PlaceAgents: Multi-Stop Pedestrian Itineraries as Platial Flows on Urban Networks

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Abstract. Urban life is made by the places that people merge together into formal routines. This manuscript introduces PlaceAgents, a framework for modelling multi-stop pedestrian itineraries on city networks using open and reproducible data. The approach uses the itinerary as the base behavioural unit and links three core principles: (1) access to open data sources, (2) enabling explicit assumptions about agents, and (3) the auditability of outputs. The approach is supported through a pipeline of data acquisition, aggregation, routing, and simulation. A pedestrian routing graph and places are extracted from OpenStreetMap and spatial context is summarised using the H3 grid. Researcher-informed agents are capable of planning short sequences of place-based visits, with movement following a transparent length-weighted A* cost on the network. In a case study on Nottingham and Birmingham city centres, the approach reveals high-throughput corridors with a platial lens and the influence of itinerary structure on flows across clusters of Points of Interest. This article presents the framework capabilities in addition to the limitations of simplified behaviour and the sparse availability of capacity or opening-hours attributes. Finally, extensions for calibrated choice models, exposure accounting, and more cross-city comparisons are discussed.

Keywords: Agent-Based Modelling · OpenStreetMap · H3 · Platial Information · Pedestrian Movement · Urban Analytics

1 Introduction

Pedestrian flows in urban spaces such as cities emerge from chained activities as opposed to isolated trips, people stitch together sequences of places for errands, work, leisure, or emergency [1]. The corridors observed are co-produced by clusters of amenities, street structures, and locations as opposed to single origin-destination (OD) pairs alone e.g., [8]. Prior work has sought to develop a large-scale agent-based model of daily pedestrian traffic flows for the city of Salzburg generating thousands of individual daily activity chains for agents representing both residents and tourists [12], producing rich disaggregated mobility patterns over entire days. Similarly, work has explored the development of open data and models for synthetic demand monitoring in Berlin [25]. The work presented in this manuscript attempts to treat urban pedestrian movement as a series of linked flows, intermediate stops, and the itinerary logic that connects them, supporting simulation design in urban analytics and planning.

Using existing challenges in agent modelling as the impetus, this manuscript presents PlaceAgents, an itinerary-centred agent-based framework that prioritises existing map-based data and auditability of results. The pipeline separates data acquisition, spatial aggregation, routing, and simulation into modular, inspect-able stages. Pedestrian networks and Points of Interest (POIs) are sourced from OpenStreetMap [18] via OSMnx [3], enabling rich use cases to be demonstrated through the framework. The approach then summarises spatial context into a H3 grid [9], enabling a spatial-platial understanding to be formed [23]. Inspired by the Mesa-Geo library [21], agents plan short sequences of place visits and move on the graph using an interpretable length-weighted shortest-path cost implemented with NetworkX [10]. This is broadly based on the concept of platial information: the basic unit is not abstract space but fuzzy places [2], with agents navigating between them.

Guided by these aims, this manuscript addresses three research questions motivating the structure of the framework, the modelling supported, and the evaluation: (RQ1.) How can multi-stop pedestrian itineraries redistribute flows across urban networks when built on open data?, (RQ2.) How can the interaction of clustered places and network structure influence the formation and concentration of pedestrian flows?, and (RQ3.) How can an itinerary-centred simulation enable interpretable flow patterns suitable for comparative analysis?

This manuscript makes three contributions: (1) it offers a reproducible pipeline that links OpenStreetMap to H3 aggregation, interpretable routing, and a discrete time-matched simulator with auditable agent event logs; (2) it models multi-stop pedestrian walking place-based itineraries over urban networks with explicit transportation simulation costs; and (3) it derives edge pedestrian load from these event logs, supporting the identification of aggregate corridors and agent mobility trajectories.

The remainder of this manuscript is organised as follows: Section 2 present the overall design of the framework and approach including the processing, aggregation, and routing. Section 3 describes the study design and presents the case study results for Nottingham and Birmingham. Section 4 demonstrates the interactive viewer. The penultimate Section (5) discusses the findings of the studies and discusses them in the wider context of the literature. Finally, Section 6 presents the conclusions and future work.

