Humanities and Social Sciences Communications

Article in Press

https://doi.org/10.1057/s41599-026-06648-8

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Received: 9 March 2025

Accepted: 29 January 2026

Cite this article as: Wang, R., Shang, W. Exploring the psychological appeal of curved streets: a multivariate analysis of expectation formation in urban spaces. *Humanit Soc Sci Commun* (2026). https://doi.org/10.1057/s41599-026-06648-8

Ruoyao Wang & Wei Shang

Exploring the Psychological Appeal of Curved Streets: A Multivariate Analysis of Expectation Formation in Urban Spaces

Abstract: Curved streets have long played a crucial role in shaping the experience of urban space, affecting the visual perception and psychological expectations of pedestrians. This study examines how key geometric variables, such as curvature, wall spacing, and segmentation, affect spatial expectations in curved environments. To carry out the study in a real setting, a field survey of 78 curved street cases in 14 countries was first conducted to extract representative spatial configurations as reference types. These are then abstracted into 3D computer graphics (3DCG) simulation models, which enable us to control the manipulation of geometric parameters while eliminating non-visual variables such as color and texture. A total of 223 participants, including professionals, students in design-related fields, and laypeople, took part in a perception-based experiment evaluating maximum desired position and desired intensity. Our setting is that participants have not actually visited these locations. The simulated environment captures universal spatial characteristics, focuses on universal perception mechanisms, and reduces the familiarity of specific locations to record the first intuitionistic feelings of participants. Multiple regression analyses were used to quantify the relationship between physical street attributes and psychological responses. The results show that streets with moderate curvature and well-spaced building elements enhance spatial depth and continuity, thus enhancing the sense of expectation, based on the above, we construct a prediction model to link geometric street features with perceived outcomes. Through empirical observation, virtual simulation, and statistical analysis, this study provides a new perspective on how spatial morphology affects human cognition. These findings can contribute both theoretically and practically to the development of more attractive, psychologically resonant, and human-centered urban public Spaces.

Keywords: Curved Streets; Spatial Perception; Environmental Psychology; Maximum Expectancy Position; Expectancy Intensity; Spatial Cognition

1. Introduction

Urban streets are more than conduits for movement; they are stages for perception, interaction, and psychological response (Guo et al., 2024). Within contemporary urban design discourse—especially in the traditions of human-centered design (Gehl & Gemzøe, 2003), New Urbanism (Skoufas et al., 2025), and spatial legibility theory—streets are increasingly regarded as active arenas for interaction, expectation, and psychological engagement (Chakraborty & Ji, 2025). Early spatial theorists such as Camillo Sitte, Gordon Cullen, and Kevin Lynch emphasized how spatial rhythm, visibility, and enclosure shape user experience. More recently, scholarship in environmental psychology, spatial cognition, and affective urbanism has demonstrated that spatial form not only influences navigation and orientation, but also deeper perceptual-emotional states such as anticipation, curiosity, and spatial comfort (Bardhan et al., 2024).

Among the various street configurations that activate these experiences, curved streets represent a particularly compelling typology. Unlike linear streets, which often reveal their spatial content all at once, curved streets sequentially unveil space as pedestrians move along them (An et al., 2023). This gradual spatial revelation generates what we define as "psychological expectation"—a dynamic perceptual effect evoked by changes in visibility, depth, and spatial rhythm (Dang et al., 2025 ; Yoshida & Nakai, 2024). As pedestrians transition through partially concealed environments, the alternation between enclosure and opening fosters anticipation toward "what lies ahead. " This anticipation is not merely aesthetic but functionally affects wayfinding, pausing behavior, and emotional engagement with the urban landscape (Albrektsen, 2025 ; Balasubramanian et al., 2022). This phenomenon has been observed across diverse global contexts. In organically developed districts in Europe, East Asia, and the Middle East, curved street layouts have emerged from topographical, cultural, and defensive needs (Kostof, 1991 ; Moudon, 1997). In contrast, contemporary planning in North America, Southeast Asia, and coastal China tends to favor rectilinear street grids, often overlooking the psychological affordances of curvature. Nonetheless, researchers are beginning to explore how geometric elements such as curvature, segmentation, and enclosure modulate spatial perception (Anderson, 1978 ; Gehl, 2010). Studies in spatial cognition, affective computing, and ecological psychology further support the notion that these attributes shape expectation and mental engagement with space (Bajada et al., 2023).

This study draws upon several theoretical frameworks to ground the notion of expectation. From a spatial cognition perspective, Lynch' s theory of spatial legibility emphasizes how visual clarity and sequential spatial cues influence navigation and emotional response (Lynch, 1960). Gibson' s ecological psychology introduces the concept of affordance, suggesting that spatial configurations imply possible actions and interactions—curved streets, for instance, afford discovery and forward movement (Gibson, 1979). Cullen' s concept of serial vision stresses how spatial experiences unfold through movement (Cullen, 1961), while Kaplan and Kaplan' s preference theory links spatial preference to coherence and mystery—both engaged by curved streets (Kaplan & Kaplan, 1989).

In addition, the study references Space Syntax theory (Chen et al., 2025 ; Hillier & Hanson, 1984) which analyzes spatial connectivity and visibility, aligning with the geometric clarity required to evoke expectation. Form Perception Theory and Environmental Enclosure Theory further explain how enclosure, segmentation, and continuity enhance spatial legibility and psychological engagement. Continuity Theory and Experience Economy concepts suggest that cohesive and immersive spatial sequences generate emotional resonance (Pine & Gilmore, 1999). Landscape Perception Theory and Human Spatial Behavior Theory illuminate how environment and behavior reciprocally shape each other (Kaplan & Kaplan, 1989 ; Zeisel, 2006). Lastly, Multisensory Design Theory and Humanistic Urban Design Theory argue for designing spaces that address not just visual but full sensory and emotional experience (Pallasmaa, 2012 ; Gehl, 2011 ; Hummon, 1992).

Despite these theoretical advances, empirical studies that quantify how specific geometric variables influence spatial expectation remain limited. Most existing research emphasizes aesthetic preferences, greenery, or safety, with minimal focus on how spatial morphology—particularly curvature—shapes psychological anticipation in a testable, model-based manner (Jiang et al., 2024 ; Van Renterghem & Lippens, 2024).

This study addresses that gap by defining "expectation" as a perceptual-psychological response triggered by the unfolding of curved spatial configurations, and examining it as a quantifiable variable.

To advance this line of inquiry, we hypothesize that curved streets with moderate curvature, consistent wall spacing, and rhythmic segmentation elicit stronger psychological expectation than fully linear or irregular configurations. To test this, we conducted a spatial typology survey of 78 curved pedestrian streets across 14 countries, focusing on walkable environments with high-resolution morphological data. While curved street patterns exist globally—including in parts of the Middle East, Latin America, and North Africa—the current study prioritized cases with high pedestrian accessibility, minimal vehicular interference, and clear morphological continuity, conditions most consistently met in the historic cores of cities in Europe, Japan, and

East Asia (Boeing, 2018 ; Louf & Barthelemy, 2014). This sampling focus aligns with the study' s goal of examining perceptual responses to walkable, curvature-dominant environments. However, several other regions were excluded due to insufficient high-resolution morphological data, limitations in street-level imagery, or inconsistencies in spatial parameters that hindered comparative modeling. While this selective strategy ensured experimental control and internal validity, it also limits the geographical inclusivity of our findings. Future research will expand the dataset as more refined urban morphological data and immersive mapping technologies become available across a broader range of cultural and geographic contexts.

Using this typological base, we developed five controlled 3D computer graphic (3DCG) simulations representing key spatial variables such as curvature, colonnade rhythm, segmentation, and enclosure. A behavioral perception experiment involving 223 participants from architecture, urban design, psychology, and non-professional backgrounds was conducted. Two indicators were measured: maximum expectation position (MEP), or where anticipation peaked along the street, and expectation intensity (EI), the strength of this psychological response. Multiple regression analysis was then applied to examine the influence of each geometric variable on perceptual outcomes.

To standardize visual conditions, the simulations were rendered at a 1:50 visual scale and presented on a screen with fixed eye-level perspective. Although VR-based navigation might offer higher ecological validity, screen-based controlled viewing remains a widely used and validated method in spatial perception studies. This limitation is acknowledged and addressed in the discussion section as a direction for future multisensory and dynamic experimentation (Figure 1).

By integrating field typology, perceptual simulation, and statistical modeling, this study contributes to the emerging field of quantified perceptual urbanism. It offers theoretical insight into the role of curvature in psychological expectation and practical guidance for designing emotionally resonant, perceptually engaging pedestrian environments. The results have implications for both historic preservation and contemporary street design, bridging the gap between spatial morphology and human-centered urban experiences.

Figure 1. Technical roadmap

2. The spatial composition of curved streets in urban spaces

2.1 Case Study

In order to explore the spatial characteristics and perceptual effects of curved streets in urban environments, and to provide empirical data support for the 3DCG simulation model used in this study, we conducted a systematic case survey of curved streets across 14 countries. The selected streets span 78 cities and encompass a diverse range of urban forms and cultural contexts, including historic cores, regenerated neighborhoods, and contemporary pedestrian zones. As shown in Figure 2, the data were obtained through a combination of field research and remote digital mapping between 2019 and 2024.

The sampling and inclusion of cases followed clearly defined spatial and methodological criteria:

- Curvature requirement: The street must exhibit a measurable degree of curvature—typically a directional change of 15° or more within a 60-meter segment—based on field mapping or satellite imagery.
- Pedestrian-oriented spatial environments: Selected streets must be primarily walkable or mixed-use with visible pedestrian activity, and not dominated by motorized vehicular traffic.
- Spatial enclosure: Streets must feature continuous architectural edges on both sides, avoiding single-sided development, open fields, waterfronts, or loosely bounded landscapes. This ensures consistent spatial enclosure for psychological analysis.
- Recordability and modeling feasibility: Cases were only included if they could be reliably documented through high-resolution on-site photography or remote data collection via platforms such as Google Earth Pro, Baidu Maps, or drone-assisted surveys.

