

## Article

# Urban Form in Sight: A City-Wide 3D ISOVIST Analysis of Pedestrian-Level Visibility Across Building Height–Coverage Typologies

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## Abstract

High-rise and high-density development is often assumed to reduce the visual quality of urban landscapes, yet building height alone does not fully explain what pedestrians can see at street level. In compact cities such as Seoul, taller buildings may obstruct views, but they may also reduce ground coverage and create more open space around buildings. This study examines how building height and building coverage jointly shape pedestrian-level visibility in high-density urban environments. Using Seoul as a case study, we developed a citywide 3D ISOVIST framework based on building footprint and height data. The city was divided into 500 m × 500 m grid cells, and road-based observation points were used to simulate pedestrian-level visual fields. Urban form was classified into nine height–coverage typologies, and visibility was measured using sky viewing ratio, building obstruction ratio, mean viewing distance, and viewing distance variance. The results show that pedestrian-level visibility varies systematically across height–coverage combinations. Visibility generally decreases as building coverage increases, while the effect of building height is not linear. In some high-rise conditions, reduced ground coverage can partly compensate for vertical obstruction and maintain visual openness at the pedestrian level. These findings suggest that urban landscape regulation should not rely on height control alone. Instead, building height, coverage, spacing, and ground-level openness should be considered together when evaluating the visual effects of dense urban development. This study contributes a scalable geometric visibility framework for urban morphology analysis while acknowledging that visual openness is only one dimension of broader urban landscape quality.



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**Keywords:** 3D ISOVIST; streetscape; visibility; urban density; Local Visibility Zone (LVZ)

## 1. Introduction

### 1.1. Background

Over the last century, urban landscapes have been dramatically transformed through rapid urbanization and increasing building density [1]. Particularly, Korean cities have experienced extensive high-rise development to accommodate population growth within limited urban land. While this development pattern has substantially altered the physical configuration of urban environments, it has also changed the visual conditions experienced at street level. Because building height and building coverage directly influence what pedestrians can visually perceive, understanding the relationship between urban form and

pedestrian-level visibility has become an important research topic. However, quantitative evidence explaining how different urban form configurations influence pedestrian-level visibility at the metropolitan scale remains limited.

Previous studies by Cullen have examined the dynamic perceptual alterations in urban landscapes attributed to pedestrian movement [2]. Notably, since the late nineteenth century, urban landscapes have transitioned from being merely the outcome of site planning to embody a visual philosophy, with visual planning strategies increasingly emphasizing a bottom-up approach [3]. This approach is rooted in human visual perception and artistic principles and enables an understanding of both the static and dynamic nature of urban space [4]. However, it's worth noting that during the early stages of urban landscape planning and management policies, the visual experience of residents within the urban landscape was often neglected. Thus, it's important to acknowledge that people primarily engage with the urban built environment by walking and perceiving their surroundings. Since most urban landscapes are experienced from streets, understanding pedestrian-level visibility has become increasingly important for evaluating how urban form shapes everyday visual environments.

The urban environment is a multifaceted composition of buildings, roads, streets, and green spaces, intricately interwoven through complex relationships to create a tangible and intricate urban fabric [5]. The perceptual landscape is profoundly shaped by the distinctive features of the built environment, and to some degree, it can be manipulated through the alteration of urban landscape elements [6]. Since humans rely on their visual faculties to gather information about their external surroundings, establishing quantitative relationships between built-environment characteristics and pedestrian-level visibility is therefore of considerable importance. As a result, scholars have documented and analyzed pedestrians' visual experiences while navigating urban streets, often using methods like photography or sketches to capture the characteristics of urban scenery [7,8].

Urban space evolves with development, impacting perceived landscape experiences. Major industrial nations experiencing rapid urbanization undergo significant socio-economic and spatial changes [9]. Korea, a prime example, grappled with housing issues amid urbanization and population growth. Consequently, the government implemented large-scale apartment complexes to accommodate the rising population, becoming a prevalent urban form due to mass production [10]. However, this development led to challenges in urban space planning and management. Apartment complexes, necessitating specific-sized development sites through lot combination, spurred rapid spatial changes and physical disconnection, creating large-scale border vacuums [11]. Such changes in urban morphology have also influenced the visual characteristics of urban environments. Previous studies have suggested that the proliferation of high-rise, high-density complexes has obscured natural and cultural landscapes, resulting in more uniform skylines and reduced visual openness [12]. These observations highlight the need to quantitatively examine how different urban form configurations influence pedestrian-level visibility.

### *1.2. Research Objectives*

Critiques of high-rise, high-density urban development in Korea center on concerns regarding the uniformity and privatization of urban landscapes, despite acknowledged benefits. Policymakers and planners often harbor negative perceptions of such approaches, neglecting their positive aspects. Notably, high-rise, high-density development can facilitate the creation of open spaces within development sites. As buildings' floor area ratio increases, the coverage ratio decreases, reducing the overall building footprint. This potentially expands the visibility range for pedestrians at ground level, enriching their experience of urban landscapes. Although high-rise, high-density development is often

associated with concerns regarding urban landscapes, its influence on pedestrian-level visibility has not been systematically quantified. Because increasing building height is frequently accompanied by lower building coverage, different urban form configurations may produce substantially different visibility conditions. Accordingly, this study aims to examine how building height and building coverage jointly influence pedestrian-level visibility across Seoul.

