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Decoding the 'Spirit of Place': A Large Language Modeling (LLM) Approach to Formulating Perceived Pedestrian Accessibility in Space-Time Prisms

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Abstract

Morphological discontinuities in urban fabric cause discrepancies between physical and perceived accessibility. In response, this research explores how personal preferences and user perception can be mathematically parameterized to bridge this gap, thereby improving the representation of user accessibility in morphologically distinct urban environments. The study proposes a novel methodology using large language modeling (LLM) to formulate how phenomenological variables and "spirit of place" reshape pedestrian accessibility within space-time prisms (STPs) through AI-based simulations. A comparative analysis is conducted between the morphologically continuous Amsterdam Centre Station Square and the spatially fragmented Istanbul Beşiktaş Barbaros Square to decode decision-making strategies in these contrasting environments. By utilizing LLMs to process qualitative preferences and narratives, the research identifies how these experiences can be integrated as specific STP components. This approach establishes a foundational AI-driven framework for bridging environmental phenomenology with technical spatial modeling, creating a simulated environment for subsequent quantitative applications and further research developed through real-user interviews.

Keywords: Large Language Modelling; Perceived Accessibility; Space-Time Prism Accessibility; Phenomenology; Urban Morphology.

1. Introduction

1.1. The Perceptual Gap: Beyond Euclidean Proximity

Urban accessibility has traditionally been assessed through geometric proximity, assuming that minimizing physical distance is the primary driver of pedestrian movement. However, contemporary metropolitan environments demonstrate that the physical availability of a path does not necessarily equate to its perceived accessibility. (De Vos et al., 2023). Measures based on travel time, network distance, and spatial connectivity have generated important insights into urban mobility. However, contemporary research in urban studies highlights a perceptual gap in which pedestrians avoid geographically optimal routes due to morphological disruptions such as visual obstructions, fragmented circulation, or atmospheres of insecurity (Elzeni et al., 2022). Such cases demonstrate that accessibility is shaped not only by measurable distance, but also by the cognitive and perceptual experience of space. This study focuses on the discrepancy between objective spatial configurations and the perception-driven interpretations generated by LLM agents, framed through the concept of the spirit of place. The core problem lies in the inherent limitation of conventional spatial models in integrating intangible, perception-based frictions. As a result, these models often overlook the role of morphological discontinuities in reshaping the psychological boundaries of the city, effectively constraining the perceived reach of pedestrian accessibility.

1.2. From Spatial Logic to Perceptual Friction: The Limitations of Traditional Modeling

The limitations in conventional spatial models originate from a historical prioritization of structural morphology over the detailed dynamics of behavioral geography. Within this tradition, space syntax has provided important insights into how street-network configurations influence movement through measures such as integration and choice (Hillier and Hanson, 1984). Likewise, GIS-based accessibility models and network simulations have improved route optimization and spatial forecasting. However, recent literature critiques these approaches for conceptualizing the urban environment primarily through geometric and network-based metrics, often reducing the city to a neutral field of circulation while overlooking experiential, sensory, and meaning-rich dimensions of pedestrian environments (Kent et al., 2023; De Vos et al., 2023; Lee et al., 2023)

Contemporary empirical findings suggest that spatial agency is affected by subjective representations; perceived navigability, rather than mere metric distance alone, determines an individual's reach (Basu and Sevtsuk, 2022). The space-time prism (STP) framework, in addition, is a fundamental tool for defining the spatial and temporal limits of human mobility (Hägerstrand, 1970). However, STP-based models also frame accessibility primarily in terms of physical and temporal constraints. Yet, a pedestrian's potential path area is not only determined by walking speed and time, but is also influenced by affective atmosphere and perceptual barriers (Poom et al., 2023). The reduction of urban space to geometric or numerical representations is a persistent epistemological bias. Recent studies have attempted to incorporate soft data into spatial models (Li et al., 2023), yet a gap remains: although numerous narratives describe urban experience, no formal protocol exists to translate these qualitative spirit of place variables into measurable parameters for spatial modeling. Consequently, the absence of a semantic bridge creates a gap between phenomenological experience and quantitative analysis, preventing conventional STP accessibility models from incorporating phenomenological qualities as operational variables and often leading to urban interventions that improve physical circulation while neglecting perceptual experience.

1.3. Decoding "Spirit of Place": LLM as a Semantic Bridge

Addressing the gap between phenomenological experience and operational modeling in STP accessibility frameworks requires the formal detection and parameterization of phenomenological variables to enable their translation into operational inputs. This study proposes a novel AI-driven framework that utilizes large language models (LLMs) as a semantic bridge between qualitative urban narratives and formal mobility STP models. The primary objective is to formulate a methodology that translates qualitative preferences and narratives into operational STP components. Unlike traditional approaches, this framework treats LLM as a tool for phenomenology, identifying how subjective experiences of LLM agents can be integrated as specific STP parameters. Here, formulation refers to the construction of a logical protocol that transforms qualitative frictions into measurable constraints, enabling the translation of the spirit of place into a structured spatial logic.

To demonstrate the applicability of this framework, a comparative analysis is conducted between two contrasting urban morphologies: the continuous fabric of Amsterdam Centre Station Square and the spatially fragmented Istanbul Beşiktaş Barbaros Square. By analyzing the decision-making strategies of LLM agents in these distinct environments, the research identifies how morphological continuity or discontinuity reshapes the perceived boundaries of accessibility. This comparison provides a foundational logic to detect and parameterize LLM-driven perceptual indicators, informing more human-centric urban interventions. Following this introduction, Section 2 details the LLM-driven methodological framework; Section 3 presents the comparative analysis; Section 4 discusses the implications of decoded accessibility; and Section 5 concludes the paper by outlining future research directions.