Of the 78 street cases selected, 47 were investigated through direct field observation by a 14-member research team, while the remaining 31 were analyzed using publicly available online spatial data. This mixed-data approach not only ensured broader geographical coverage but also allowed us to compare differences in the precision and modeling consistency between field-based and digitally derived data—laying the foundation for future technical validation.

Importantly, this study focuses exclusively on spatial morphology, not functional classification. Although many of the selected curved streets naturally correspond to residential or everyday pedestrian zones, we deliberately avoided labeling them by use type (e. g., commercial vs. residential) to reduce confounding variables in subsequent perception experiments. Instead, the emphasis was placed on morphological variables such as curvature geometry, wall segmentation rhythm, facade openness, presence of colonnades, vegetation, and lighting—each systematically documented and measured for use in the 3DCG model.

The contextual patterns of the selected cases are primarily derived from historical urban cores in cities across Europe, Japan, and China, where organically evolved curved street forms have been well preserved and are embedded within walkable, enclosed, and rhythmically organized environments. These settings offer ideal conditions for spatial simulation and perceptual evaluation, particularly in relation to psychological anticipation in pedestrian experience.

While organically developed curved streets are also found in regions such as the Middle East, Western Asia, and Latin America, this study prioritizes cases where consistent spatial data and morphological detail were most accessible and directly compatible with the analytical framework of this research. This approach ensures comparability and methodological rigor across all samples, allowing the investigation to focus on how specific geometric variables—such as curvature, enclosure, and segmentation rhythm—influence pedestrian psychological responses.

This structured and criteria-based selection process ensures comparability and reliability across cases and allows the research to isolate how geometric configurations of curved streets affect pedestrian psychological expectation. These cases form the empirical basis for the simulation and regression analysis in subsequent chapters.

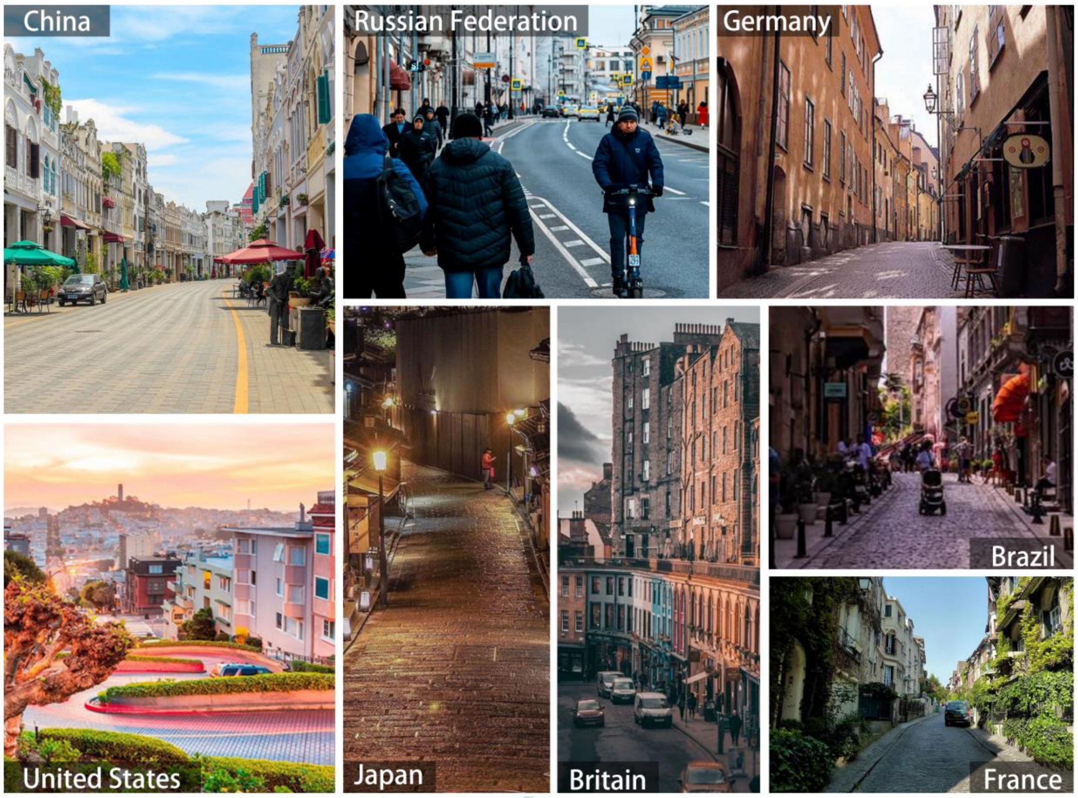


Figure 2. Survey Participants

2.2 Types of Curved Street Spaces

To systematically explore the morphological diversity of curved streets and their perceptual implications, we conducted a typological analysis of the 78 selected cases. This classification was carried out along two parallel dimensions: (1) the overall spatial layout of street spaces, and (2) the arrangement of continuous landscape elements along street edges. These are respectively summarized as "Classification of Street Space Shapes" and "Classification of Continuous Elements Related to Street Space" (Table 1 and Figure 3).

(1) Classification of Street Space Shapes

The spatial enclosure patterns of curved streets were categorized into three major types based on the configuration of built interfaces:

- Two-side wall type: The most prevalent form across the dataset, where both sides of the street are flanked by continuous architectural facades.
- Outer wall type: Defined by an asymmetrical configuration, with one continuous wall on one side and an open edge on the other (such as a green space, plaza, or setback zone).
- Inner wall type: Characterized by buildings that frame open spaces on both sides—typically green courtyards or small squares—fostering a stronger integration between the street and its surrounding public realm.

Each street was assigned to one of these types based on spatial measurements such as curvature degree (angle change per 60 meters), average wall spacing (distance between buildings), and segmentation continuity (presence of visual interruptions like arcades or gaps).

(2) Classification of Continuous Elements Related to Street Space

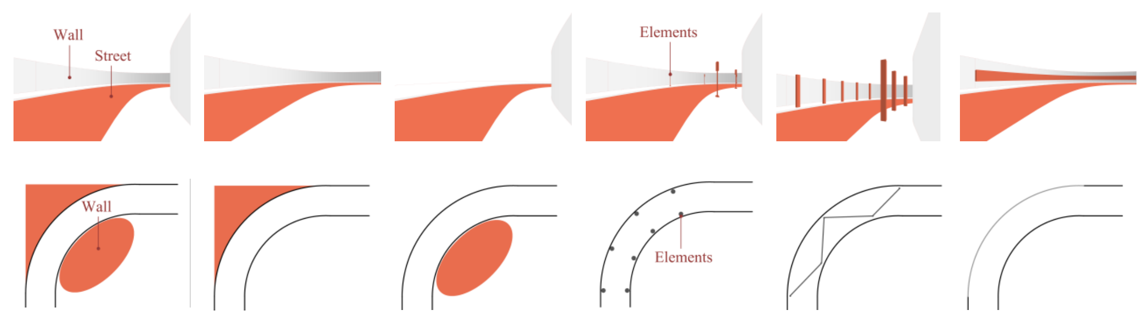
In addition to architectural enclosure, we examined the arrangement of landscape and infrastructural elements that visually shape the pedestrian experience. Based on field observations and spatial rhythm, we identified four major types of element configurations:

- Vertical (parallel) type: Trees, utility poles, or lighting posts are arranged in uniform rows along both sides of the street, enhancing a sense of volumetric enclosure.
- Vertical (crossed) type: Elements are arranged in staggered or alternating patterns across the axis of the street, producing dynamic movement and directional contrast.
- Parallel (planar) type: Fences, railings, or low walls are aligned in a continuous horizontal rhythm, emphasizing regularity and directionality.

It is important to note that some street segments exhibit multiple landscape configurations within the same segment (e. g., vertical planting on one side and planar fencing on the other). Therefore, as shown in Figure 3, the total frequency of these configurations exceeds the number of unique street cases (78), due to overlapping feature arrangements.

Table 1. Types of Curved Street Spaces

Classification of Street Space Shapes			**Classification of Continuous Elements Related to Street Space**		
Two-Side Wall Type	Outer Wall Type	Inner Wall Type	Vertical (Parallel) Type	Vertical (Crossed) Type	Parallel Type



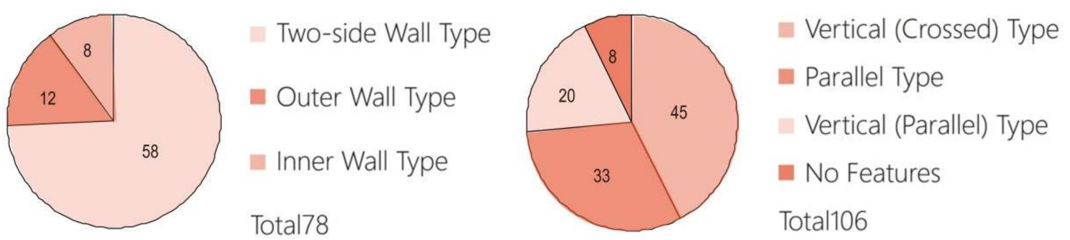


Figure 3. Statistics of Curved Street Space Types

3. Experiment on Expectation in Curved Streets

3.1 Selection of Experimental Subjects

To clarify the scope of the study, we emphasize that the research is exclusively focused on pedestrian-oriented curved streets, rather than those designed primarily for vehicular traffic. Although in many real urban environments, pedestrian routes often follow the curvature of adjacent vehicular streets—with their edges formed by arc curves and turning radii adapted to vehicle maneuverability—this study deliberately abstracts away from vehicular considerations. Specifically, we do not involve the calculation of vehicle flow lines or turning radii typically required in road design.

