dsv8xtsxuneaarc71c&e=1&dl=0

between modelers and public agencies, moving from isolated academic pursuits to collaborative, policy-informed modeling.

Bridging this gap requires greater attention to the interface between modeling tools and planning practice. Specifically, modelers must design models that are accessible, adaptable, and relevant to the needs of planners and policymakers. This is particularly critical in light of the disparities in data availability across different urban contexts. To serve both data-rich and data-scarce environments, modeling frameworks must be flexible—capable of incorporating both publicly and commercially available data—and robust enough to provide meaningful insights even in data-limited settings.

The evolution of the World Bank's and other international agencies' project portfolios over the past three decades illustrates a promising trend: an increasing institutional recognition of pedestrian needs. Whereas earlier efforts paid minimal attention to walking as a mode of transport, more recent investments reflect a growing commitment to pedestrian-oriented planning. These projects range from basic connectivity initiatives—focused on improving movement between key points—to more holistic "complete streets" approaches that prioritize safety, accessibility, and multimodal integration. This trajectory signals the importance of aligning modeling tools with evolving policy priorities to ensure models can meaningfully support inclusive and sustainable urban development.

4.2.3 Modeling Without Impact? Addressing the Policy Disconnect in Walkability Planning

There is often a disconnect between what researchers aim to achieve with pedestrian modeling and how those models are actually used in policy and planning. While modelers highlight the importance of walkability and develop increasingly complex tools, there is a risk that their results could be misunderstood or misused by decision-makers. This raises important questions about the direction modeling is taking—are we becoming too focused on data and complexity without ensuring that sophisticated models translate into tangible, practical changes on the ground? While many multimodal land use–transportation interaction (LUTI) models have become highly complex, it is important for pedestrian modelers to avoid excessive complexity if it compromises policy relevance and practical applicability.

A related issue is seen in many Global South cities. These cities often begin with high levels of walking and pedestrian activity. But as they grow and become more car-oriented, they tend to lose this pedestrian share. Later, after recognizing this loss, cities attempt to restore walkability through new plans and policies. Urban planning needs to support a smarter path forward—one that does not trade away walking and vibrant street life in the name of car-focused development, but instead preserves and builds on the strengths these cities already have.

5. Conclusion

In conclusion, pedestrian modeling has emerged as an essential tool for shaping more inclusive, walkable, and sustainable urban environments. The comparative evaluation of models such as UNA, MATSim, MoPeD, sDNA, and Place Syntax reveals a rich diversity of approaches, each offering unique strengths tailored to specific data contexts, spatial scales, and planning needs. However, significant gaps remain in current practices—particularly the underrepresentation of leisure walking, demographic diversity, and informal urban systems. To better align pedestrian modeling with real-world planning and policy goals, future research must focus on enhancing model flexibility, incorporating comprehensive simple but powerful metrics, and engaging communities throughout the modeling process. Moreover, despite increasing technical sophistication, pedestrian models are not consistently embedded in policy-making or early-stage planning.

Strengthening collaboration between researchers and public agencies is also critical to ensure models are not only methodologically sound but also impactful in guiding policy and design decisions. To maximize impact, pedestrian modeling must evolve into a flexible, inclusive, and policy-relevant practice. This involves not only embracing methodological pluralism but also ensuring models are accessible to planners, responsive to diverse user needs, and capable of operating in both data-rich and data-poor environments. By reframing pedestrian modeling as a tool for exploration, evaluation, and community engagement—not merely prediction—researchers and practitioners can better support the creation of walkable, equitable, and vibrant cities. In doing so, pedestrian models can fulfill their potential as vital instruments in the global transition toward sustainable urban mobility. By embracing complexity and acknowledging the lived experiences of urban pedestrians, the next generation of pedestrian models can become powerful instruments for advancing equity, health, and environmental sustainability in cities worldwide.

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Appendix

Seminar Outline and Structure

A two-day seminar held on October 5–6, 2023, brought together researchers, policy-engaged academics, and practitioners with an interest in pedestrian mobility, behavior, and modeling. Participants were invited to present and engage in discussions centered on state-of-the-art pedestrian modeling and simulation. The first day of the seminar featured presentation panels, while the second day was structured as a workshop to critically examine the strengths and limitations of existing pedestrian modeling frameworks. Each framework was evaluated against the components of the four-step transportation model. A detailed program of the event and participant biographies are available on the program webpage: cityform.mit.edu/projects/modeling-pedestrian-mobility-seminar-2023.