2. Materials and Methods

The research methodology proposes a perception-driven computational framework that bridges morphological discontinuities and perceived accessibility within STP variables. The central assumption is that urban accessibility is equally shaped by the perceptual and cognitive interpretation of spatial configurations, extending beyond geometric and metric properties.

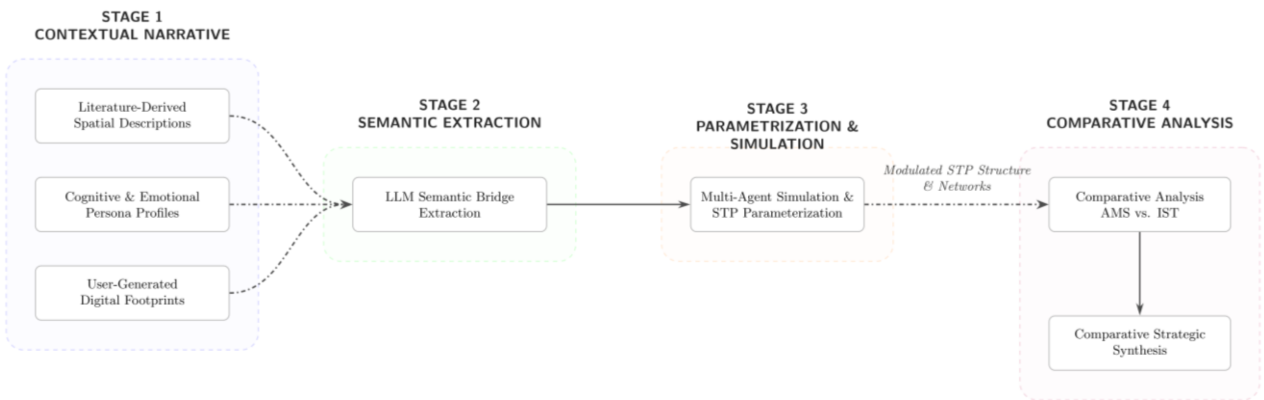


Figure 1. Research Methodology (Developed by the Author).

To operationalize this assumption, LLMs are used as semantic mediators that transform qualitative urban experience into structured logical parameters. The deployment of LLM-based agents as semantic mediators is preferred over traditional human trials implementing the silicon sampling paradigm (Park et al., 2023). This agentic approach facilitates scalable, controlled simulations of diverse pedestrian personas, enabling the systematic isolation of perceptual variables across varying urban fabrics (Carranza et al., 2025; Filomena et al., 2022; Verma et al., 2023). By utilizing generative agents, the framework filters out subjective noise, offering a high-fidelity environment for evaluating the impact of morphology on specific cognitive movement strategies. Rather than performing geometric computation, the framework focuses on translating urban narratives into perception-informed accessibility modifiers. Figure 1 illustrates that the research methodology is organized into four sequential stages: (i) contextual narrative construction, (ii) semantic extraction of perceptual variables, (iii) phenomenological parameterization, and (iv) comparative strategic synthesis.

2.1. Contextual Narrative Construction

A structured textual dataset is constructed to represent contrasting urban morphologies characterized by varying degrees of spatial continuity and fragmentation, as presented in Figure 2. These conditions are defined abstractly to enable a controlled comparative analysis of perception-driven accessibility across different urban configurations. Considering the diverse origins of urban experiences, LLMs are utilized to synthesize varied textual data into a cohesive narrative framework. This dataset is assembled from three main data sources, which together encompass formal spatial information alongside experiential urban perspectives. First, literature-derived spatial descriptions are collected from academic studies, urban design reports, and planning documents. These sources are filtered based on their relevance to spatial perception and urban morphology, focusing experiential attributes such as legibility, continuity, enclosure, and movement clarity. The literature review synthesizes traditional empirical studies, primarily those utilizing human-subject experiments and surveys to evaluate spatial experience, with emerging research focused on digital agent-based simulations. By integrating these two distinct domains, the study adopts a comprehensive perspective that bridges physical human experience with the computational insights offered by digital agents. Second, user-generated digital content is incorporated from publicly accessible location-based platforms, including map-based reviews and social media descriptions. These texts provide informal and experience-driven evaluations of spatial environments and are filtered to remove irrelevant or low-quality entries. The inclusion of digital footprint data provides a critical empirical layer, as these traces offer objective insights into large-scale, real-world human mobility patterns. All textual inputs are subject to basic pre-processing, including cleaning, normalization, and formatting into a consistent structure. The final dataset is organized as a unified narrative dataset which is used for the generation of LLM-based role simulations in the further stage. Prompt templates represent diverse user profiles (e.g., commuters, tourists, elderly users), allowing the model to produce consistent narratives that reflect different experiential readings of urban space enabling comparison across different morphological conditions.