Instead, our objective is to explore the psychological impact of curvature on pedestrian perception. To isolate and examine the perceptual and psychological effects caused purely by variations in street form, we selected a series of idealized spatial models based on actual transitions from straight to curved streets. These models were developed from real-world pedestrian streets, but were standardized and simplified to reflect a range of curvature variations while eliminating interference from traffic-related elements.

This approach enables a more accurate understanding of how changes in curvature influence visual experience and psychological expectation, allowing us to focus on how pedestrians perceive and respond to spatial morphology alone. The final selection of experimental street types is summarized in Figure 4.

Actual (Shape of the route, such as highways or railways)	Shapes used in the experiment

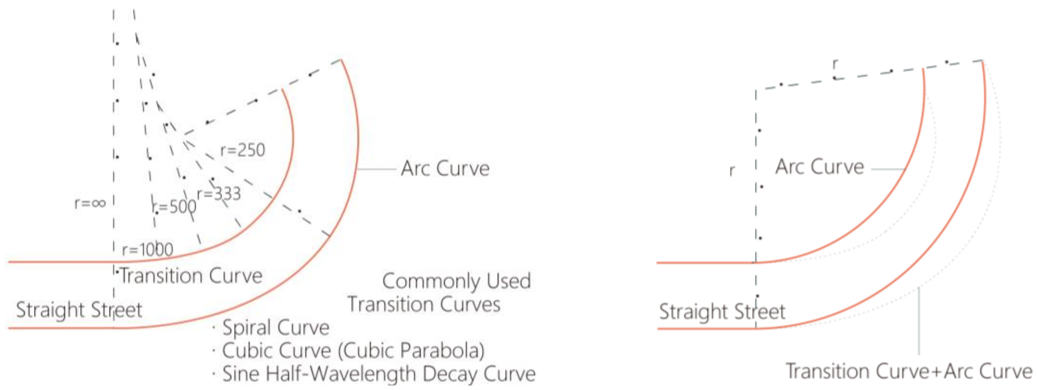


Figure 4. Experimental Subjects

3.2 Establishment of the Experimental Model

To ensure consistency and comparability across simulated curved street environments, this study adopts a Standard Stimulus Model, established through the Method of Equivalent Stimuli (ME) approach commonly used in environmental perception research. This method requires identifying a spatial configuration that elicits the lowest level of psychological expectation, thereby serving as the baseline condition for comparative analysis.

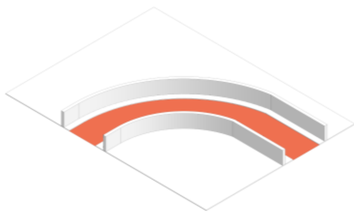
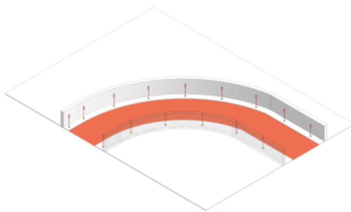
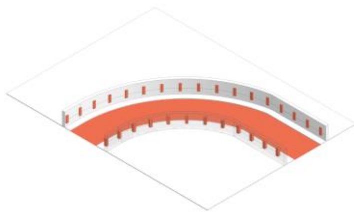
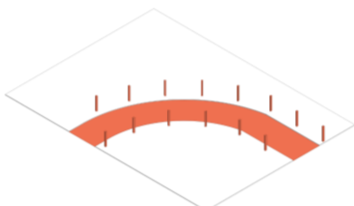
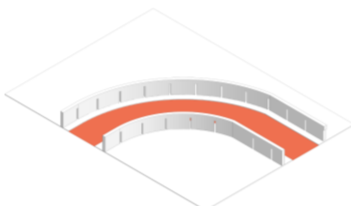
In selecting this standard spatial configuration, an 8-meter street width paired with a 6-meter building wall height was adopted based on a combination of empirical observation and preliminary perceptual testing. Analysis of 78 pedestrian-oriented curved street cases across 14 countries revealed that street widths ranging from 6 to 10 meters were most typical in historical cores and walkable neighborhoods. Within this range, the 8-meter width—yielding a height-to-width ratio (h/d) of 0.75—consistently produced the clearest and most interpretable psychological responses during the simulated transition from straight to curved paths. Streets wider than 12 meters weakened the perceptual influence of curvature due to excessive openness, while narrower streets (<6 meters) often evoked alley-like impressions, reducing spatial legibility and ecological validity. Thus, the 8-meter width represents a perceptually optimal and typologically representative baseline for studying psychological anticipation in curved street environments.

The final Standard Stimulus Model featured this 8-meter street width, a curvature of 1/24, and no façade openings or vertical elements. These parameters were selected to minimize depth variation, enclosure fluctuation, and rhythmic visual interruption—three key factors influencing spatial anticipation. This configuration consistently generated the weakest perceptual stimulation in preliminary trials (n = 45), and was therefore designated as the reference stimulus, with an average psychological expectation score set at ME = 0.

To maintain ecological validity and reflect realistic pedestrian experiences, each simulated street segment was set at 40 meters in length—approximating a 30-second walking time, which allows for perceptual formation without cognitive fatigue. Building upon this baseline, four experimental variations were developed using 3D Computer Graphics (3DCG) simulation, each targeting a distinct morphological feature observed in the surveyed curved streets. These variations were informed by extensive field and typological analysis, and were rendered under consistent lighting and camera parameters to ensure strict experimental control. The detailed parameters for each condition are presented in Table 2.

This structured simulation framework enables the systematic investigation of how geometric and morphological street features influence pedestrian psychological expectation, forming the empirical basis for subsequent regression analysis and spatial cognition modeling.

Table 2. 3DCG Model

		
Standard Stimuli	(1) Configuration of Streetlights	(2) Configuration of Protruding Spaces in Building Walls
Road Width: 8m Wall Height: 6m Curvature: 1/24	Streetlight Height: 5m Spacing: 10m	Protruding Space: Rectangular Prism with a base of 0.2m x 0.2m Spacing: 5m
		Scenario (1): Continuous vertical elements enhance the sense of expectation, while also increasing the sense of enclosure;
(3) Colonnades Replacing Building Walls Columns: Rectangular Prisms with a base of 0.2m x 0.2m Spacing: 0.4~15m	(4) Variation in Wall Area Ratio Wall Segment Length: 1~5m Wall Area Ratio: 10%~90%	Scenario (2): The sense of enclosure weakens, but the sense of realism decreases only slightly; Scenario (3): The openness of the street enhances the sense of expectation; Scenario (4): The concealment of the street increases the sense of expectation.

Building on this baseline model, four experimental variations were developed using 3D Computer Graphics (3DCG) simulation, each targeting a distinct morphological feature observed in real curved streets. These include:

(1) Configuration of Streetlights

Based on field survey results, vertical elements such as trees and utility poles are commonly found along curved streets. Therefore, in the standard model, a 5-meter-high streetlight is placed at regular intervals of 10 meters on both sides of the street to simulate the presence of vertical elements.

(2) Configuration of Protruding Spaces in Building Walls

To simulate subtle spatial changes often found in actual building facades, cube-shaped protruding spaces (0.2 meters in length) are placed every 5 meters along the building walls in the standard model.

(3) Colonnades Replacing Building Walls

In order to examine the effect of open versus enclosed street boundaries, the building walls on both sides of the curved street are replaced by regularly spaced columns. Each column has a base length of 0.2 meters, and the column spacing varies between 0.4 meters and 1.5 meters.

(4) Variation in Wall Area Ratio

This study defines “wall area ratio” as the ratio of the wall-covered area to the total elevation area on both sides of the street. Wall openings are distributed at fixed intervals ranging from 1 to 5 meters, with the wall area ratio varying from 10% to 90%. Two conditions are modeled: one
with evenly spaced openings and the other with unevenly spaced ones.

As shown in Table 2, the four simulated scenarios correspond directly to the four specific spatial configurations derived from field observation and typological classification:

- Scenario (1) represents the Configuration of Streetlights, simulating vertical elements commonly found along curved streets that establish rhythmic visual guidance and help articulate the street’ s spatial structure.
- Scenario (2) corresponds to the Configuration of Protruding Spaces in Building Walls, reflecting subtle changes in façade articulation through regularly spaced shallow projections that introduce micro-level variations along the street edge.
- Scenario (3) represents the use of Colonnades Replacing Building Walls, used to test enclosure variation through open structural boundaries.
- Scenario (4) models the Variation in Wall Area Ratio, simulating differing degrees of wall solidity and visual openness.

These scenarios are not hypotheses but standardized experimental conditions constructed for controlled testing of perceptual responses under varied geometric configurations. All were informed by prior field documentation and integrated into the 3DCG simulation environment to ensure empirical validity and comparability across conditions.

