Informed urban design in Knowledge Districts

Developing a parametric and graph-based design tool for Urban Vitality using Place Quality attributes

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Abstract. *Urban configurations support sustainable development by combining social and environmental qualities with economic opportunities, yet their parameters are numerous and often conflicting. This paper expands a Rhino–Grasshopper parametric model of Moulon, Paris-Saclay, to analyse urban vitality in not-yet-consolidated contexts through place-quality attributes, a key condition for attracting and retaining knowledge workers. It implements the Visit Potential Model, a graph that estimates potential pedestrian flows from interactions between population and attractor objects. The model incorporates two selected public-space quality attributes as impedance weights that modify perceived walking cost: the accessibility of privately-owned public spaces and the quality of streets' microlevel design. Three scenarios test this integration by considering building uses, distribution, densities, block-typology configurations, and microlevel street-design parameters such as tree coverage, sidewalks, and cycle lanes. Results show how street comfort, block permeability, and amenities concentration redistribute potential pedestrian flows, allowing urban-vitality scenarios to be compared before observed pedestrian data exist. The broader goal is a design tool that analyses urban-vitality performance by comparing design scenarios, supporting knowledge-district creation through retrofit and new design.*
Keywords. *Knowledge-based Urban Development, Urban Vitality, Place Quality, Parametric Modeling, Design Tool.*

INTRODUCTION

Contemporary urban development must reconcile environmental sustainability, social quality, and economic productivity within increasingly complex urban systems. Urban morphology is central to this challenge: the spatial configuration of the built environment conditions mobility, environmental quality, and the capacity of public spaces to sustain social and economic life (Hillier, 1996; Jacobs, 1992; Kropf, 2009). Together, these spatial and functional qualities define a place's quality, which underpins vibrant urban environments. Urban vitality, which can be measured by the number of pedestrians using public spaces (Doan & Zhang, 2025), is commonly attributed to the intensity and diversity of activities, but recent work shows it also depends on place quality itself (Esmaeilpoorarabi et al., 2018). High-quality environments encourage people to remain in and use public spaces, while the presence of people and activities reinforces their perceived quality (Gehl, 2011).

In knowledge districts, which depend on attracting and retaining highly qualified workers whose location choices are associated with quality of life and urban vibrancy, this relationship is particularly relevant. Since many of these districts are former technology parks and monofunctional campuses on urban fringes, vitality does not emerge spontaneously, as it does in consolidated urban centres. Instead, it must be induced, even before occupation, through design decisions that articulate functional efficiency, environmental performance, and spatial attributes oriented toward the creative class's everyday needs and lifestyle preferences (Esmaeilpoorarabi et al., 2018; Florida, 2012).

In these districts, buildings such as universities, research centres, and student residences form large-scale blocks that can become barriers to walkability and, given their monofunctional uses, reduce street-level activation. This impact may be diluted into the urban fabric through design strategies that make such developments less intrusive at the pedestrian scale and in street-level life. Among these, public spaces and privately-owned public spaces (POPS) can mediate the building-street interface when combined with active and transparent frontages, accessible edges, and continuity with the pedestrian network (Carmona, 2015; Gehl, 2011).

Street-network morphology, in turn, structures accessibility to everyday destinations, while its microlevel design quality supports the comfort and attractiveness of active mobility, enhancing the streets' use as spaces for social life (Noronha et al., 2022). Beirão (2012) proposes an ontology for representing streets in generative tools, describing them through the network's functional hierarchy, the streets' typological nomenclature, and the minimum composition of street profiles. Building on this, Noronha et al. (2022) show that microlevel design features, such as traffic-zone configuration, sidewalk continuity, pedestrian crossings, buffer areas, and tree coverage, translate into geometry-based indicators of walkability, comfort, and pedestrian priority.

Within a pedestrian graph, in which the street network defines the topology of movement, these two attributes can be operationalised as factors that reduce or increase the perceived impedance of movement: POPS accessibility expresses the capacity of these spaces to support staying and social interaction, as well as their contribution to the internal permeability of blocks and buildings, while the microlevel design quality of streets conditions pedestrian comfort and safety. The Visit Potential Model (VPM) provides a suitable framework for this integration (Herthogs et al., 2018). It uses a weighted graph to estimate the potential presence of people in public space, with population origins and attractor destinations as its elements. Incorporating morphological indicators as impedance weights on the graph edges allows design interventions to be assessed both for spatial quality and for their redistributive effects on pedestrian movement across the network.