2.2. Semantic Extraction of Perceptual Variables

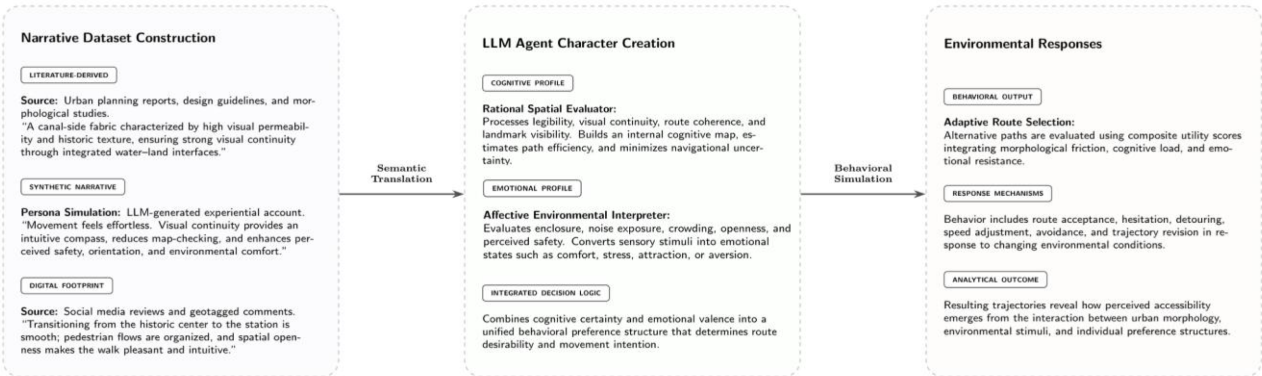


Figure 2. LLM-Driven Perceptual Response Modeling Framework (Developed by the Author).

In the second stage, the LLM serves as a semantic extraction mechanism, identifying latent perceptual structures embedded within the narrative dataset. Its objective is to convert unstructured textual data into analytically usable perceptual variables that mediate between spatial form and perceived accessibility. This process involves two main operations. First, the model identifies recurring experiential constructs across narratives such as enclosure, openness, visual continuity, fragmentation, legibility, flow, and disorientation. These are treated not as physical measurements, but as phenomenological descriptors of spatial experience. To capture variation in human perception, LLM agents are assigned distinct perceptual and affective profiles, facilitating the generation of synthesized experiential narratives that simulate diverse cognitive and emotional responses to urban space based on existing footprints and literature (Zheng et al., 2025; Noyman et al., 2026; Liu et al., 2026). Second, the model performs contextual affect mapping, linking each perceptual variable to its associated morphological condition. For instance, visual continuity is associated with higher legibility and smoother movement, while spatial interruptions are associated with fragmentation and greater navigation uncertainty. Likewise, open environments tend to reduce perceptual resistance, whereas obstructed environments tend to increase it. Through this process, the spirit of place is operationalized as a structured set of perceptual variables. These variables serve as the foundational inputs for the subsequent Stage 3, where they are translated into specific STP parameters to formulate how morphology is cognitively and emotionally translated into the final urban experience.

2.3 Phenomenological Parameterization within STP

The phenomenological parameterization stage constitutes the core analytical contribution of the framework, formalizing the transformation of perceptual variables into operational STP parameters through LLM semantic bridge extraction. Moving beyond purely physical constraints like time budgets, the model assumes that accessibility is systematically modified by perception-driven spatial distortions (Lättman et al., 2018; Manley et al., 2021; Negm et al., 2025). This process is implemented through three integrated mechanisms as illustrated in Figure 3. First, LLM semantic bridge extraction replaces traditional manual mapping by utilizing LLMs to decode semantic links between qualitative urban narratives and quantitative spatial modifiers, translating environmental representations into structured perceptual anchors. Second, multi-agent simulation is introduced to operationalize these parameters, deploying (cognitive + emotional) LLM agent personas, simulated individuals with specific cognitive loads and emotional states, into a virtualized urban network. These agents interact with the morphology to determine how factors like fragmentation or enclosure modulate the effective strength of spatial constraints. Third, to eliminate model-specific biases and ensure structural consistency, the simulation is executed across three distinct LLM architectures: Gemini, Llama-3, and OpenAI. This tri-model approach facilitates inter-model consensus, verifying that accessibility modifications reflect a generalized, cross-validated perceptual response rather than algorithmic artifacts. Consequently, morphological discontinuities are redefined as perception-driven distortions that reshape the effective structure of spatial accessibility, integrating subjective experience into the computational geometry of the space-time prism.

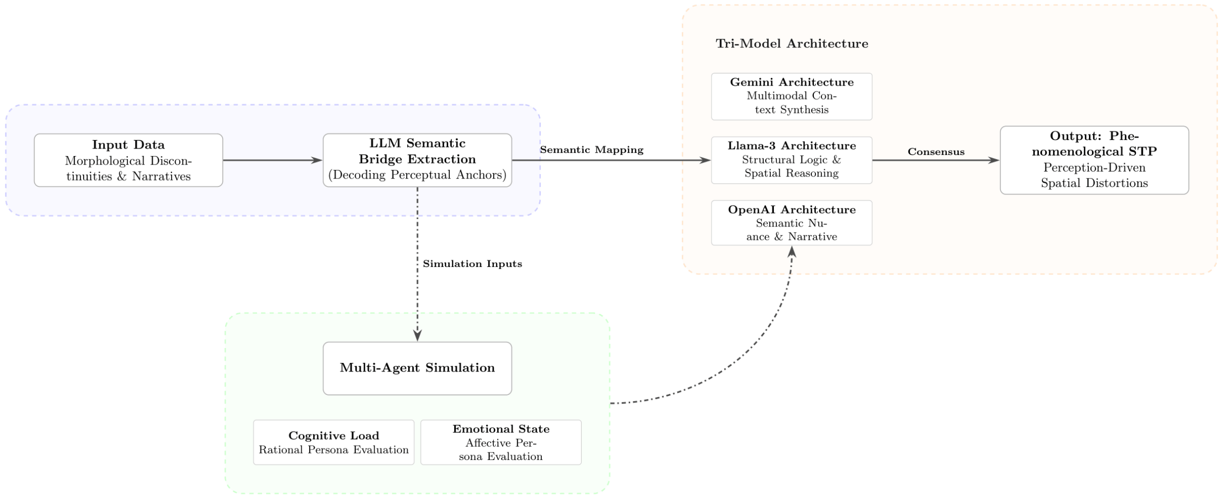


Figure 3. Phenomenological Parameterization within STP (Developed by the Author).