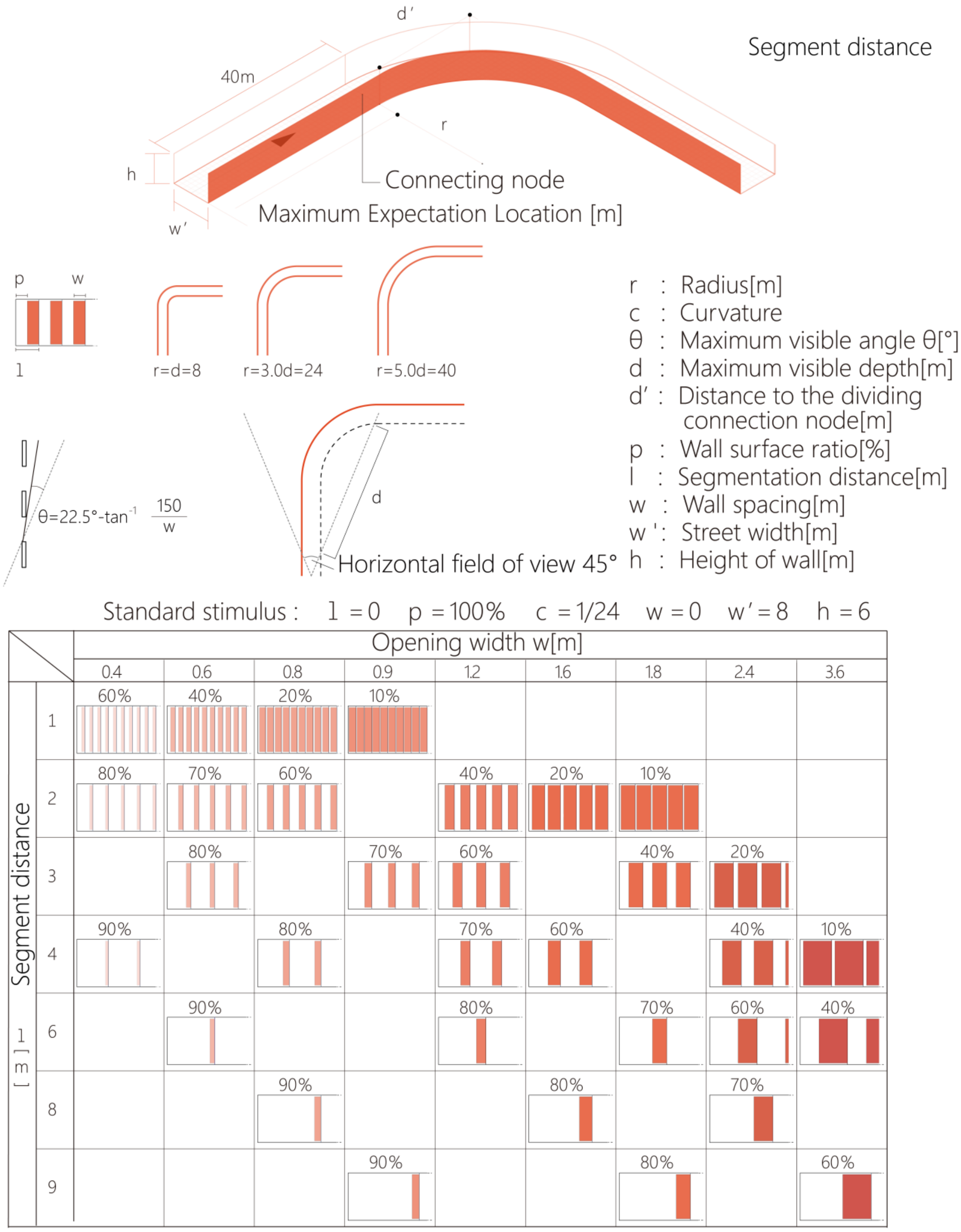


Figure 5. Target Space Pattern in the Simulator Experiment

*The spatial parameters and variables presented in Figure 5 are not derived from a universal spatial equation or generative algorithm. Instead, they are empirically abstracted from 78 real-world curved street cases based on field surveys and typological analysis. Given the complexity and context-dependency of urban morphology, this study adopts a data-driven modeling approach rather than a rule-based formula. Each variable—such as curvature, wall spacing, segmentation rhythm—was measured and normalized from actual streets to ensure the simulations reflect realistic spatial conditions.

The spatial variables used in the experiment—whether expressed in metric units or as ratios—represent distinct yet complementary morphological factors, such as enclosure, segmentation, and interface porosity. While some variables may interact to influence perceptual outcomes, they do not follow any simple mathematical relationship. Their representation in figures serves to illustrate their coordinated spatial roles, rather than to imply dimensional equivalence or functional substitution.

3.3 Experiment Contents

(1) Participant Training

Before the experiment began, participants were clearly informed that the sense of expectation towards space is defined as a psychological response where, as they walk, they become aware of and drawn to the space ahead, leading to a desire to explore it further. The formation of this sense of expectation is closely related to the characteristics of the space, such as its curves, walls, and openings, as proposed by the renowned American ecological psychologist J. Gibson in his theory of "ecological psychology, " which states that perception is the result of interaction with the environment, and human actions and perceptions are inseparable in a specific space (Reser, 2007). Referring to the theories of "openness" and "enclosure" in human spatial perception, where individuals typically perceive uncertainty in complex spaces, this uncertainty often triggers a sense of expectation toward the future space (Ford, 1999). Participants were also instructed that their evaluations should be based on their intuitive perception of the experimental space, avoiding psychological influences unrelated to the experiment caused by transitioning from a straight street to a curved street.

(2) 3DCG model (3D Computer Graphics model)

To systematically explore the perceptual effects of curved street morphology, this study constructed 99 distinct spatial models by combining variations in five key spatial parameters: curvature degree, wall segmentation distance, wall opening ratio, wall area ratio, and wall spacing (Figure 6). Each model represents a typical configuration abstracted from real-world curved street scenarios, ensuring that the experimental design closely reflects actual urban spatial structures.

These 99 spatial models were designed to represent incremental yet controlled differences in geometric properties. This approach supports detailed analysis of how subtle spatial changes influence pedestrian expectation and perception, while also providing a robust dataset for multivariate regression analysis. The diversity and structure of these models enhance the generalizability of the findings across a wide range of urban street forms.

To enhance participants' spatial understanding and depth perception during the evaluation process, each virtual scene incorporated 1.8-meter-tall human figures positioned on both sides of the street as body-scale references, in line with spatial perception theory (Reser, 2007). In addition, 1-meter interval grid lines were applied to the road surface to strengthen spatial legibility and directional awareness, drawing on established research that highlights the cognitive role of structured visual references (Cui, 2024).

All 3D models were developed using a unified software platform, rendered in neutral grayscale tones, and illuminated under standardized lighting conditions. This ensured that participants' perceptual responses were shaped entirely by spatial form rather than non-geometric cues such as material color, surface texture, or lighting variability. A standard reference stimulus was presented before testing to establish a perceptual baseline, followed by randomized sequences of test stimuli to control for any order effects.

The design of these spatial models and the controlled presentation environment together create a clear and focused experimental condition for investigating the spatial mechanisms underlying pedestrian psychological expectation. The resulting data structure allows for detailed comparisons between different model types and supports the generation of form-based spatial design insights for future street planning practices.

It is also important to note that this experiment represents the first phase of a broader, staged research framework. While the current phase focused on form-driven spatial perception, future stages will incorporate additional visual and environmental variables, including color temperature, material texture, and lighting dynamics. These will be complemented by comparative tabulated data and statistical controls to better simulate complex real-world perceptual contexts.

The deliberate simplification of the visual environment in this phase served as a necessary methodological control, enabling clearer attribution of perceptual responses to geometric variations.

(3) Model Demonstration Method

The differences in perception at different heights within the human visual system allow participants to perceive the space from an angle that better aligns with real walking experiences (Muratovski, 2023). The experiment used a 1/50 scale model and captured images from a 1.65-meter viewing height using a model space perception simulator, simulating the perspective of a subject in an actual street environment. The captured images were displayed on a 55-inch high-definition LCD television. At the beginning of the experiment, the standard model image was first displayed. This standard stimulus facilitated comparisons with subsequent experimental images, minimizing subjective bias and ensuring that participants' perceptions of spatial changes were based on perceptual differences rather than preset assumptions. When participants watch these videos, the psychological "sequence effect" will influence their assessment of the space (Hennessy et al., 2016). To eliminate this effect, the remaining 98 images were randomly played, effectively preventing participants from mimicking evaluations due to watching similar images, thus ensuring the experimental results are more objective and reliable (Pineño & Miller, 2005).

In this study, the term '1:50 scale' refers to the representational fidelity between the simulated environment and real-life spatial perception, rather than a literal physical scale on screen. All 3DCG scenes were rendered using a standardized eye-level viewpoint (1.65m) and displayed on a 55-inch HD monitor viewed from a fixed distance (~1.5m), aligning with established protocols in environmental perception research. While screen-based viewing cannot fully replicate embodied spatial experience, prior literature confirms that controlled visualizations can effectively simulate perceptual responses related to depth, enclosure, and spatial expectation, particularly when physical interaction is not required.

3.4 Evaluation method for the maximum expectation location and the intensity of expectation

To comprehensively assess the spatial expectation from the transition of a straight street to a curved street, this study employed the method of adjustable movement and the moment estimation method (ME method) as evaluation techniques. These two methods were used to evaluate the maximum expectation location and the intensity of expectation, respectively (Tomazinaki & Stiliaris, 2023 ; Li et al., 2024).

(1) Method for Evaluating the Maximum Expectation Location

He method of movable adjustment of images is used to explore the location where the curve street generates the maximum expectation for pedestrians. The movable adjustment method refers to the process where participants independently manipulate experimental images to determine the spatial location where they perceive the strongest sense of expectation (Xie et al., 2025). Participants watch pre-recorded street videos and freely control the video playback progress until they find the location where they perceive the strongest sense of expectation.

The researchers record the maximum expectation location chosen by each participant. This method is similar to the "perceptual environment interaction model" proposed by Gibson (1979), which emphasizes the close relationship between human perception of movement through space and the spatial structure (Vaa, 2014). It can accurately identify specific areas in curved streets that trigger the highest sense of expectation, providing data support for further analysis of the impact of spatial composition on psychological perception.