To this end, this study uses a parametric urban model. Our model was applied to a semi-abstract representation of the Moulon district in Paris-Saclay, an area on the southern urban fringe of the Paris metropolitan area (Eloah et al., 2025). Moulon is one of three districts in the Établissement public d'aménagement Paris-Saclay (EPAPS) area, a national-interest operation launched in 2010 to transform the Saclay Plateau, formerly marked by large rural plots and isolated scientific facilities, into an integrated urban environment oriented toward innovation, everyday life, and environmental quality (EPAPS, 2022). This district was selected for this analysis because it corresponds to the first development phase and is the most advanced of the three districts of which the EPAPS is composed.

This research aims to develop a parametric design tool that handles often-conflicting parameters and analyses urban-vitality performance by assessing and comparing design scenarios, supporting the creation of knowledge districts through both retrofit and new design. As a step toward this goal, the present paper extends a previously published parametric model (Eloah et al., 2025) in three aspects: (i) implementing the VPM as the computational structure of the pedestrian graph, with population and attractor objects derived from the knowledge district's land uses and densities; (ii) incorporating the scores of two place-quality attributes, POPS accessibility and street quality, as impedance weights on the graph edges; and (iii) using this structure to compare design and urban-vitality scenarios by their resulting pedestrian-flow distributions.

METHODOLOGY

This study follows the Constructive Research Approach (Lukka, 2003), as part of an ongoing project to develop a parametric tool for analysing and comparing urban-vitality scenarios at the design-conception stage. It applies City Information Modeling (CIM) (Gil, 2020) through algorithmic-parametric modelling in Rhino–Grasshopper. This stage estimates potential pedestrian flows on a graph weighted by public-space quality attributes. The case study is presented first, followed by the analytical model, structured in four layers: (i) Moulon's semi-abstract parametric base; (ii) the graph structure, composed of segments, nodes, population objects, and attractor objects with their need frequencies (*nf*); (iii) the combined evaluation of the microlevel street-design and POPS accessibility scores, converted into impedance factors; and (iv) the VPM calculation, which applies these factors to the graph edges.

Case study: Paris-Saclay Moulon

As stated above, Moulon is one of the three districts of an ongoing urban project on the Saclay Plateau. Moulon's master plan is structured by an east–west axis connecting the project's two main anchors: the Synchrotron SOLEIL to the east and the École Polytechnique campus to the west. This axis unfolds into three structural lines: (i) the scientific axis, Le Deck, a linear public space that articulates academic and research facilities with leisure areas, plazas, gardens, and public transport infrastructure; (ii) the economic axis to the north, concentrating research centres and companies; and (iii) the pedestrianised commercial street to the south, combining local retail and daily services close to family housing, student residences, and public facilities (germe&JAM, 2017).

The district's morphological evolution develops through three phases (Figure 1): (i) the first formed by isolated buildings set within open green spaces, tied to the modernist legacy; (ii) the second characterised by large perimeter blocks with internal courtyards, associated with larger-scale urbanisation; and (iii) the third based on more fragmented blocks, with greater diversity in building typologies and land uses. Moulon's open-space and green-infrastructure system also connects public spaces, internal block areas, and collective facilities, supporting pedestrian continuity, environmental comfort, and the activation of staying spaces. Elements such as Le Deck, the Parc du Moulon, the Carré des Sciences, and the Jardin Argenté square structure public life by combining environmental functions, such as drainage, microclimate regulation, and biodiversity, with social and urban ones (germe&JAM, 2017).

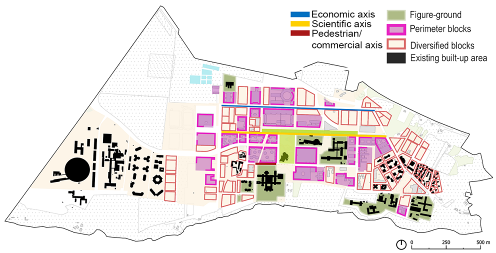

Figure 1
Spatial structure of the Moulon district: main axes, land uses, and master plan organisation. Source: Adapted from germe&JAM (2017).

Parametric model

Moulon's semi-abstract parametric-analytical structure preserves the master plan's main spatial relations in simplified form, making it suitable for testing alternative scenarios. The model is composed of three layers: (i) the structuring-axis hierarchy; (ii) the block typologies, with their degrees of density, use, and permeability; and (iii) the public-space and green-infrastructure system (Eloah et al., 2025).