2.4. Comparative Accessibility Analysis

The final stage applies the parameterized framework to conduct a comparative analysis across urban environments with diverse morphological characteristics, evaluating how variations in spatial structure produce distinct perception-adjusted accessibility outcomes through generated agent-based networks. The analysis begins with behavioral strategy inference, utilizing tri-model simulation results to observe how spatial continuity supports linear, efficient movement, whereas fragmented configurations trigger adaptive, negotiation-based navigation patterns. These emergent behaviors are interpreted as products of the LLM semantic bridge rather than static geometric properties. Subsequently, STP deformation analysis is conducted by integrating perceptual parameters derived from the consensus outputs of Gemini, Llama-3, and OpenAI models, enabling the conceptual deformation of space-time prisms according to perception-mediated accessibility conditions. This allows the framework to demonstrate how identical physical distances yield divergent accessibility outcomes based on perceptual conditions like visual continuity or fragmentation. Finally, comparative synthesis generates a generalized interpretive framework that identifies systematic relationships between morphological continuity, perceptual structure, and accessibility distortion.

Overall, the proposed model establishes a three-layer transformation: (1) translating urban environments into narratives, (2) extracting structured perceptual variables via LLMs, and (3) formalizing these into STP-compatible modifiers through multi-agent simulation. By positioning LLMs as both semantic mediators and active cognitive agents, the framework integrates qualitative urban experience into computational spatial modeling, extending traditional accessibility analysis toward a perception-aware and morphology-sensitive paradigm.

3. Results

The results of the tri-model simulation and the subsequent phenomenological parameterization reveal a profound divergence in how urban environments are perceived and navigated by agentic personas. By utilizing LLMs to decode the spirit of place, this research evaluates the operational impact of urban morphology on pedestrian accessibility, moving beyond Euclidean metrics into the realm of cognitive and emotional spatial logic.

3.1. Comparative Simulation Outcomes: Agentic Navigational Strategies

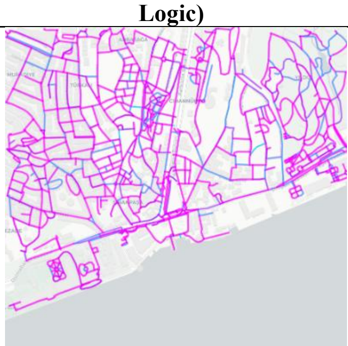
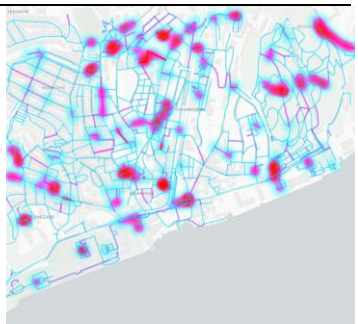
The first stage of the analysis focuses on the digital decoding of urban environments through a multi-agent simulation. To ensure the reliability of the findings and mitigate the risk of algorithmic bias, this study adopts a tri-model consensus approach utilizing three state-of-the-art LLMs: Gemini (Google), Llama-3 (Meta), and OpenAI (GPT-5.4). The decision to employ multiple agents is rooted in contemporary literature, which suggests that relying on a single model may lead to perceptual tunneling or model-specific biases. Recent studies on LLM-based social simulations demonstrate that prompt-conditioned and multi-agent architectures can generate heterogeneous behavioral outputs, establishing a computational foundation for representing cognitive variance in human-like agents (Kıcıman et al., 2023; Park et al., 2023). Parallel research on perceived accessibility further reveals that spatial environments are cognitively interpreted in systematically different ways (Pot et al., 2021). Specifically, each agent was selected for its distinct specialized strength within the urban navigation task. Gemini, multimodal architectures and large-scale pre-training enable the processing of spatial and environmental inputs, aligning with embodied multimodal reasoning in LLMs (Driess et al., 2023). Llama-3 was selected for its strength in decision-making reasoning and structured task decomposition, consistent with findings that LLMs can perform hierarchical reasoning through chain-of-thought prompting (Wei et al., 2022). OpenAI-based LLMs were employed for semantic interpretation and contextual inference, supporting the extraction of nuanced meanings and abstract experiential descriptions through few-shot learning and generalization capabilities (Brown et al., 2020).