(2) Method for Evaluating Expectation Intensity

The Magnitude Estimation (ME) method was used to measure the intensity of expectation from a straight street to a curved street (Hegland et al., 2017). Participants provided a quantified intensity evaluation based on their intuitive perception of the spatial stimulus, reflecting the strength of their perception. In this study, the difference from the standard stimulus was used as the comparison stimulus, with the reference standard stimulus set to 100.By comparing the intensity of expectation in various spaces, participants evaluated the expectation intensity of other spaces as multiples of the standard stimulus. When the expectation intensity of a particular spatial configuration is half of the standard stimulus, its value is 50; if its intensity is twice that of the standard stimulus, the value is 200.

3.5 Participant Demographics and Experimental Procedure

A total of 223 participants were recruited to participate in this experiment, conducted between July 22 and October 25, 2024. Considering the duration and intensity of the visual evaluation tasks, each experimental session was designed to last approximately 2 hours per participant, with each visual stimulus presented for 35 seconds and two 10-minute rest periods provided to minimize fatigue effects.

Detailed demographic information—including age group, gender, education level, field of study, and urban design experience—was collected from all participants. Although these demographic variables were not the focus of the main regression analysis, they were systematically recorded to ensure data integrity. A preliminary statistical check confirmed that age and gender did not significantly affect spatial expectation in this visual context, supporting their exclusion from the final model. However, these details have been included in the supplementary appendix to enhance transparency.

Table 3. Participant Data Summary

Variable	Category	N	Percentage (%)
Total Participants	—	223	1
Age Range	20–29	139	0.624
	30–39	69	0.309
	40–59	15	0.067
Gender	Male	111	0.498
	Female	112	0.502
Education Level	General Public	145	0.650
	Undergraduate	41	0.184
	Master' s degree	26	0.116
	Doctoral degree	11	0.050
Field of Study	Other industry or professional background	185	0.829

Architecture / Urban Design	38	0.171

4. Experimental Results

4.1 Analysis of Participant Evaluations

To investigate the perceptual mechanisms underlying curved street design, this study conducted a two-stage participant-based analysis focusing on two core variables: maximum expectation position and expectation intensity.

All participants were tested individually in a controlled, enclosed laboratory environment to ensure the reliability and independence of perceptual responses. Each session was conducted one-on-one, without the presence of other participants, thereby eliminating potential external influences such as group dynamics, environmental noise, or temperature fluctuation. This individualized testing protocol was designed to preserve the objectivity and consistency of the data collected across all 223 participants.

From the initial pool of 223 participants, 150 individuals were selected to participate in the position analysis phase. This selection followed a rigorous data quality control protocol:

(1) Incomplete or interrupted responses were excluded;

(2) Responses containing contradictory or illogical information were filtered out;

(3) Uniform or repetitive responses across all stimuli—suggesting inattention—were removed;

(4) In cases with highly similar values across the same questionnaire, only one representative entry was retained to reduce redundancy.

Subsequently, a separate group of 45 participants was selected from the validated pool for the expectation intensity evaluation, conducted using the magnitude estimation (ME) method. As the ME task requires sustained attention and complex comparative judgment relative to a fixed standard stimulus, participants were chosen based on demonstrated stability, cognitive engagement, and availability. To ensure unbiased results, those involved in the intensity task did not participate in the earlier position-based experiment.

This two-stage filtering and task-specific grouping strategy was designed to maximize internal validity and perceptual clarity. Importantly, the 73 excluded cases—approximately 32.7%—were not invalid in the technical sense, but were removed as a precautionary step to ensure data integrity and reduce noise caused by redundant or low-variance responses.

The final sample sizes of 150 for expectation position analysis and 45 for intensity evaluation were sufficient to support the multivariate regression models applied in later sections. Together, these analyses allowed the study to reveal consistent trends and differences in spatial perception across diverse participant groups, ultimately contributing to evidence-based design recommendations for curved street environments.

This two-stage filtering and selective grouping strategy allowed us to retain high-quality, methodologically consistent data for both experimental phases. The final sample sizes of 150 (position analysis) and 45 (intensity evaluation) provided sufficient statistical power and response diversity for multivariate regression modeling, while ensuring the reliability, transparency, and scientific rigor of the study.

4.2 Analysis of Expectancy

(1) Maximum Expectancy Position

The relationship between the maximum expectation position and key spatial variables is illustrated in Figure 6. Results show that the position of maximum expectation is primarily influenced by wall spacing (w) and curvature (c). As wall spacing increases, the expectation position shifts farther from the junction of the straight and curved streets. Conversely, as curvature decreases, the expectation position moves closer to the junction, indicating that gentler curves lead to earlier spatial anticipation.

Wider wall spacing also increases the visible maximum angle (θ), expanding the field of view and enhancing forward-looking expectation. Meanwhile, smaller curvature increases the visible depth (d), reinforcing a stronger sense of spatial anticipation through perceived depth.

(2) Expectancy Intensity

The relationship between expectation intensity (ME value) and spatial variables is presented in Figures 6 to 7. Results show that curvature (c) has a strong negative correlation with expectation intensity: smaller curvature leads to stronger spatial expectation, as it enhances perceived depth and stimulates forward-looking curiosity.

Wall spacing (w) also affects expectation intensity. As wall spacing increases, expectation initially strengthens but eventually declines beyond a certain width. This relationship follows a curved trend, with an optimal value identified as maximum expectation wall spacing (w_{max}). Figure 8 to 9 shows that w_{max} increases with segmentation distance (l), but begins to decline when l exceeds 6 meters. Excessively wide openings may fail to attract attention, reducing perceptual impact.

These findings suggest that a segmentation distance around 6 meters achieves the most effective balance, supporting stronger spatial anticipation in curved street design.

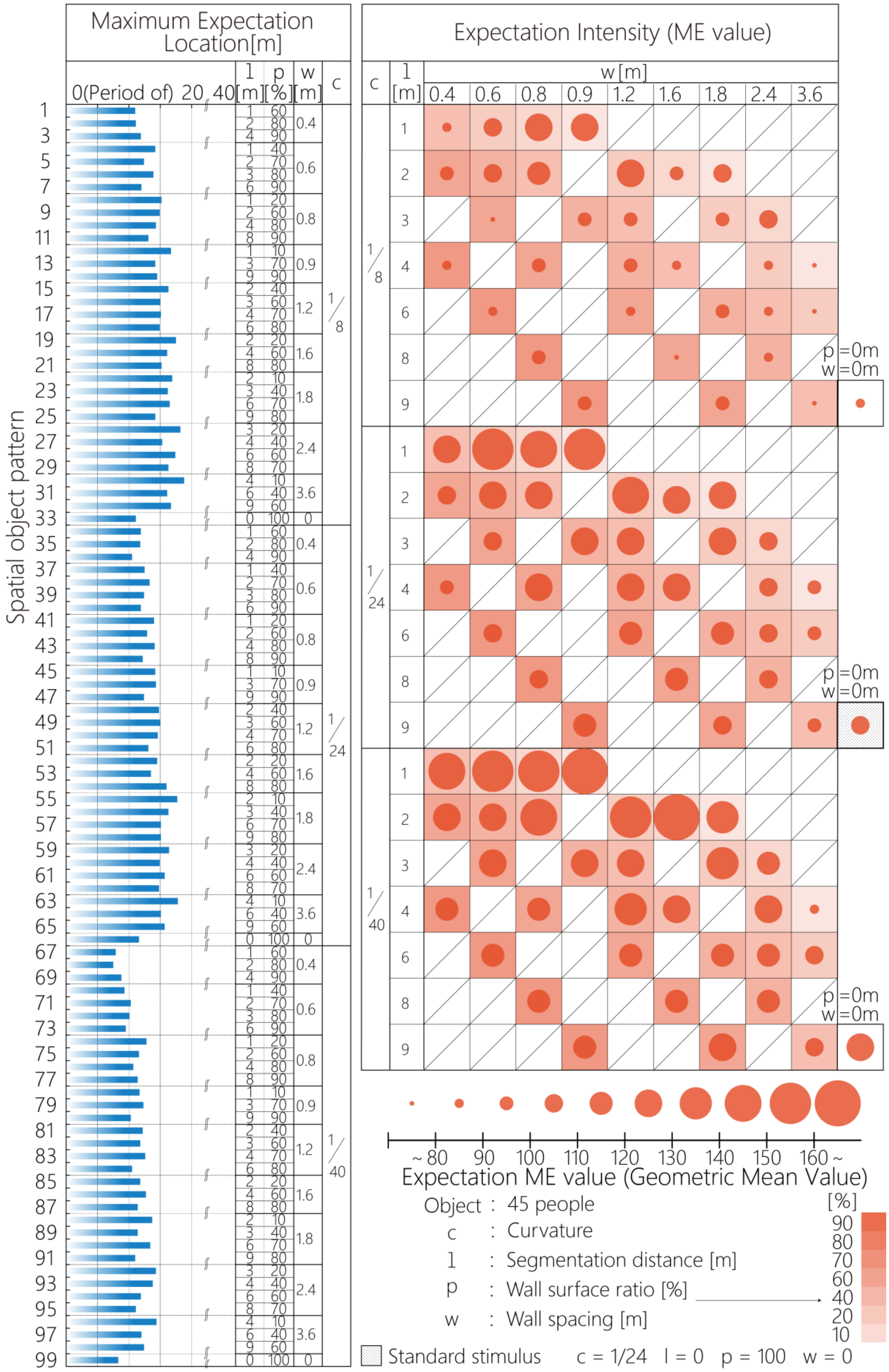

Maximum Expectation Location[m]
0(Period of) 20 40[m]
Spatial object pattern
l [m]
p [%]
w [m]
c
Expectation Intensity (ME value)
w [m]
0.4
0.6
0.8
0.9
1.2
1.6
1.8
2.4
3.6
1/8
1/24
1/40
p=0m
w=0m
~80
90
100
110
120
130
140
150
160~
Expectation ME value (Geometric Mean Value)
Object : 45 people
c : Curvature
l : Segmentation distance [m]
p : Wall surface ratio [%]
w : Wall spacing [m]
[%]
90
80
70
60
40
20
10
Standard stimulus c = 1/24 l = 0 p = 100 w = 0