2 Framework

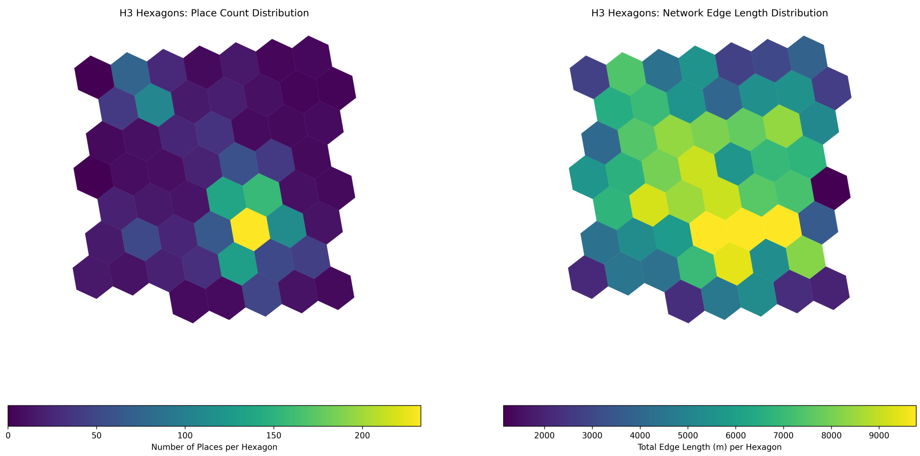


Fig. 1: H3 distribution visualisations for Birmingham, showing (left) POI count distribution, and (right) network edge distribution.

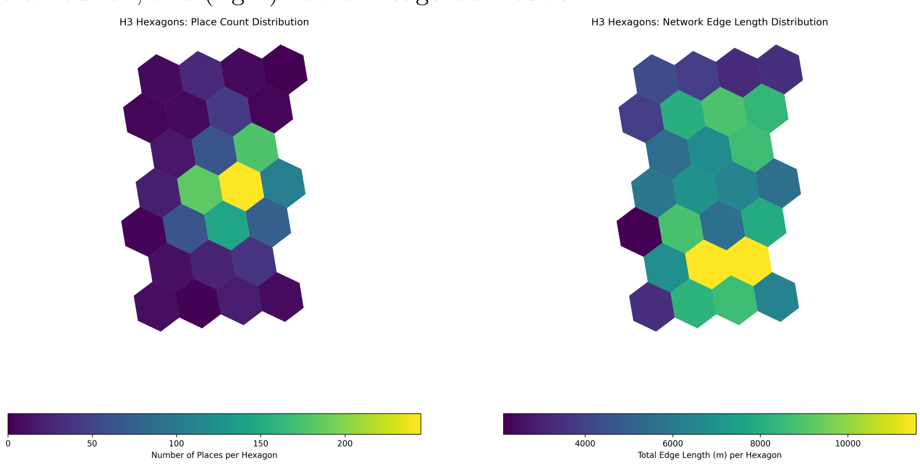


Fig. 2: H3 distribution visualisations for Nottingham, showing (left) POI count distribution, and (right) network edge distribution.

PlaceAgents is a itinerary-centred framework for simulating platial flows in urban networks. The framework treats the city as linked places embedded in a pedestrian graph, separating representation (e.g., places formed from POIs [24], network graphs, and H3 spatial context) from behaviour (e.g., itinerary choice and time-based movement). It enables auditable event streams that aggregate to edge-level load without imputing missing attributes from open data. PlaceAgents inputs a single scenario file (yaml) to determine processing characteristics.

2.1 Processing

Processing begins through the construction of a pedestrian network and catalogue of places downloaded directly from OpenStreetMap [18] for each city centre bounding box. The routable network is extracted using OSMnx [3] with a walking filter that includes footways, paths, pedestrian roads, steps, and shared surfaces while excluding prohibited areas. Topology is simplified to collapse intermediate degree-2 nodes that carry no turns, preserve a directed MultiDiGraph so parallel segments and one-way restrictions remain explicit, and compute metric edge lengths. For each edge, identifier tuples, geometries, highway class, access flags, and length is metres is retained. This yields a routable pedestrian graph that reflects OpenStreetMap tags without performing additional imputation.