The comparative findings are summarized in Table 1 (Amsterdam, Station Square) and Table 2 (Istanbul, Beşiktaş Barbaros Square), presenting agentic feedback through three critical lenses: physical observations, decision-making logic, and semantic-nuance status. The simulation results, visualized through a cold blue/cyan spectrum, indicate high perceived accessibility across all models. Progression toward purple, magenta, and red tones corresponds to increasing levels of perceived cognitive load within the environment, with red tone accumulations marking the perceptual breakdown points of LLM agents. The Amsterdam (Station Square) case study demonstrates that the agents interacted with a planned, linear, water-oriented morphology characterized by flat topography and high visual transparency. Table 1 indicates that, due to the topological conditions and spatial openness of the area, Gemini presented high sensitivity to visual continuity and waterfront vistas, while Llama-3 maintained a strict decision-making logic focused on network efficiency. OpenAI confirmed that the majority of the site remains accessible, while identifying minor perceptual friction points. The soft transitions in the resulting maps suggest that Amsterdam's pedestrian fluidity is exposed as an environment of low cognitive load and high invitational quality. Conversely, Istanbul (Beşiktaş Barbaros Square) analysis tested the adaptability of the framework against a chaotic, organic tissue marked by steep topography and sharp thresholds, such as the Barbaros axis. Here, Table 2 exhibits the models shifted toward purple and magenta hues, indicating a significant increase in perceptual load. Gemini agents reported physical discontinuities and obstructions, while Llama-3 agents highlighted that the cognitive load of navigating the barrier networks far outweighed the physical distances. OpenAI presented a high density of perceptual breakdown points (red nodes), particularly within the dense bazaar texture. This transition from flow in Amsterdam to perceptual bottlenecks in Istanbul highlights how fragmented morphology acts as a cognitive barrier, even when a physical path is present.

Table 1. Comparative LLM Interpretations of Amsterdam (Station Square) Waterfront (Developed by the Author).

Case	**A: Gemini (Multimodal Context)**	**B: Llama-3 (Decision-Making Logic)**	**C: OpenAI (Semantic Nuance)**
Amsterdam (Station Square)			
Interpretation Bias	High sensitivity to visual/spatial continuity and context.	Focuses on topological connectivity and rule-based logic very well in Amsterdam.	Strong emphasis on narrative depth and semantic anchors.
Morphological Sensitivity	Detects "visual fractures" in the waterfront façade.	Prioritizes "network efficiency" and physical path junctions.	Identifies "atmosphere" and historical/narrative significance.
Agent Affect (D)	More balanced, integrating environment and mood.	Conservative; emphasizes cognitive load over emotion.	High emotional variance; reactive to narrative descriptions.
STP Transformation	Moderately elastic; reflects broad spatial context.	Rigid; focuses on precise geometric constraints.	Highly fluid; distorted by perceived semantic intensity.
Correlation	Correlates with "Scenic/Viewpoint" quality.	Correlates with "Shortest/Functional" routes.	Correlates with "Experiential/Iconic" locations.

Table 2. Comparative LLM Interpretations of Istanbul (Beşiktaş Barbaros Square) Waterfront (Developed by the Author).

Case	A: Gemini (Multimodal Context)	B: Llama-3 (Decision-Making Logic)	C: OpenAI (Semantic Nuance)
Istanbul (Beşiktaş Square)			
Interpretation Bias	High sensivity to physical barriers caused by topological properties.	Analyzes the barrier networks as high-cost physical segments of Beşiktaş square and main arteries.	Interprets the effort and fatigue narrative of site movement.
Morphological Sensitivity	Focuses on the Barbaros axis as a major visual and physical fracture.	Prioritizes the main arterial connectivity and transit hubs.	Highlights the chaos vs. calm transition between Sinanpaşa and Yıldız.
Agent Affect (D)	Balances sea-level accessibility with the effort of barrier experiencing personas.	Conservative; prioritizes physical energy expenditure over emotional mood.	High reactive variance; sensitive to the "noise" and "crowd" narratives of the area.
STP Transformation	Moderately elastic; reflects the limited physical accessibility range.	Rigid; focuses on the physical constraints of the steep, dense urban tissue.	Highly fluid; distorted by the perceived intensity of social and commercial nodes.
Correlation	Correlates with vista points and Bosphorus visibility axes.	Correlates with transit hubs and Barbaros Boulevard connectivity.	Correlates with atmospheric/historic nodes and pedestrian-heavy bazaar areas.

3.2. Modeling Perceived Reach: Temporal Compression and Kinesthetic Delta

The quantitative synthesis of the research also highlights a direct correlation between perceived spatial distortions and the resulting navigational effort. This relationship is analyzed through three primary metrics: the perceived accessibility modifier (A_{mod}), behavioral friction index (k), and morphological resistance (φ). The interaction between A_{mod} and φ is illustrated in the comparative scatter plot (Figure 4). In the Amsterdam dataset (blue), perceived accessibility modifier values remain consistently high, clustering between 0.8 and 1.0 even as resistance increases. This stability confirms a state of temporal elasticity, where the legibility of the environment offsets psychological friction. Conversely, the Istanbul data (magenta) shows a sharp non-linear decline; as φ exceeds a threshold of approximately 0.6, A_{mod} collapses toward 0.2. This trend quantifies the temporal compression effect, where the steep topography of Beşiktaş Barbaros Square and organic fragmentation effectively reduce the functional boundaries of the STP.

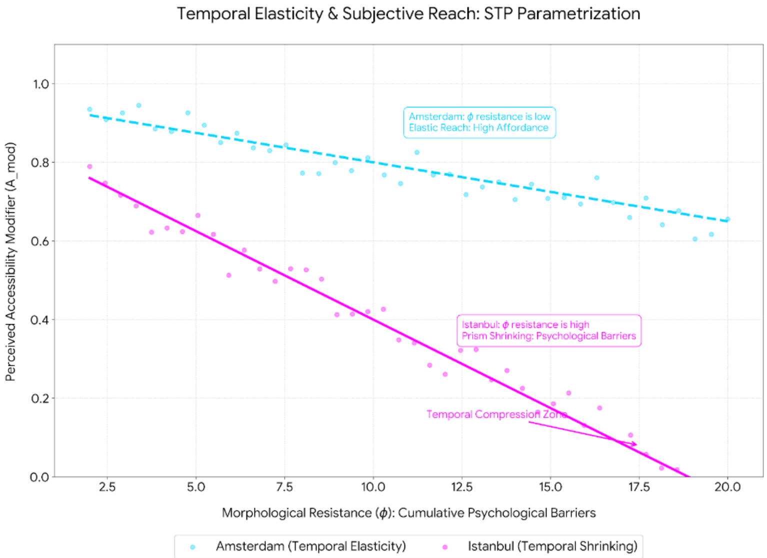


Figure 4. Temporal Elasticity and Subjective Reach: STP Parametrization (Developed by the Author).