The street hierarchy is organised into seven groups: the master plan's three axes — scientific, economic, and commercial — the fully pedestrianised mall, which inherits the commercial street's total width as a continuous sidewalk, the street squares associated with Parc du Moulon, the remaining collector streets, and the local streets. These axes are classified using three classes from Beirão's (2012) ontology: collector streets (S1), local streets (S2), and the fully pedestrianised commercial mall. Each class is associated with mandatory and optional components, parameterised by width, quantity, and presence or absence, according to its position in the hierarchy. Their minimum and maximum dimensions follow Noronha et al. (2022), except for the minimum sidewalk width of both street classes, taken from Beirão (2012) as the threshold required for simultaneous pedestrian passage and tree planting. Bus lanes, when present, have a fixed width of 4 m, while street trees are parameterised by tree spacing (Table 1).

From Moulon's three development phases, six block typologies are extracted. Since a single block can accommodate more than one use simultaneously, these typologies and land uses are combined into twelve building configurations, each assigning one or more uses to its blocks. Occupancy and typology also determine whether a block has an active frontage, as well as the type and accessibility classification of its POPS. POPS comprise block interiors, internal building passages, front setbacks open to public use, and the open spaces of the modernist typologies. Building on Carmona (2015), POPS are classified across four accessibility levels defined for this study, according to their degree of access restriction, from 1 (fully open to the public) to 0.1 (fully restricted) (Figure 2).

Axes	Classes	S	TL		L		BL	TC	TS
		w	n	w	n	w	w	w	w
Scientific Economic Commercial Collector	S1	1.9	2	3	2	0.8	1.2	4	5
Local Street Square	S2	1.9	2	3	2	0.8	1.2	4	5
Pedestrian	Pedestrian mall	entire width	-	-	-	-	-	-	5

S: sidewalk; TL: traffic lanes; L: landscape strip; BL: bike lane; TC: transport corridor; TS: tree spacing; n: number; w: width (m).

Table 1
Street classes assigned to each axis and minimum component values. Grey cells indicate mandatory components; non-shaded ones are optional. Source: Adapted from Beirão (2012) and Noronha et al. (2022).

The local population is estimated from the district's available data, including student-housing units, jobs offered, resident numbers, university-student numbers, and the built-density distribution across uses (EPAPS, 2022). This population is then distributed across the buildings according to their uses, which, in the parametric model, define the number of storeys and building heights.

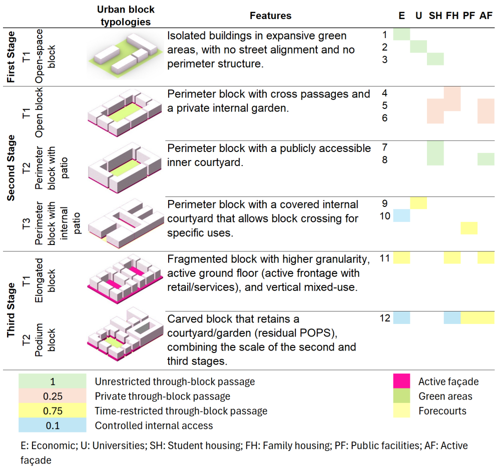

Figure 2
Parametric block typologies developed in this study, based on the morphological evolution of Moulon, illustrating variations in permeability, active frontages, and land-use configuration.

Weighted Graph model

The graph structure is defined from the street axes, which form its edges, subdivided into 25 m segments

Table 2
Amenities represented as attractor objects in the model and their respective nf values, used to weight the relative attractiveness of different land-use types. Source: Based on Murillo et al. (2025) and EPAPS (2022).

Category	Attractor	nf (visit/day)
Commerce & Services	Gyms	1/4
	Pharmacy; Laundry	1/16
	Hair salon	1/64
	Clothing / Music store; Bank	1/128
Entertainment	Cafeterias	1/1
	Leisure	1/8
	Bars	1/16
	Cinema	1/64
Food & Services	Bakeries	1/1
	Restaurants	1/2
	Supermarkets / Groceries	1/4
	General practitioner	1/64
Health	Health center	1/64
	Dental practice	1/128
	Physiotherapy clinic	1/128
Culture	Theatre / Cinema	1/64
	Art gallery	1/128
	Museum	1/128
Innovation Infra	Learning center	1/2
	Fab labs	1/8
	Research labs	1/16
Sports	Sports center	1/2
	Aquatic center	1/4
Green Areas	Le Deck	1/2
	Parc du Moulon	1/4
	Plateau agricole	1/64

whose points become the public-space nodes. Land uses are classified into population objects and attractor objects, which represent people entering and leaving buildings and their potential destinations, respectively (Herthogs et al., 2018).