Using the same bounding box, POIs are extracted using OSMnx's geometry query with a whitelist of OpenStreetMap tags corresponding with the scenarios place types (e.g., cafes, libraries, supermarkets, restaurants, banks, heritage sites, museums, and fast food). Polygons are converted to representative points (centroids constrained to lie within the source geometry), and key attributes such as name, tags, opening hours, capacity, and the OSM identifier are retained. To enable node-to-node routing, each place point is snapped to its nearest network node, with the snapped node id and snap distance recorded in metres. No synthetic nodes or edges are created and places without a plausible snap (for example, beyond a threshold) are flagged and excluded from routing, any POI with missing attributes is left missing.

2.2 Spatial Aggregation

PlaceAgents integrates a discrete global grid system (DGGS) to segment the map into distinct, indexable cells [13]. For the work conducted in this article, the H3 grid was selected due to its mature functionality [13], enabling a uniform representation of spatial context [9]. DGGS are increasingly used in existing literature, such as classifying walkable grid cells in leisure route recommendations [22], estimating urban areas based on historical census data [19], and spatial aggregation from SAR images [14]. The multi-resolution hierarchical implementation enables consistent and predictable aggregation of network and place features across multiple scales, motivating its use in this work.

Network and place context is summarised into a H3 grid cell [9] as demonstrated in Figures 1 and 2 at a fixed resolution selected in the scenario. For each scenario, a set of hexagon cells covering the full extent are used with the H3 index attached. POIs are snapped to hexagons through associating the point to the polygon, with data then being summarised by cell. To relate the simulated movement to spatial context the total edge length is reported through intersecting geometries and edge load in proportion to segment overlap. Formally, with H

as a hexagon cell and L as the directed edge load, place counts, network length, and distributed load are reported as in Equation (1).

$$\mathrm{poi}_H = \sum_{p \in H} 1, \qquad L_H = \sum_{e} \mathrm{length}(e \cap H)\,, \qquad \bar{L}_H = \sum_{e} L_e \, \frac{\mathrm{length}(e \cap H)}{\mathrm{length}(e)}. \tag{1}$$

Where poi_H counts snapped places in hex H; L_H sums metric lengths of edge segments inside H; $\bar{L}_H$ distributes each edge's load into hexes in proportion to segment length.

2.3 Agents and Engine

Agents represent the pedestrians executing short itineraries of place visits on the simulated network. Each agent maintains a current node, an ordered target list of places snapped to the network, a planned path, and a finite state of: {*planning*, *moving*, *arrived*, *stuck*, *finished*}. Origin points are sampled from network nodes within the scenario extent and snapped to the network and targets are sampled from the places extracted filtered from the scenario's tag filter. Where the OpenStreetMap data has opening hours, places are treated as temporarily not possible. Where opening hours are missing, the visit proceeds without a temporal limitation. This itinerary-centred design follows work that foregrounds work with urban subdivision in pedestrian movement simulations [6].

Each leg of the route is computed on the directed pedestrian MultiDiGraph using the A* graph traversal algorithm with the edge length as objective and a straight-line heuristic, following Equation 2, implemented with NetworkX [10][11]. During these phases the agent is considered to be *planning* or *moving*, if no feasible path is possible the agent transitions to the *stuck* state and terminates. Agents move along the network by a fixed distance per tick, upon reaching a destination node the *arrived* state is emitted and the agent returns to the *planning* or *finished state*. During this process the directed edge load is calculated as presented in Equation 3, and is also summarised into H3 cells (Equation 1).

$$f(n) = g(n) + h(n), \qquad g(n) = \sum_{e \in \mathrm{path}(s \to n)} \mathrm{length}_e, \qquad h(n) = d_{\mathrm{gc}}(n, \mathrm{goal}). \tag{2}$$

Where s is the start node, length_e is the edge length, and d_{gc} is great-circle distance; with length weights, h is admissible.

2.4 Outputs

PlaceAgents produces a set of artefacts from which all figures, statistics, and simulations are computed. The per-tick event log records every *move* and *arrival* event, from which it is possible to derive edge loads as counts of traversals as demonstrated in Equation 3, which are then attached to the pedestrian network for mapping and analysis. H3 summaries are also generated at the scenarios fixed resolution: place counts, network length, and load based on segment overlap. Finally, a run summary is produced which captures the scenario, network, and aggregate outcomes (bbox, duration, number of agents, etc).