Day 1 – Presentation Panels

Panel 1 – Pedestrian models in urban planning and design

This panel was designed to provide an opportunity for researchers with interest in modeling and simulation to present the current state of modeling frameworks developed by various research groups and institutions around the world. This panel included 15-minute presentations followed by time for questions and answers, with these presentation titles:

- Kelly Clifton, University of British Columbia. The Evolution of the Model of Pedestrian Demand (MoPeD).
- Alain Chiaradia, University of Hong Kong. Accessibility and Journey Level of Service in Volumetric Transport Interchange Hubs. sDNA model.
- Adrian Meister, Swiss Federal Institute of Technology (ETH). Integration of active mobility into the agent-based simulation framework MATSim.
- Lars Marcus, Chalmers University of Technology. The Issue of Representation in Modeling Pedestrian Mobility.
- Abdulaziz Alhassan / Andres Sevtsuk. Massachusetts Institute of Technology. Pedestrian modeling with Urban Network Analysis and automation with a new Python Library Madina.
- Rounaq Basu / Andres Sevtsuk. Massachusetts Institute of Technology. Pedestrian flow model calibration, and pedestrian impact assessment.
- Louis Merlin, Florida Atlantic University. Reconciling various theoretical models of pedestrian travel behavior.

Panel 2 – Pedestrian models in urban transport and policy.

This Panel was intended to shed light on practical issues facing policy makers and municipal officials around pedestrian activity, highlighting qualitative and behavioral aspects related to pedestrian mobility. Discussions revolved around bridging the gap between modeling theory and practical considerations. Presentations in this panel presented on the following titles:

- Geetam Tiwari, IIT Delhi. Pedestrian risk perception and actual risk in city streets in Delhi, India.
- Mark Seaman, Senior Economist, Office of the Commissioner New York City Department of Transportation. Stated Preference Valuation of Livable Street Improvements.
- Filipe Moura, University of Lisbon. On the importance of measuring walkability and exposure to changes of the pedestrian environment.
- Kevin Manaugh, McGill University. Visualizing Active Living Potential at various spatial scales.

- Mark Zuidgeest, University of Cape Town. Modeling pedestrian crossing behavior on Cape Town's freeways: Caught between a rock and a hard place?
- Winnie V. Mitullah Institute for Development Studies and UNESCO. Planning and Governance of Walking in African Cities.
- Juan Antonio Carrasco, Universidad de Concepción. Understanding the experience of traveling and walking: A mixed method perspective.
- Rosa Félix, University of Lisbon. Jittering: A method for generation pedestrian and bicycle realistic route networks from Origin-Destination data

Summary Discussion

In conclusion of the first day, moderated discussion was held to focus on the following themes

- What are the most important types of application areas for pedestrian models and how do we build global awareness about them?
- What are policy challenges preventing the use of pedestrian modeling in policy support?
- How do we achieve more applications of modeling and simulation in the Global South? More research collaborations? What critical data are needed?

A synthesis of this discussion is provided in section Workshop Summary and Future Directions

Day 2 – Modeling Discussion Workshops

The second day was dedicated to a workshop designed to elicit feedback on the current pedestrian modeling frameworks. Participants included researchers interested in modeling, as well as researchers and practitioners interested in practical policy relevance. Participants were divided into four groups; each group was assigned a modeling framework to critique and present. Each group had one or more subject matter experts in the modeling framework assigned to the group. The Workshop included Four sessions of breakout group discussion followed by a communal across group summarizing discussion. Each session was centered around a single prompt given to all teams. The day concluded with an open discussion around challenges and opportunities for pedestrian modeling frameworks.

Breakout Session 1: Pedestrian Trip Generation.

Prompts: With respect to your assigned modeling framework, describe:

- How is trip generation handled in models?
- What data is needed to calibrate the models?
- Is accessibility conceptualized in models, and if so how?
- What are the shortcomings of how the generation of pedestrian trips is represented and how could they be improved?
- Is the conceptualization of trip generation useful for policy and planning, if so how?

Breakout Session 2: Pedestrian Trip Distribution.

Prompts: With respect to your assigned modeling framework, describe:

- How is trip distribution handled in models?
- How are pedestrian destinations represented, at what resolution?
- Are activity schedules handled in models, and if so how?
- What data is needed to calibrate the models?
- What are limitations of how the distribution of pedestrian trips is modeled? How could they be improved?
- Is the conceptualization of trip distribution useful for policy and planning, if so how?

Breakout Session 3: Pedestrian Mode Choice.

Prompts: With respect to your assigned modeling framework, describe:

- Is mode choice handled in the models? If so, how?
- If not, how could it be included?
- What data is needed to calibrate the models?
- What are limitations of handling pedestrian mode choice? How could they be improved?
- Is the conceptualization of mode choice useful for policy and planning, if so how?

Breakout Session 4: Pedestrian Route Assignment

Prompts: With respect to your assigned modeling framework, describe:

- How is pedestrian route assignment handled in models?
- What route characteristics can be accounted for as part of travel costs? What data is needed to calibrate the models?
- What are limitations of handling pedestrian route assignment? How could they be improved?
- Is the conceptualization of route assignment useful for policy and planning, if so how?

Open Discussion - Challenges and opportunities of pedestrian models

The discussion was focused around the following themes:

- How to account for socio-demographic differences in modeling walking trips?
- Is it important to use activity schedules in models? What are the tradeoffs?
- How to better integrate mode-choice into pedestrian models?
- Upcoming grant applications and potential for collaborative work.