Figure 6. Expected Experimental Target Space

Figure 7. Expected Experimental Target Space Magnitude Estimation (ME) Value

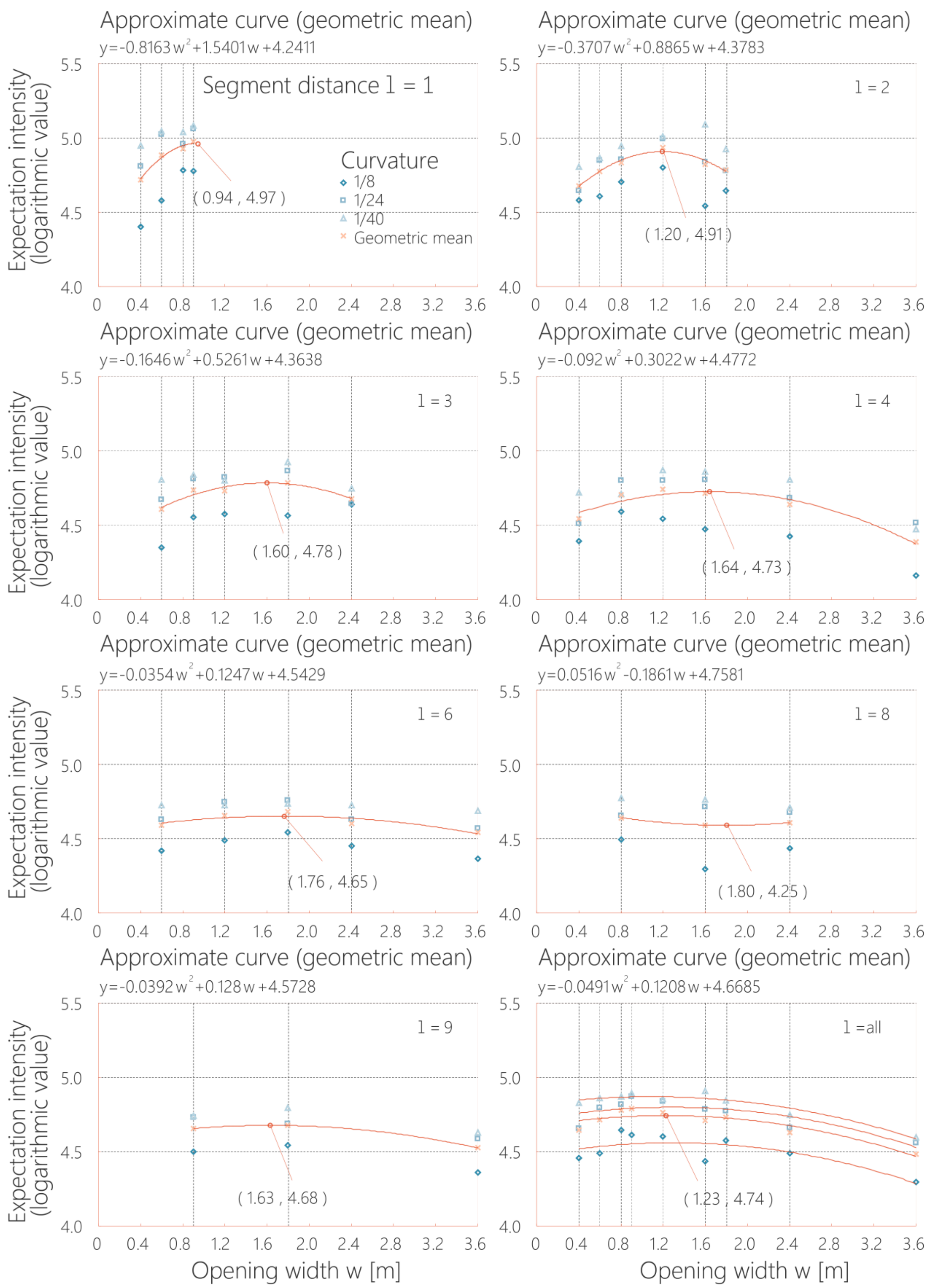


Figure 8. Wall Spacing and Expectation Intensity (Logarithmic Value) at Different Partition Distances

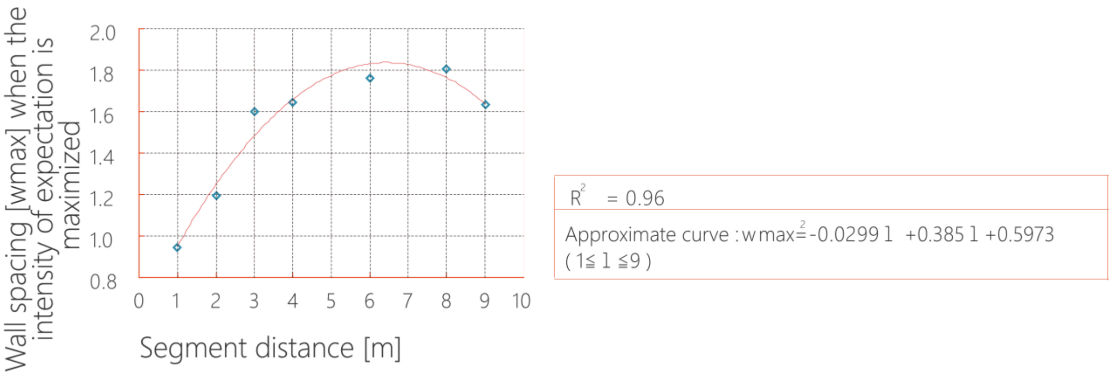


Figure 9. Prediction Formula for Wall Spacing at Maximum Expectation Intensity

4.3 Evaluation of Maximum Expectation Position and Intensity

To construct the regression models evaluating maximum expectation position and expectation intensity, we selected a set of explanatory variables based on three main criteria:

(1) established theoretical relevance from environmental psychology and spatial cognition (e. g., curvature, wall spacing, segmentation)

(2) prevalence and measurability within the 78 real-world curved street cases

(3) empirical significance observed in preliminary correlation analysis.

For the model predicting maximum expectation position, independent variables included the maximum visible angle (θ), visible depth (d), wall curvature ratio (p/c), and curvature (c). These variables were chosen to represent both the visual field dynamics and morphological enclosure properties of the street environment.

For the expectation intensity model, we selected curvature (c), the squared difference between actual wall spacing and optimal wall spacing $(w - w_{max})^2$, and the reciprocal of segmentation distance (1/l), based on prior findings that these factors jointly influence spatial anticipation.

All models were constructed using standard multiple linear regression. We verified key statistical assumptions, including linearity, normality of residuals, homoscedasticity, and low multicollinearity (with variance inflation factors [VIF] < 5). The resulting models demonstrated strong predictive power, with $R^2 = 0.80$ for the expectation position model and $R^2 = 0.82$ for the intensity model, confirming the robustness of the selected variables.

(1) Maximum Expectancy Location

To evaluate the maximum expectation location, we used the experimental results as the dependent variable. Based on participant responses, three spatial variables—maximum visible angle (θ), visible depth ratio (θ/d), and wall curvature ratio (p/c) —were selected as independent variables for multiple regression analysis. The resulting model achieved a coefficient of determination (R^2) of 0.80. As shown in Figure 10, when the visible angle (θ) and curvature (c) are small, and both the visible depth (d) and wall area ratio (p) are large, the expectation location tends to be closer to the junction. A wider angle and gentler curvature help generate spatial anticipation, while greater depth and wall area extend the peak of expectation further along the curved path.

(2) Expectancy Intensity

To evaluate expectation intensity, the average intensity value was used as the dependent variable. Based on correlation analysis, three explanatory variables were selected for multiple regression: curvature (c), the squared difference between wall spacing and the optimal spacing $(w - w_{max})$ 2$(w - w_{max})$ ^2$(w - w_{max})$ 2, and the reciprocal of segment distance (1/l). The resulting model achieved a high explanatory power ($R^2 = 0.82$). As shown in

Figure 11, lower curvature, shorter segment distance, and wall spacing close to the optimal value (w_{max}) are associated with stronger expectation intensity. Smaller curvature and shorter segments enhance spatial depth and continuity, while optimal wall spacing maximizes pedestrians' curiosity and spatial attraction.

Table 4. Correlation Graph between Experimental and Predicted Values of Maximum Expectation Location

Negative correlation coefficient $R=0.90$	Coefficient of determination $R^2=0.80$
Maximum Expectation Location [m]=$11\theta/l - 0.001p/c + 12.55$	
($0 \leqq \theta/l \leqq 50.42$, $10\% \leqq p \leqq 100\%$, $1/40 \leqq c \leqq 1/8$)	
$F_0=196.61>F(2, 96)(0.01)=4.83$, it is found to be significant at the 1% level.	

Table 5. Correlation Graph between Experimental and Predicted Values of Expectation Intensity

Negative correlation coefficient $R=0.90$	Coefficient of determination $R^2=0.82$
Expectation Intensity (Logarithmic Value) =$-3.03c + 0.27/l - 0.06(w - w_{max})^2 + 4.84$	
($1/40 \leqq c \leqq 1/8$, $0.1 \leqq 1/l \leqq 1$, $0.001 \leqq (w - w_{max})^2 \leqq 3.8$)	
$F_0=141.98>F(3, 95)(0.01)=3.99$, it is found to be significant at the 1% level.	