Reported based on these output artefacts are: (1) completion metrics based on the share of agents completing all stops, and the mean stops completed; (2) path statistics based on the mean, media, and deciles of leg lengths based from the A* (Equation 2); and (3) plausibility checks including the spearman rank correlations between node/edge load and centralities (degree, edge betweenness) [20][7] and the Gini coefficient of the edge-load distribution for analysing corridor concentration [5]. All measures are computed directly from the open-data derived network and exported.

$$L_e = \sum_a \sum_k \mathbf{1}\{\, a \text{ traverses edge } e \text{ at } t_k \,\}. \tag{3}$$

The indicator $\mathbf{1}\{\cdot\}$ equals one when agent a moves along edge e at tick t_k, else zero; L_e is a raw count suitable for mapping and summaries.

3 Case Studies

The PlaceAgent model is evaluated in two UK city centres: Nottingham (around the Old Market Square and Lace Market areas) and Birmingham (around New Street Station, the Bullring, and Victoria Square). Both simulations use the same pipelines, H3 resolution, time steps, and POI tag selection. The only variations are the local network and POI mix differing between runs. Scenario parameters are presented in Table 1 demonstrating the similarities of the simulations and city-specific characteristics are presented in Table 2, highlighting the comparatively larger scope of Birmingham particularly in nodes, edges and POIs.

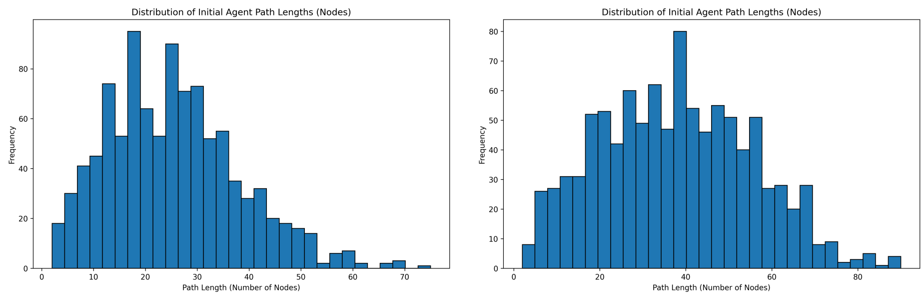
Table 1: PlaceAgents scenario parameters defined in the scenario setting file presented by city.

City	BBox (min lon, min lat, max lon, max lat)	Agents	Duration	Step	H3 size	POI tags
Nottingham	`[-1.164, 52.948, -1.131, 52.967]`	1000	360	5	9	see note
Birmingham	`[-1.918, 52.472, -1.885, 52.492]`	1000	360	5	9	see note

Note: Tags used: `cafe`, `park`, `library`, `supermarket`, `fast_food`, `restaurant`, `pharmacy`, `bank`, `bar`, `pub`.

Table 2: Data characteristics of Birmingham and Nottingham extracted from the input data from OpenStreetMap [18].

City	Nodes	Edges	POIs	Hexagons	Median edge length [m]
Nottingham	2460	6446	1317	26	19.466
Birmingham	3297	8918	1858	54	24.475



(a) Nottingham (b) Birmingham

Fig. 3: Distribution of path lengths (nodes) for the simulated itinerary legs for Nottingham and Birmingham.

The case studies both completed successfully, with 100% of agents reaching all intended destinations on the simulated network. Figure 3 presents a comparison of the path lengths for both Nottingham (a) and Birmingham (b), indicating a slightly longer average edge length in the Birmingham scenario. The remainder of this section will present the results for both cities and provide descriptive statistics regarding the simulations.

3.1 Nottingham Results

The Nottingham simulation resulted in an interesting series of results representing more concentrated corridors through the core street grid, with lighter use on backstreets and side roads. Agents in the Nottingham simulation had a mean stop count of 4, representing a distributed amount of itinerary simulations. Figure 4 demonstrates sample agent trajectories (a) and these condensed edge loads in practice (b). The resulting leg lengths are compact for a city-centre itinerary median = 631 m; 10-90% = 263-1,235 m), while load inequality is high (Gini = 0.82), indicating a small set of dominant segments. The plausibility checks show a strong association between node load and node betweenness (Spearman $\rho = 0.83$) and a moderate association with degree ($\rho = 0.52$). The hexagon level load is weakly correlated for Nottingham ($r = 0.16$).