Figure 5 illustrates the analysis of movement quality, visualized in the behavioral density graph, revealing a stark divergence in kinetic energy distribution. Amsterdam's profile peaks prominently within the preferred zone (peaking at $k \approx 0.15$), indicating high rhythmic efficiency with minimal friction. In contrast, Istanbul's movement distribution is heavily clustered toward the struggled and avoided sectors, with a secondary peak in the high-friction range ($k > 0.7$). The kinesthetic delta, marked by the black arrow, measures the distance between these two peaks. This delta represents a quantifiable perceptual tax; it demonstrates that navigating Beşiktaş Barbaros Square requires nearly 4 times the cognitive and behavioral adjustment compared to Amsterdam Station Square to achieve the same spatial progress.

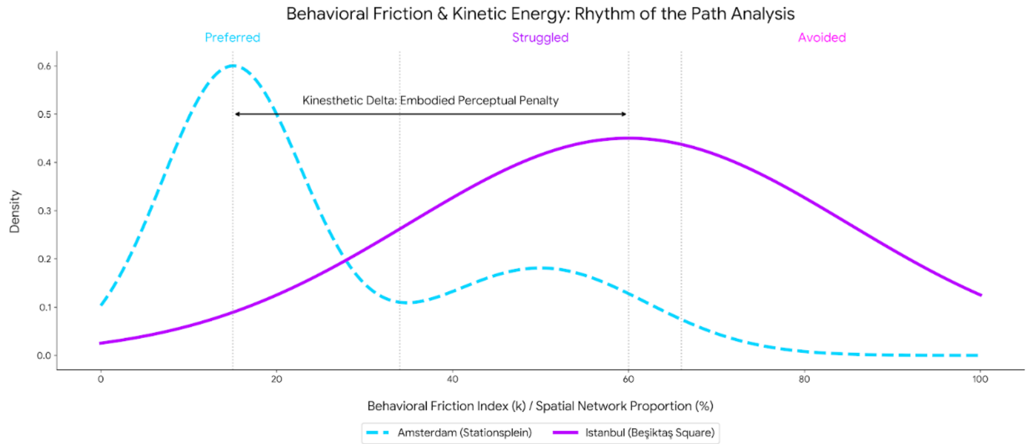
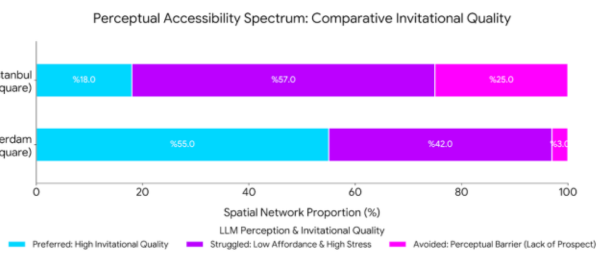
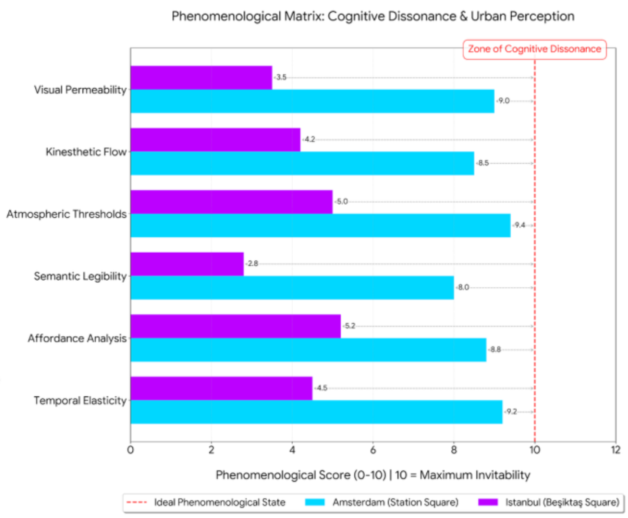


Figure 5. Behavioral Friction and Kinetic Energy: Rhythm of the Path (Developed by the Author).

3.3. Space-Time Prism Parameterization: From Phenomenological Mapping to Decoding the Spirit of Place

The final quantification of invitational quality is established by synthesizing agentic narratives into a comparative framework. To identify the underlying drivers of spatial choices, agents were prompted to report their navigational experiences using descriptive keywords. These qualitative reports were then aggregated into six phenomenological dimensions: visual permeability, kinesthetic flow, atmospheric thresholds, semantic legibility, affordance analysis, and temporal elasticity.





Figures 6 and 7. Perceptual Accessibility Spectrum and Phenomenological Matrix Graphs (Developed by the Author).