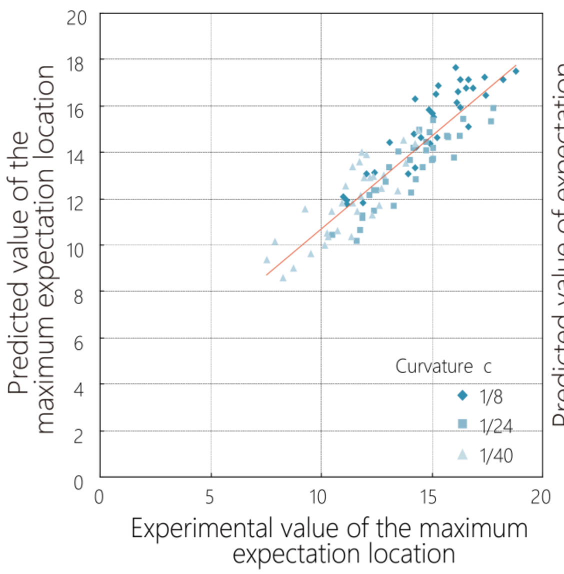


Figure 10. The correlation between experimental and predicted values of the maximum Expectation position.

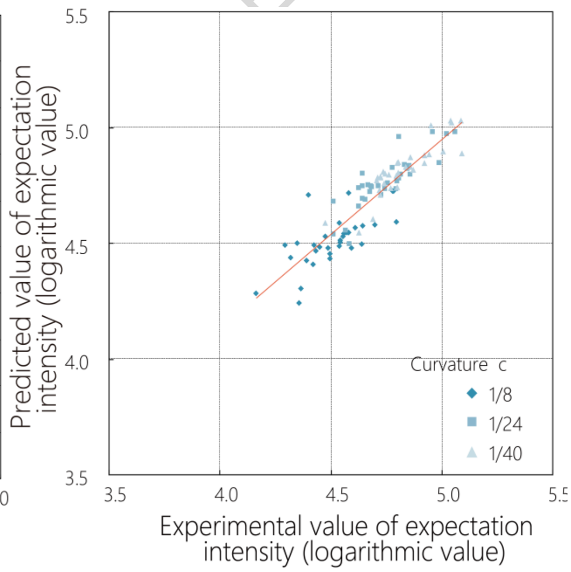


Figure 11. The correlation between experimental and predicted values of expectation intensity.

5. Design Strategies for Curved Streets

As a key element of urban spatial morphology, the design quality of curved streets directly influences pedestrians' perceptual experience. This section proposes a set of urban design strategies derived from the experimental findings on maximum expectation position and expectation intensity, supported by relevant theoretical frameworks in environmental psychology, spatial cognition, and urban design theory. These strategies aim to enhance spatial anticipation, legibility, and behavioral engagement in curved street environments.

5.1 Optimize Wall Spacing and Wall-to-Surface Ratio

Our study demonstrates that wall spacing significantly affects both the intensity and position of psychological expectation. This aligns with Space Syntax Theory and Expectation Theory, which suggest that spatial predictability and anticipation are influenced not only by physical dimensions but also by spatial configuration

(Li et al., 2023 ; Young, 2024). Appropriately increasing wall spacing—particularly on the inner side of curved streets—and designing continuous or rhythmically segmented openings can improve visual depth and spatial legibility. These features strengthen pedestrians' exploratory interest and forward-looking anticipation, thereby enhancing spatial directionality and engagement.

5.2 Adjust Curvature Based on Desired Depth and Anticipation

Curvature is a central variable influencing psychological expectation. Our regression results confirm that streets with smaller curvature are associated with stronger expectation intensity due to increased visible depth and enhanced perceptual continuity. This supports theories of human spatial behavior and visual flow, which posit that curved geometries guide attention and movement. In practice, designers can adjust curvature based on desired spatial effects: gentle curves may be suited for creating mystery and progressive reveal, while sharper turns may increase intimacy and spatial compactness.

5.3 Coordinate Wall Segmentation and Column Rhythm

Wall segmentation and column design also influence spatial rhythm and anticipation. Drawing on Form Perception Theory and Environmental Enclosure Theory, segmented façades and rhythmically spaced columns can shape openness, obstruction, and perceived spatial hierarchy (Grossberg, 1984 ; Shi et al., 2014). Our data suggest that reduced spacing between vertical elements increases the intensity of psychological anticipation, while overly wide gaps may weaken enclosure and reduce spatial tension. Therefore, adjusting the segmentation rhythm can help modulate pedestrian experience in a controlled and engaging way.

5.4 Enhance Continuity and Layering of Openings

While not a direct focus of our simulations, results related to segmentation and wall area ratio imply that opening layout plays an important role in shaping expectation. Theories such as Continuity Theory and Experience Economy suggest that spatial layering and alternating openings enhance perceptual interest and narrative flow (Bonnet-Weill & Frankowska, 2024 ; Florido-Benítez et al., 2025). Strategically distributed openings—with varying scales and ordered transitions—may help sustain anticipation along movement paths. Though this was not empirically tested in this study, it remains a theoretically grounded recommendation for future design applications.

5.5 Integrate Landscape Elements with Theoretical Caution

Although landscape elements such as trees or planting rows were included in our initial typological analysis, the 3DCG simulations in this study employed abstract representations. As such, findings regarding the perceptual effect of greenery or textures remain theoretical. Ecological Psychology and Landscape Perception Theory highlight the emotional and cognitive importance of landscape cues, but their influence on spatial expectation was not directly validated here (Schaller, 2020). Future research with ecologically detailed simulations is needed to examine how natural elements interact with built morphology to shape anticipation.

5.6 Address Population Differences and Multisensory Experience

This study focused on geometric perception in a visually standardized environment. However, theories in Multisensory Design and Humanistic Urbanism argue that spatial experience is shaped by diverse sensory and demographic factors (Macruz et al., 2024 ; Wang, 2023). While our analysis emphasizes positive psychological responses such as anticipation and curiosity, it is equally important to acknowledge that curved streets may also evoke negative feelings—such as fear of the unknown, disorientation, or lack of visual control—especially in contexts where visibility is obstructed or safety is a concern. As suggested in criminology and environmental psychology, reduced sightlines and enclosed views can trigger anxiety or defensive behavior under certain spatial or social conditions (Nasar & Fisher, 1993).

Although these aspects were beyond the scope of our current experimental design, they represent an essential direction for future inquiry. Subsequent research should incorporate auditory, tactile, and emotional variables, as well as cultural and demographic differences, to understand how spatial expectation is modulated by both positive and negative perceptual mechanisms. Comparing the psychological appeal of concealment and anticipation with the discomfort induced by limited visibility could yield a more nuanced understanding of curved street design. This perspective supports the development of more inclusive and adaptable urban environments and extends the perceptual framework of curved streets beyond aesthetic engagement to include affective and behavioral safety considerations.

6. Limitations and Future Research

This study provides a structured exploration of how specific geometric variables—including curvature, segmentation distance, wall spacing, and enclosure ratio—are related to psychological expectation in curved street environments. While the research design offers internal consistency and theoretical focus, several necessary limitations are acknowledged to define the scope of this work and identify directions for future development.

(1) Controlled abstraction of visual attributes such as color, lighting, and materiality

To ensure the isolability of spatial variables, the visual environment used in this study intentionally excluded expressive qualities such as color, surface texture, light variation, and material differentiation. All visual forms were presented in a neutralized style to minimize confounding effects and preserve geometric clarity. While these attributes are known to contribute to urban perception, their exclusion in this phase was methodologically necessary. Future work will reintroduce selected visual elements—particularly surface color, reflectivity, and lighting gradients—through parametrically controlled simulations, enabling investigation of how they interact with spatial geometry to influence perceptual expectation.

(2) Absence of vegetation, natural textures, and seasonal dynamics

While the simulation included stylized spatial segmentation and layering, it did not feature ecologically realistic elements such as vegetation types, tree canopies, ground surfaces, or seasonal variability. These were excluded to maintain focus on built form geometry. However, they remain important factors in shaping urban environmental perception. Subsequent studies will incorporate environmentally detailed 3D models, including diverse greenery configurations and natural material cues, to analyze how these factors influence expectation patterns when interacting with geometric form.

(3) Fixed, screen-based viewpoint and limited bodily interaction

In the current research phase, a fixed, screen-based viewpoint was employed to ensure consistency and control across all experimental conditions. This design allowed us to isolate key geometric variables—curvature, segmentation distance, wall spacing, and enclosure ratio—without the influence of participant-driven motion or orientation shifts, thereby enhancing internal validity and facilitating replicable comparisons. This controlled setup was essential at this stage to identify the baseline perceptual effects of visual morphology in curved street spaces. We also recognize that the spatial experience in real environments needs to be achieved through body movements, changes in orientation, and interactive participation. However, the current experimental setups do not extend to this level. To meet the higher requirements for ecological validity and immersive realism, future research will introduce virtual reality (VR) environments that support dynamic interaction for more in-depth studies.

(4) No systematic analysis of individual, demographic, or cultural differences

Although the participant pool covered a broad range of backgrounds, this study did not aim to quantitatively assess how perception may vary by age, gender, disciplinary training, or cultural familiarity with specific spatial forms. These dimensions are not taken into account as influencing factors in our current research. This is done to control the internal related variables, making the research more targeted and rigorous. Planned future studies will incorporate cross-cultural comparisons and segmented analysis to better understand how psychological expectation may be mediated by individual or social factors across different urban contexts.