The Nottingham results represent more concentrated pedestrian patterns which address RQ1 by showing how short, multi-stop itineraries can generate highly unequal pedestrian flows within a compact city-centre scenario, even when using simplified behavioural assumptions.

(a) Nottingham sample agent trajectories. (b) Nottingham edge load.

Fig. 4: Demonstration of sample agent first-leg trajectories for Nottingham (a) and edge load distribution (b) for the same area.

3.2 Birmingham Results

The Birmingham simulation demonstrates comparatively longer legs (median = 1,243 m; 10-90% = 441-2,131 m) and lower concentration than Nottingham (Gini = 0.77), reflecting the larger graph and wider amenity spread. All agent finished with a mean of four stops. The simulation results presented in Figure 5 shows strong plausibility checks, node load correlates very strong with node betweenness (Spearman $\rho = 0.87$) and moderately with degree ($\rho = 0.57$). The hexagon level load correlates at a moderate level too ($r = 0.52$), indicating that amenity clusters align with high throughput corridors more clearly than the Nottingham results.

The Birmingham case study presents wider and less concentrated flows which represent the larger network extent and number of places applicable to the location. This case study addresses RQ2 by demonstrating how larger amenity clusters and networks interact to shape pedestrian flow and corridor formation.

(a) Birmingham sample agent trajectories.

(b) Birmingham edge load.

Fig. 5: Demonstration of sample agent first-leg trajectories for Birmingham (a) and edge load distribution (b) for the same area.

Combined with the Nottingham case study, the results demonstrate how a consistent itinerary design can produce different movement structures depending on the context of the city.

4 Interactive Viewer

Figure 6 presents a snapshot of the generated PlaceAgents viewer for Nottingham City Centre, presented on a OpenStreetMap basemap [18]. Pedestrian edges are visualised by simulated load, places appear as large circular orange points, agents render as animated moving markers during playback, and can leave a coloured trace on the map. The overlaying left panel controls layers, city selection, and the sampling of agents displayed, and the bottom bar enables the user inspecting to scrub through the simulation playback. In this Nottingham City Centre scenario 1,000 agents are simulated, with each segment changing the visualised colour of the agent. The viewer enables the illustration of how itineraries begin to concentrate flow along a small set of corridors while backstreets and suburban roads remain lightly used.

5 Discussion

5.1 Interpretation of Results

The itinerary perspective adds additional explanatory detail beyond OD approaches. Across both centres it is possible to observer unequal corridor formation from short multi-stop chains, with high concentration in Nottingham

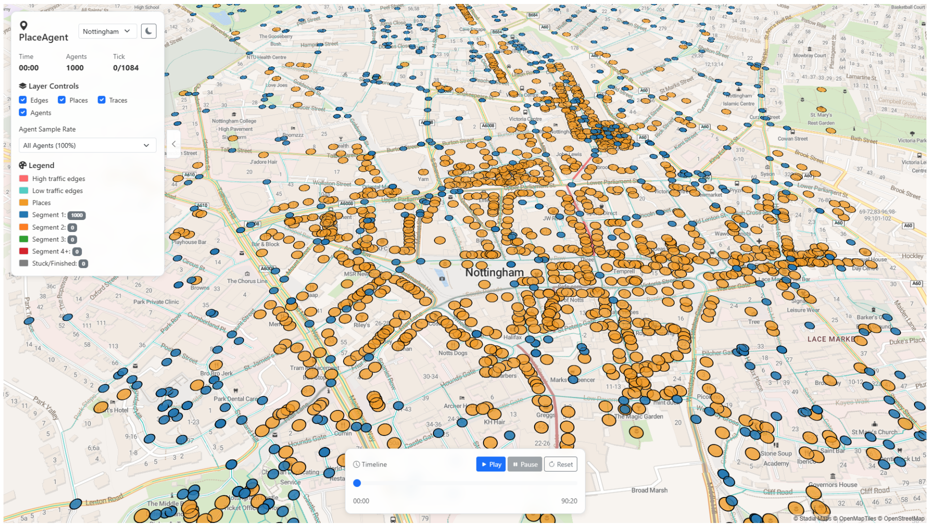


Fig. 6: PlaceAgents viewer (Nottingham city centre): edges coloured by simulated load, places as points, animated agent positions (snapshot). Basemap is OpenStreetMap contributors [18].