Population objects correspond to economic-activity buildings, universities, and family and student housing, their population assigned to each building's entrance points. **Attractor objects** relate to public facilities, active frontages, and public and green spaces: public facilities relate to the entrance points of their respective buildings; active-frontage points come from dividing the footprint by an estimated shop-and-service area; and green-space points from subdividing their borders.

These points are classified by the amenity uses mapped by Murillo et al. (2025), which identified urban attractors relevant to daily life in knowledge districts, and by the master-plan green spaces, including Le Deck, the Parc du Moulon, and the Plateau agricole. The **nf values assigned** to amenity points are illustrative estimates defined for this study by amenity type. They represent visit-need frequency and differentiate the relative attractiveness among attractor types (Table 2).

Assessment of public-space attributes and impedance factors

The assessment of public-space quality attributes combines two scores: the street-quality, derived from Noronha et al.'s (2022) Evaluation Module (EM), and the POPS accessibility level, where present. The EM measures how far a street's microlevel design prioritises walking over automobility, scoring 11 design patterns from 19 indicators, where 0 is neutral, positive values are pedestrian-friendly, and negative ones car-dominated or hostile.

Each design pattern is evaluated through geometry-based indicators associated with street-profile components. Three of them were selected for this implementation: (i) traffic-lane width (P3), rewarding a narrower, calmer traffic zone; (ii) the safety-barrier pattern (P5), corresponding to the buffer that shields pedestrians from traffic; and (iii) tree coverage (P11), based on tree spacing. A fourth indicator, R5, is added to represent sidewalk width. Each indicator uses a two-point linear function (Table 3).

Table 3
Street-score variables and calculation functions. Source: Adapted from Noronha et al. (2022).

P	Input variable	Linear function
3	W_1 = avg. curb-to-curb width	$R1 = 100 \cdot (1 - W_1/14)$
	W_2 = avg. traffic-zone width	$R2 = 100 \cdot (1 - W_2/6)$
	N = avg. number of through-traffic lanes	$R3 = 100 \cdot (1 - N/2)$
	W_3 = avg. through-traffic lane width	$R4 = 100 \cdot (1 - W_3/3)$
5*	$R11$ = avg. landscape strip (both sides) R12 = avg. bike lane	$20 \cdot (R11 + R12) - 50$
11*	S = tree spacing	$S = 5 \rightarrow 100$; $S = 18 \rightarrow 0$
R5*	W_4 = sidewalk width	$100 \cdot (W_4/1.9 - 1)$

Widths in metres. Scores range from −100 to 100; P5 ranges from −50 to 100. W_1 comprises traffic lanes, the transport corridor, and bike lanes; W_2 comprises traffic lanes only. Adapted from the original: P5*: buffer zone (R10) and on-street parking (R13) excluded. P11*: tree spacing set directly as a parameter (instead of the number of trees per segment). R5*: added indicator (sidewalk width, Beirão's 1.9 m threshold).

Each street type's score is the average of its pattern scores (Equation 1); the pedestrian mall, being entirely pedestrian-priority, reaches the 100-point benchmark, leaving tree coverage (P11) as its only varying term (Equation 2).

- **S1 and S2:**

$$Score = (P3 + P5 + R5 + P11)/4 \qquad (1)$$

- **Pedestrian mall:**

$$Score = (300 + P11)/4 \tag{2}$$

The impedance factors assigned to the graph edges result from the calibration of these scores. The street-quality score is converted into an impedance factor (w_{street}) that scales the effective travel cost of the corresponding street edge, ranging from 0.5 to 1.5, where 1.0 is the neutral reference. For each street class, the neutral reference (S_0) corresponds to the score of the minimum configuration of parameters and mandatory components (Table 1): with 9 m tree spacing, 16.4 for S_1, 8.4 for S_2, and 92.3 for the pedestrianised commercial street. Based on these values, Equation (3) calibrates the simulated street-quality score:

$$w_{\text{street}}(S) = \begin{cases} 1.0 - 0.5 \cdot \dfrac{S - S_0}{100 - S_0}, & \text{if } S \geq S_0 \\ 1.0 + 0.5 \cdot \dfrac{S_0 - S}{S_0 + 100}, & \text{if } S < S_0 \end{cases} \tag{3}$$

where w_{street} is the impedance factor derived from the street-quality score; S is the simulated street-quality score; and S_0 is the neutral reference score for each street class.