(5) Theoretical focus limited to spatial form and perceptual structure

The current research is framed within the domains of environmental psychology, spatial cognition, and urban morphology. Broader symbolic, socio-political, or affective interpretations of street space were outside the scope of this phase. However, we recognize the importance of semantic and cultural dimensions in urban experience. Future interdisciplinary work will integrate theories from ecological psychology, phenomenology, and humanistic urbanism to explore how meaning, memory, and social context interact with geometric form to shape perception.

7. Conclusion

This study contributes to the growing body of research at the intersection of spatial cognition, urban morphology, and psychological perception by introducing and validating "spatial expectation" as a quantifiable index for analyzing human engagement with curved street environments. Through a combination of international spatial typology surveys, controlled 3DCG simulations, and behavioral data from 223 participants, we systematically investigated how geometric features—such as curvature, segmentation distance, wall spacing, and enclosure—structure perceptual anticipation during street traversal.

The experimental results offer several key insights. First, maximum expectation position (MEP) is dynamically influenced by the interaction of curvature and enclosure, confirming that visibility constraints inherent in curved geometries modulate spatial anticipation in a progressive and location-specific manner. Second, the intensity of expectation (EI) is most significantly heightened when streets exhibit rhythmic spatial segmentation and wall spacing approximating a perceptual threshold (w_{max}), suggesting that serial visual transition is more influential than curvature alone in activating emotional engagement. Third, variables such as wall spacing (w) and segmentation distance (l) emerged as the most consistent predictors of both MEP and EI, reinforcing the hypothesis that expectation is shaped not merely by static form, but by its rhythmic unfolding along the movement trajectory. These findings deepen the understanding of how spatial geometry elicits anticipation and provide an empirical framework for designers seeking to modulate psychological response through morphological composition (Figure 12).

The study not only responds to theoretical calls for more cognitively grounded approaches in human-centered design but also provides practically applicable metrics for predicting where and how anticipation peaks in real-world street design scenarios. By shifting the analytical lens from visual preference or aesthetic evaluation to predictive perception modeling, this research lays the groundwork for new spatial design tools that align formal properties with human perceptual behavior.

Additionally, by situating the discussion within a broader theoretical framework—including spatial syntax, form perception theory, ecological psychology, and experience economy—the study highlights the multi-layered structure of urban expectation, integrating both embodied cognition and environmental affordance into a unified analytical construct. This synthesis of theory and method not only advances scholarly discourse but also opens new avenues for interdisciplinary research, including immersive interaction design, cultural psychology, and sensory urbanism.

In conclusion, this research positions curved street design not as a residual form of historical urbanism or a matter of stylistic preference, but as a strategic spatial language that can orchestrate emotional resonance, guide movement, and stimulate cognitive anticipation. By formalizing this relationship between geometry and psychological expectation, the study offers a methodologically robust and theoretically generative contribution to urban design research—one that invites further exploration across cultural contexts, sensory modalities, and embodied experience.

Building on the key contributions of this study in quantifying spatial expectation related to curved street morphology, future research should focus on integrating multisensory inputs, such as sound and touch, to capture more holistic pedestrian experiences. Additionally, incorporating dynamic, real-time movement data through technologies like virtual reality and tracking systems can better simulate actual urban navigation. Cross-cultural investigations are also necessary to explore how diverse backgrounds influence spatial anticipation. Finally, embedding these findings into computational design tools will support adaptive and human-centered urban planning. These directions will expand the applicability and depth of spatial expectation research beyond the current controlled visual framework.

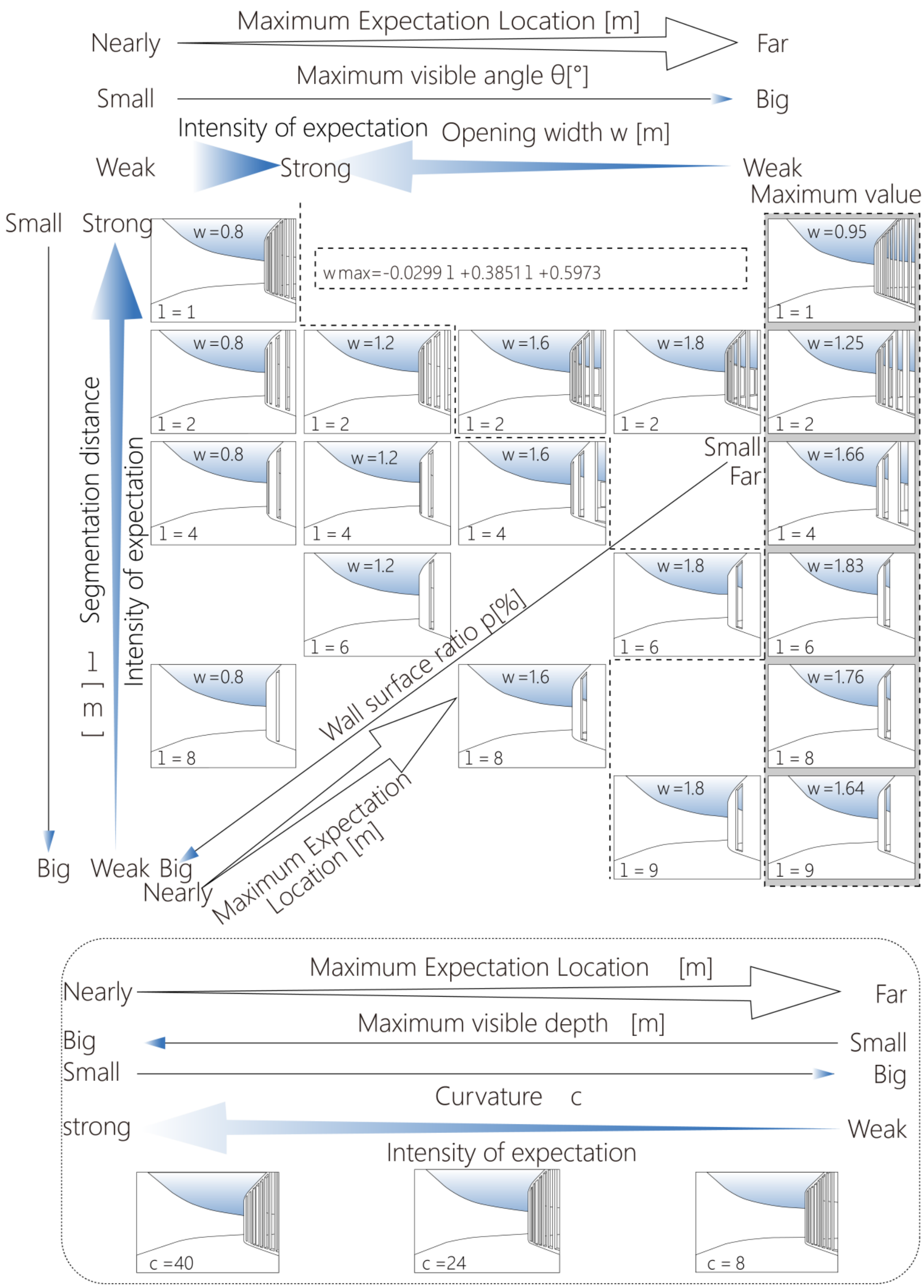


Figure 12. The Correlation between the Maximum Expectation Position and Intensity

Funding: This paper was funded by the Key Laboratory of Intelligent Health Perception and Ecological

Restoration of Rivers and Lakes, Ministry of Education Hubei University of Technology; This paper was fund by the Innovation Demonstration Base of Ecological Environment Geotechnical and Ecological Restoration of Rivers and Lakes (2020EJB004).

Data Availability Statement: The data presented in this study are available within this article.

Conflicts of Interest: The authors declare no conflicts of interest.

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Ethical Approval

This study involved human participants and therefore required full ethics approval. The research protocol, experimental procedures, data-collection process, and consent procedures were reviewed and approved by the Institutional Ethics Committee of Hubei University of Technology.

Approval Number : HBUT 20240087

Approval Date: [2024-05-18]

Approval Body: Institutional Ethics Committee, Hubei University of Technology

The scope of the approval covered:

(1) recruitment of adult participants;

(2) administration of 3DCG urban-scene visual experiments;

(3) collection of perceptual responses, cursor-based expectation-marking data, and questionnaire responses;

(4) secure storage, anonymisation, and use of the data exclusively for academic research.

The Ethics Committee confirmed that the study posed minimal risk, involved no physical or invasive procedures, and complied with all applicable ethical guidelines for human-subject research, including the principles of the Declaration of Helsinki and institutional regulations.

All components of the study—including pilot testing, participant briefing, data acquisition, and analysis—were performed in accordance with approved procedures. No part of the research commenced prior to obtaining formal approval.

Informed Consent

Written informed consent was obtained from all 223 participants prior to enrolment. The consent was administered in person from 2024-06-05 to 2024-07-05 by trained members of the research team.

Participants were provided with full information regarding:

(1) Purpose of the study – to examine perceptual expectation formation in curved-street environments;

(2) Experimental procedures – viewing 3DCG street simulations, marking points of maximum expectation using mouse input, and completing a short questionnaire (total duration approx. 2 hours);

(3) Voluntary participation – participants could withdraw at any time, without penalty;

(4) Potential risks – minimal visual fatigue possible; no physical, invasive, or high-risk procedures involved;

(5) Data scope and usage – cursor-trajectory data, perceptual ratings, and questionnaire responses were anonymised, securely stored, and used solely for academic research and publication;

(6) Confidentiality – no personal identifiers were collected or used in any part of the study or future dissemination.

No minors or vulnerable individuals were included.

No oral consent procedures were used; all consent was written and obtained prior to participation.

Participants were explicitly informed of the purpose of the research, how their anonymised data would be utilised, and that their anonymity was fully assured. All consent procedures conformed to institutional ethics guidelines and the approval granted by the Institutional Ethics Committee.