(Gini = 0.82) and slightly lower in Birmingham (Gini = 0.77). Across the results plausibility checks show that simulated load aligns strongly with structural connectivity (Spearman ρ with node betweenness = 0.83-0.87) but only moderately with degree (ρ = 0.52-0.58). The patterns discovered are consistent with the pedestrian agents traversing connective junctions that stitch place clusters together, rather than just accumulating at busier intersections. On the hexagon level, the associations indicate that amenity structure shapes where corridors run (moderate load-POI correlation in Birmingham) but does not determine them on its own (weak correlation in Nottingham). This indicates an interaction between platial clustering and network form, which will be explored more in future work.

5.2 Platial Implications

PlaceAgents impact is twofold, first, the platial lens is used to support the identification of high throughput place-based locations in cities imported from OpenStreetMap, enabling flows and platial clusters of pedestrian agents to be discovered. The second impact is the potential of using the agents event log, edge demand, and output H3 summaries to inform the identification of places where more traditional GPS traces are not available, encouraging ongoing work in the identification of meaningful places to individuals. Additionally the perspective works towards treating the city as linked places as opposed to abstract space [2], chaining activities and local semantics that OD approaches could miss. In practice, the approach serves as a baseline for generating rapid simulations of urban environments from OpenStreetMap data. Extended work on PlaceAgents will focus on enabling larger scale simulation, particularly in the routing, when attached to expanded contextual detail.

5.3 Limitations

The current implementation adopts several simplified behavioural assumptions: agents are walkers only, plan short multi-stop sequences, and select routes using interpretable length-based cost. OpenStreetMap and volunteered geographic information constraints such as limitations in the availability of opening hours and venue capacity means that these restrictions are enforced only where such tags are present, which can be limited by the completeness and accuracy of data [4][16]. The choices of agents may yield optimistic itineraries and understate local importance or congestion, therefore future work will focus on integrating richer narratives into the itineraries e.g., [15][17]. Despite this, current results are still sensitive to OpenStreetMap tag completeness.

6 Conclusions and Future Work

This manuscript presented PlaceAgents, a baseline for itinerary-centred pedestrian simulation as platial flows on urban networks. The framework enabled OpenStreetMap data to be used to form interpretable time-distance routing in addition to auditable event logs for inspection and reuse. The framework is also demonstrated through a web-based viewer, enabling agent trajectories to be monitored. This manuscript demonstrated the PlaceAgents multi-stop sequences across two city centre case studies, demonstrating how these sequences redistribute pedestrian flow across core corridors and POI clusters.

To address the three research questions, the results of this manuscript demonstrate that itinerary-centred, platial perspectives and produce interpretable patterns of pedestrian movement. The results for the Nottingham and Birmingham case studies responded to the first two research questions (RQ1, RQ2) by demonstrating how multi-stop itineraries interact with different place and network configurations to generate corridor concentrations. The final research question (RQ3) is supported by these results, due to enabling a transparent event-based log of pedestrian simulation within agent-based modelling.

PlaceAgents could support the simulation of more contextual factors, for example, through layering in exposure data (air pollution, noise, heat, safety) into the summarised H3 grid. Further work will also explore the introduction of richer user cohorts and narratives (e.g., commuters travelling to work or students attending school/university), each of these will add more distinct schedules and preferences which could enable a more human-centred model of place interaction to be incorporated.

Acknowledgments. Data used is OpenStreetMap® open data, licensed under the Open Data Commons Open Database License (ODbL) by the OpenStreetMap Foundation (OSMF), © OpenStreetMap contributors. openstreetmap.org/copyright. Demonstrator and data available from: https://github.com/jwilliamsresearch/PlaceAgents.

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