The perceptual accessibility spectrum (Figure 6) illustrates a clear contrast in environmental invitation. In Amsterdam, 55% of the urban fabric is categorized within the preferred zone, indicating that more than half of the environment actively invites spontaneous movement. In contrast, Istanbul's invitational area drops significantly to only 18%, while the avoided zones, representing points of total perceptual breakdown, climb to 25%. These results confirm that despite potentially similar metric distances, the psychological resistance in Istanbul is nearly 8.3 times higher than in Amsterdam. The phenomenological matrix (Figure 7) decodes the specific cognitive drivers behind these scores. The zone of cognitive dissonance in Istanbul is primarily driven by critical deficits in semantic legibility (2.8) and visual permeability (3.5). Agent reports for the Beşiktaş area consistently cited sensory overload, lack of clear prospect, and morphological disorientation as primary reasons for route avoidance. These low scores indicate that the organic complexity and steep topography of the site create a high cognitive load that effectively limits the pedestrian's accessibility. Conversely, Amsterdam achieves near-optimal performance across all six dimensions, with a peak score in atmospheric thresholds (9.4). The agents described their experience through keywords associated with spatial clarity, uninterrupted vistas, and effortless flow. This high invitational quality is directly correlated with its high temporal elasticity (9.2), proving that an environment that is semantically legible and visually permeable allows for a more expansive and fluid pedestrian experience.

The perceptual accessibility spectrum extends Hägerstrand's classical time-geographic framework by incorporating perception-based variations into the spatial and temporal constraints that define the STP. In its canonical formulation, movement is restricted by the temporal envelope, and within these constraints, the set of all potentially reachable locations is defined as the potential path area (PPA) as in Eq. (1).

$$PPA = \{ j \in \Omega \mid t(h_0, j) + d_a + t(j, h_1) \leq T_\beta \} \quad (1)$$

where $t(h0, j)$ and $t(j, h1)$ denote Euclidean distance-based travel times between two anchor points ($h0$ and $h1$); $j \in \Omega$ is a potential intermediate location for activities; da is the minimum activity duration; $h0$ is the origin node (e.g., transit hub); $h1$ is the final destination node (e.g., workplace); $T\beta$ is the total time budget. This formulation constitutes the classical geometric interpretation of accessibility, where reachability is governed exclusively by metric distance, temporal budget, and physical movement capacity under idealized conditions, neglecting the perceptual indicators. However, regarding the empirical contrast between Amsterdam and Istanbul cases, the present study extends the classical STP–PPA framework by introducing a perception-conditioned accessibility formulation. The empirical contrast between Amsterdam and Istanbul indicates that this classical formulation can be extended to address the existing limitations. Specifically, this study refines the STP–PPA framework by redefining travel time as a perception-conditioned cost function.

$$PPA = \{ j \in \Omega \mid t^B(h_0, j) + d_a + t^B(j, h_1) \leq T_\beta \} \quad (2)$$

$$t^B(h_0, h_1) = t(h_0, h_1) \times F_m \quad (3)$$

where t^B represents the base travel time already embedded with perceptual distance distortion effects in Eq. (2), while F_m functions as a friction modulator that scales effective temporal cost as shown in Eq. (3). It is a parameter depending on the interaction between morphological resistance (φ), behavioral friction (k), and phenomenological perception (ε) (Eq.(4)). φ denotes morphological resistance (e.g., topography, fragmentation, discontinuity); k represents the behavioral friction index derived from observed movement deviation, and ε is defined as a structured perceptual vector composed of multiple environmental cognition dimensions.

$$F_m = 1 + \left(\frac{\varphi\ .k}{\varepsilon}\right) \quad (4)$$

$$\varepsilon = \sum_{i-1}^{n} \varepsilon_i \quad (5)$$

Eq. (5) illustrates that each component ε_i corresponds to a distinct perceptual dimension derived from environmental cognition, including visual permeability (ε_v), kinesthetic flow (ε_k), atmospheric thresholds (ε_a), semantic legibility (ε_s), affordance structure (ε_f), and temporal elasticity (ε_t). Table 3 presents the qualitative reports of LLM agents, which were aggregated into six primary phenomenological dimensions, each assigned a mathematical variable ε to be integrated into the final accessibility equations.

Table 3. STP Extension via Phenomenological Parameterization (Developed by the Author).

Parameter	Variable	Agentic Descriptive Keywords	Amsterdam (Station Square)	Istanbul (Beşiktaş Barbaros Square)
Visual Permeability	ε_v	Prospect, visual continuity, transparency, focal points.	9.0	3.5
Kinesthetic Flow	ε_k	Effortless, rhythmic, slope impact, uninterrupted.	8.5	4.2
Atmospheric Thresholds	ε_a	Sensory load, thermal comfort, safety, openness.	9.4	5.0
Semantic Legibility	ε_s	Landmark, orientation, signage, clarity.	8.0	2.8
Affordance Analysis	ε_f	Seating, shade, sidewalk width, functional diversity.	8.8	5.2
Temporal Elasticity	ε_t	Fluidity, pace, time-perception, reachability.	9.2	4.5

These results collectively establish a consistent linkage between the empirically observed mobility patterns and the underlying phenomenological structure of the environment. By integrating the six-dimensional perceptual vector (ε) into the friction-modulated STP formulation, the study demonstrates that accessibility is not solely a function of geometric or temporal constraints, but is systematically shaped by the interaction between morphological resistance, behavioral friction, and perception-driven environmental interpretation. In this framework, the classical space-time prism is effectively transformed into a perception-conditioned accessibility field, where variations in ε directly translate into measurable deformations of the potential path area. Consequently, the contrasting cases of Amsterdam and Istanbul empirically validate the proposed extension, showing that environments with higher phenomenological coherence sustain greater temporal elasticity, while those with fragmented perceptual structures produce accelerated compression of reachable space.

4. Discussion

The findings of this research provide empirical evidence that urban accessibility is a perception-mediated construct shaped by the morphological spirit of place rather than mere geometric distance. By utilizing LLMs as a semantic bridge, this study demonstrates how different urban textures either facilitate temporal elasticity or impose temporal compression on the pedestrian experience.