Where a street segment is adjacent to a POPS entry point, w_{street} is further reduced in proportion to the accessibility level assigned to that space (Figure 2), representing the added network permeability provided by internal block connections and building passages, as well as the staying and social interaction spaces these POPS offer. The reduction reaches 20% for a fully accessible POPS and vanishes for the most restricted one (Equation 4):

$$w_{final} = w_{street}\left(1 - 0.2 \cdot \frac{p - 0.1}{0.9}\right) \tag{4}$$

where $p \in [0.1, 1.0]$ is the POPS accessibility level; w_{street} is the impedance factor; and w_{final} is the final edge weight, used in the weighted shortest-path calculation and in the distribution of VPM.

For edges without an adjacent POPS entry point, the final weight is taken as w_{street} (Equation 5):

$$w_{final} = w_{street} \tag{5}$$

Visit Potential on the Weighted Graph

The VPM estimates the presence of people in public spaces through a weighted-graph model that combines a universal law of urban visit frequencies with gravity-based accessibility measures. It defines three variants of visit potential. This analysis adopts Aggregate Pedestrian Movement, VP(3), which measures the flow of people passing through a public space along their shortest path between an origin (population) and a destination (attractor), weighted by the attractor's relative need frequency (nf^a) and the shortest distance (Herthogs et al., 2018).

For implementation, the model assumes that the entire population represented by a population-object point (P_j) is in motion. This flow is distributed proportionally: P_j is split among the available attractors according to the balance between nf (nf^a) and distance impedance ($(d_j^a)^{-2}$, both weighted equally in the destination choice.

VP(3) is assigned to the graph through an additive process at the segment nodes. Computing the shortest path with the ShortestWalk plugin, the model identifies each node along the route between origin ***j*** and destination ***a***. If a node ***i*** belongs to the shortest-path set (SP_j^a), it receives the share of population corresponding to that route (Equation 6).

$$VP_i^{(3)} = \sum_{a=0}^{|A|}\sum_{j=0}^{|J|} SP_j^{a,i} \cdot P_j \cdot \left[\frac{(d_j^a)^{-2}}{\sum_{a=0}^{|A|}(d_j^a)^{-2}} + \frac{nf^a}{\sum_{a=0}^{|A|} nf^a}\right] \cdot \frac{1}{2} \tag{6}$$

where: ***A*** is the total number of attractor nodes; ***J*** is the total number of population nodes; $SP_{j,i}^{a}=1$ if edge or node ***i*** lies on the shortest path from ***j*** to ***a***, and 0 otherwise; P_j is the ingress-egress rate (population) at origin node ***j***; d_j^a is the shortest-path distance between ***j*** and ***a*** ; nf^a is the need frequency of attractor ***a*** .

A point's final VP(3) is therefore the accumulated sum of all individual flows, from every simulated trajectory, that cross that space. This allows strategically positioned spaces, such as well-connected intersections, to show high visit potential even without attractors or housing in their immediate surroundings, capturing the movement and occupancy dynamics of the urban fabric.

Unlike purely topological models, the VPM lets qualitative attributes shape the pedestrian's perceived distance. To this end, the final weight (w_{final}), which combines the street-quality and POPS accessibility levels, is applied to the physical length (L_e) of each analysed street segment. This defines the effective walking cost (C_e) of each edge (Equation 7):

$$Ce = Le \cdot w_{final} \tag{7}$$

w_{final} acts as a distance multiplier. When $w_{final} < 1$, positive features such as greater tree coverage or wider sidewalks reduce the effective travel cost of a street segment, simulating a shorter perceived distance for pedestrians. Conversely, when $w_{final} > 1$, the effective travel cost increases, representing a lower-quality environment that discourages pedestrian movement.

This cost (C_e) is fed into the ShortestWalk plugin to compute the least-cost paths. As a result, the model redistributes VP toward the axes that offer greater comfort and attractiveness, making it possible to compare how different urban-design interventions intensify or mitigate vitality across specific areas of the district.

RESULTS

Scenario Building. Three scenarios were built using the model defined above. Their purpose is not to assess or propose changes to the actual Moulon district, but simply to use it as an example of an urban situation that can accommodate alternative configurations. The scenarios activate the model's mechanisms progressively. Scenario 1 runs without impedance factors, so flow distribution depends solely on network topology, the location and nf of amenities, and population concentration. Scenario 2 keeps every street at the minimum configuration of its class and activates the impedance factors: since each section scores its class's neutral reference, street quality remains neutral (w_{street} = 1.0) and only POPS accessibility affects the edges. Scenario 3 combines improved street sections, wider sidewalks, landscape strips, cycling infrastructure, and reduced tree spacing, with both attributes active. All of the scenarios keep population distribution, amenity locations, and their *nf* values constant. The results are summarised in Table 4 and illustrated in Figure 3.

Table 4
Comparison of street configurations, street-quality scores, impedance factors, and VP(3) results across the three scenarios. Scenarios 1 and 2 use the minimum configurations (Table 1) with 9 m tree spacing; Scenario 1 runs without impedance factors.

Axis	S w	L n*w	BL n*w	TC n*w	TS w	EM_{min}	$VP^{(3)}_1$	$w_{final\ 2}$	$VP^{(3)}_2$	EM_3	$w_{final\ 3}$	$VP^{(3)}_3$
Scientific	2	2×1.0	2×1.2	2×4	9	12.8	63.3	0.9	50.5	27.1	0.8	43
Pedestrian	–	–	–	–	5	92.3	16	0.9	33.3	100	0.4	80.1
Commercial	2	2×1.0	2×1.2	–	5	16.4	18.1	0.9	18.1	38.3	0.8	25.4
Economic	2.5	2×1.0	2×1.5	–	7	16.4	34.3	0.9	39.5	43.8	0.7	43.5
Collector	1.9	2×0.8	2×1.2	–	9	16.4	3.2	0.9	2.8	27.3	0.8	3.7
Local	2	2×0.8	–	–	6	8.4	20.3	0.9	18.7	23.5	0.8	18.1
Street Square*	2.5	2×1.0	–	–	5	8.4	11	0.9	17	41.6	0.7	26.8

* *Street Square: single 3 m traffic lane in Scenario 3 (lane reduction); all other axes have 2×3 m lanes.*
S: sidewalk; L: landscape strip; BL: bike lane; TC: transport corridor; TS: tree spacing; n*w: number × width(m); EM_{min}: street-quality score of the minimum configuration (Scenarios 1–2); EM_3: street-quality score in Scenario 3; w_{final}: final impedance factor; $VP^{(3)}$: Visit Potential.

Scenario 1 reveals the district's underlying circulation structure before the introduction of place-quality interventions. The scientific axis records the highest VP(3). This result can be attributed to three factors: the presence of Le Deck as a major leisure and staying space, the axis's central position within the network, and its concentration of universities and housing, which generates the district's highest population density. The economic axis follows, while the pedestrian mall remains modest.

Scenario 2 isolates the effect of POPS accessibility. Even so, pedestrian flow is redistributed. The pedestrian mall more than doubles its visit potential, favoured by the through-block passages of the student and family housing adjacent to the axis. The economic axis gains importance, likely due to block crossings and the large open spaces in the model's northern sector, while the scientific axis falls. This result shows that the staying spaces and internal permeability provided by POPS redirect potential movement before any change to the street sections themselves.

Scenario 3 produces the most pronounced flow redistribution among the scenarios. The pedestrian

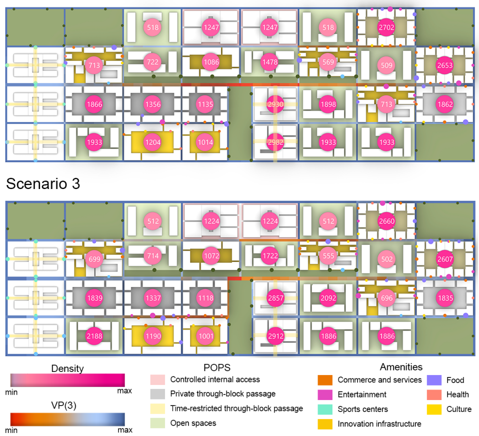

Figure 3
Scenarios 1 and 3. Circles within blocks represent population density, with colour indicating the number of people assigned to each block. Coloured circles represent amenities, whose size varies according to their *nf* (Table 2).

mall reaches the highest value across the network, five times its baseline, with the lowest final weight. This result reflects the combined effect of the two attributes: the high street-quality score associated with its pedestrian-oriented configuration, together with POPS accessibility and the concentration of amenities along the axis. The economic axis also increases, although this gain is not sufficient to make it dominant. The scientific axis falls despite more than doubling its quality score, and both therefore become secondary poles in relation to the mall, while collector streets remain marginal. Flow thus responds to relative rather than absolute quality.