4.1. Towards Perceptive Urbanism: Defining the Spirit of Place as a Measurable Constraint

The empirical contrast between Amsterdam and Istanbul validates the extension of the potential path area (PPA) formula (Eq. (1)) into a perception-conditioned model as shown in Eq. (2). In Amsterdam, the perceived accessibility modifier remains stable between 0.8 and 1.0 (Figure 4), confirming a state of temporal elasticity. This is mathematically supported by the high scores in the perceptual vector components (Table 3), where temporal elasticity (ε_t) is 9.2 and visual permeability (ε_v) is 9.0. In our formulation (Eq. (4)), these high values act as denominators that minimize the friction modulator (F_m). Conversely, Istanbul data exhibit a non-linear collapse. As the morphological resistance (φ), driven by steep topography and organic fragmentation, exceeds a threshold of 11.0, the perceived accessibility modifier drops sharply toward 0.25-0.10 (Figure 4). In the context of Eq. (3), this collapse represents an accelerated growth of the perception-conditioned cost function (t^B). This trend is further evidenced by the kinesthetic delta (Figure 5), where the behavioral friction index (k) for Istanbul shows a 4-fold increase compared to Amsterdam. This confirms that k in Eq. (4) is not a minor adjustment but a primary driver that limits the functional reach of the STP.

By synthesizing agentic narratives into the six-dimensional perceptual vector (ε) (Eq. (5)), the study identifies the specific cognitive drivers behind spatial exclusion. The zone of cognitive dissonance (Figure 7) highlights that the accessibility breakdown in Istanbul is primarily driven by critical deficits in semantic legibility ($\varepsilon_s = 2.8$) and visual permeability ($\varepsilon_v = 3.5$). When these low phenomenological values trigger an inverse escalation of F_m (Eq. (4)), the resulting psychological resistance is mathematically 8.3 times higher than in continuous fabrics (Figure 6). This provides a rigorous evidence-based validation for perceptive urbanism: the intangible spirit of place is effectively a measurable friction that scales the effective temporal cost (t^B), dictating pedestrian movement more than metric distance alone. The alignment between low phenomenological scores and high avoidance rates (25% in Istanbul) provides a pre-construction simulation framework for urban planning. By monitoring the perceived accessibility modifier relative to morphological resistance, practitioners can identify perceptual bottlenecks where the STP begins to compress. This shifts the focus from optimizing the physical network to actively maximizing the invitational quality of the city, ensuring that investments in connectivity are not negated by the psychological avoidance of fragmented urban morphologies.

4.2. Limitations and Future Directions

Despite its consistency, this study faces limitations inherent to silicon sampling (Park et al., 2023). While the tri-model consensus mitigates algorithmic bias, LLMs cannot fully replicate the physiological complexity of human experience, such as the real-time impact of noise or weather. Furthermore, while the contrast between planned linearity and organic fragmentation is clear, further validation is needed for different urban typologies.

Future research within the scope of this study will involve empirical experiments with real human participants, allowing the calibration of perceptual vector components (ε_i) against observed biometric responses. This will subsequently enable comparative analyses between human-subject experiments and LLM-based agent simulations, thereby establishing a hybrid validation framework for refining accessibility modifiers. Ultimately, the goal is to develop a universal protocol for phenomenology, ensuring that the spirit of place becomes a standard data point in designing more humane and accessible cities.

5. Conclusions

This research establishes that urban accessibility is not a fixed geometric property but a perception-mediated construct. By introducing LLMs as a semantic bridge, the study quantifies how the intangible atmosphere of the city reshapes the physical boundaries of human mobility. The comparative analysis between Amsterdam and Istanbul serves as a foundational proof of concept: while spatial continuity sustains temporal elasticity, morphological fragmentation triggers temporal compression, effectively shrinking the functional reach of the pedestrian regardless of metric proximity. The primary contribution of this work lies in the formulation of phenomenology, a protocol that translates qualitative narratives into operational parameters within the STP framework. This study advances computational urbanism by pioneering a tri-model silicon sampling methodology that provides a proxy for cognitive variance while mitigating individual model bias. By parameterizing six dimensions, from visual permeability to kinesthetic flow, the research proves that these soft variables are, in fact, hard spatial constraints that dictate movement more than distance alone.

For urban policy and professional practice, the findings offer a transformative tool that shifts the focus from metric-centric to human-centric design. The empirical findings provide a pre-construction simulation framework that allows practitioners to evaluate the invitational quality of a project before it is physically finalized. Evidence-based planning can now identify perceptual bottlenecks, such as the high cognitive load points observed in Istanbul, enabling interventions that prioritize visual permeability or semantic clarity. Ultimately, the research proves that investments in physical connectivity may fail if the resulting morphology remains psychologically avoided, emphasizing that urban design must prioritize the continuity of the perceptual fabric alongside the physical network. While this study establishes a scalable AI-driven framework, it represents a foundational step toward a broader integration of machine intelligence and phenomenology. A candid limitation of this work is its reliance on the latent data of LLMs, which cannot fully replicate the physiological complexity of human experience, such as the real-time impact of noise or weather conditions, yet. Therefore, future scholarship can aim to integrate these agentic simulations with real-world human participants' data to calibrate perceptual anchors. Expanding this framework to include diverse comparisons of digital agent profiles and human participants will further refine the perceived accessibility modifiers, ensuring that the spirit of place becomes a standard data point in designing more humane and accessible cities.

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