Conversely, streets in the district's northern sector, where amenities are scarce and quality scores are low, exhibit a substantial decline in simulated pedestrian activity, with one segment reaching zero flow. This pattern suggests that the intervention redistributes rather than generates demand, concentrating pedestrians along more attractive routes while reducing activity in less favourable parts of the network.

Because VP(3) accumulates a count on every segment a trajectory crosses, network totals and averages are not conserved across scenarios (Herthogs et al., 2018). The population in motion is fixed by construction: each population point is fully distributed among the attractors, so VP(3) values are compared as the relative distribution of potential flow, not as absolute counts.

DISCUSSION

This paper extended a semi-abstract parametric model of the Moulon district, Paris-Saclay, to evaluate urban vitality in knowledge districts. Its main contribution is integrating the VPM with place-quality attributes, incorporated into the graph as impedance weights on the edges. These attributes are street quality, derived from microlevel street-design parameters, and POPS accessibility levels. The model also articulates the characteristics of knowledge districts, such as block typologies, population density, land uses, amenities, and nf values. The three simulated scenarios show that public-space quality alters the potential distribution of pedestrians across the network, with clear differences between axes that perform distinct urban functions.

The results point to an important planning implication: improving one axis does not affect that stretch alone but reorganises the preferred paths across the whole network. Microlevel interventions should therefore not be assessed in isolation. Place-quality strategies should thus be planned at the district scale, not street by street.

The model's central contribution is enabling the analysis of urban vitality before the territory is effectively occupied. Rather than relying on observed behaviour, the analysis rests on measurable spatial and functional attributes. This makes it possible to compare scenarios at the conception stage, when empirical data on how spaces are used do not yet exist. This capacity makes the model applicable both to designing new knowledge districts and to identifying retrofit priorities in existing ones.

Several limitations should be acknowledged. The nf values assigned to attractor types are illustrative estimates, defined to produce relative differences between scenarios rather than to predict absolute pedestrian counts. Similarly, population values were estimated from Paris-Saclay data and distributed proportionally across buildings according to block typology and land use. Moulon is only one of the three districts in the EPAPS area: some users may live in one district while studying or working in another, a mobility pattern the model does not yet capture. Flow values should therefore be read as approximations of relative pedestrian distribution, not as precise measurements of real behaviour.

A simplification of the method should also be made explicit. The VPM assigns the flow of each origin-destination pair to the least-cost path in the graph. In the proposed implementation, this cost is not only the geometric distance, as it is weighted by public-space quality attributes. A physically longer route may therefore be selected when its total impedance is lower. This formulation, however, concentrates flow on the least-impedance path and assumes that all pedestrians respond in the same way to the attributes assessed, without representing individual variations in route choice. Future calibration with empirical data will be needed to verify how closely the weighted distance approximates real route choices.

The model's graph structure also helps position it relative to data-driven approaches. Machine-learning methods can identify patterns from large datasets, but the relationship between inputs and outputs is not always transparent, which can limit their usefulness for design decision-making (Bedra et al., 2023). By contrast, the VPM explicitly represents the mechanisms that generate each simulated flow, allowing their individual contributions to be examined. The proposed parametric framework is therefore not intended as an alternative to data-driven methods, but as a complementary and interpretable foundation for their integration. Future developments could use machine learning to calibrate impedance weights from empirical observations, while surrogate models could accelerate computationally expensive calculations (Lamine et al., 2025; Huang et al., 2026).

Future development of the model will follow four main directions: incorporating other place-quality attributes that influence urban vitality in knowledge districts, such as the quality of the public-private interface, urban morphology, and density treated as a vitality attribute in itself rather than only as the basis for the population calculation; including public-transport nodes as dynamic entry and exit points able to modulate user presence across the territory; optimising the spatial distribution of amenities to broaden their accessibility for different user groups; and introducing temporal variation to simulate pedestrian flows at different times of day and days of the week. Together, these extensions would move the model from a static comparison of scenarios toward a dynamic tool for the design and planning of knowledge districts.

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