To achieve this objective, a method capable of capturing pedestrian-level visual experiences is required. The 3D ISOVIST method quantifies spatial proximity and distance through visibility, offering a three-dimensional assessment of the visual fields experienced by individuals on the ground. By enabling the quantitative evaluation of visibility within complex urban environments, this method provides an appropriate framework for examining how urban form shapes pedestrian-level visual conditions. Accordingly, this study investigates how pedestrian-level visibility varies across urban form typologies defined by building height and building coverage. Rather than assessing broader planning outcomes, the analysis focuses on identifying measurable relationships between urban morphology and pedestrian-level visibility.

Building upon this analytical framework, this study contributes by developing a Seoul-wide 3D ISOVIST framework for evaluating pedestrian-level visibility across different urban form typologies. Unlike conventional skyline- or view-corridor-based approaches, which primarily assess visibility from selected viewpoints or scenic corridors, the proposed framework evaluates visibility from everyday pedestrian observation points and identifies nonlinear relationships between building height, building coverage, and visibility. By providing city-scale empirical evidence on these relationships, the study advances the quantitative understanding of how urban morphology influences pedestrian-level visibility and establishes a foundation for future visibility-related urban morphology research.

## 2. Literature Review

### 2.1. Urban Compactness and Visibility

In recent decades, the urban landscape in the Western world has faced criticism, leading to calls for critical design solutions [13]. Movements like New Urbanism and Smart Growth advocate for compact development, minimizing urban sprawl and car dependency, and prioritizing human-scale activities [14]. This approach, akin to Korea's apartment complexes, aims for high-density development to accommodate diverse activities on limited land. However, despite its intentions, Korea's apartment complexes are criticized for homogenizing and obstructing the urban landscape due to their scale.

The compact and high-rise development also correlated with the perception or the creation of landmarks. Although apartment complexes provide an important context for understanding Korean urban development, pedestrian visibility is shaped by a wide range of urban environments, including residential neighborhoods, commercial districts, mixed-use developments, and public open spaces. Across these diverse urban settings, previous studies have shown that visibility influences spatial perception, landmark recognition, and the experiential quality of urban environments [15]. Traditionally, high-rise buildings serve as landmarks, but an excessive concentration of such structures can diminish urban space quality. Kevin Lynch identified visibility as a key element in mental city mapping. According to him, the dominance of historic or symbolic monumental buildings in more visible areas is a desirable result for contribution to their function [16]. Landmark status not only enhances function but also elevates real estate value [17]. Conversely, unremarkable buildings merely act as visual barriers. Previous research has examined the impact of tall buildings on cityscapes from aesthetic, visibility, and symbolic perspectives [18].

Compact cities, characterized by dense development within limited land areas, are promoted for their environmental and economic advantages; however, their implications for residents remain contested [19]. While proponents highlight their contribution to urban efficiency and community sustainability [20], critics point to potential adverse effects on residents' health [21] and quality of life [22]. These debates underscore the importance of understanding how urban morphology shapes everyday environmental experiences. Since visibility is fundamentally influenced by the spatial arrangement of the built environment, it serves as a key mechanism linking urban form and landscape perception. Accordingly, examining the relationship between urban morphology and urban landscape is critical for sustainable urban development.

Analyzing visible areas and changes in visibility across various urban densities and building heights holds significance for several reasons. Firstly, visibility greatly impacts the aesthetics and quality of urban landscapes, with landmark prominence, including high-rise buildings, shaping a city's visual appeal and cultural identity. Secondly, understanding visibility and its correlation with compactness is crucial for sustainable urban development. As cities densify to accommodate growing populations, comprehending how compactness influences visibility is vital for designing environments that enhance resident well-being and satisfaction. This analysis provides a geometric basis for understanding how density-related urban form affects pedestrian-level visual openness, which may be combined with other environmental and perceptual indicators in broader urban design evaluation.

## 2.2. 3D ISOVIST

Visibility analysis methods, such as ISOVIST, help quantify the relationship between physical urban form and spatial perception [23]. Originally developed in the fields of landscape and geography, the ISOVIST concept was later introduced into architectural and urban studies [24–26]. Through this analytical approach, spatial composition can be characterized by defining the volume of space visible from a specific point, allowing the visual properties of the built environment to be systematically evaluated [25,26]. Recent visibility-based studies have further shown that ISOVIST-derived measures can be applied to evaluate user preferences and perceptions of urban environments [27]. ISOVIST methods include ray-tracing techniques [28], shadow-projection approaches [26], and agent-based simulations [29]. These methods are effective for quantifying spatial qualities such as area, perimeter, enclosure, and dispersion based on vector data [30]. Previous studies have applied ISOVIST analysis to evaluate streetscape quality, environmental perception, and urban morphology by quantifying pedestrian-level visibility. More recently, three-dimensional visibility analysis has been extended to city-scale applications, demonstrating its potential for evaluating complex urban environments [8].

Previous visibility studies have employed ISOVIST analysis and related computational approaches for several analytical purposes in urban design. First, visibility analysis has been applied to assess visual accessibility and spatial connectivity, thereby explaining how people perceive movement paths and navigational choices. Second, ISOVIST indicators such as visible area, perimeter, enclosure, and mean depth have been used to evaluate spatial openness, enclosure, and the visual structure of streets and public spaces. Third, visibility graph analysis and space syntax approaches have linked visual fields with movement potential, spatial cognition, and environmental legibility. More recently, three-dimensional and parametric approaches have extended these analytical frameworks by incorporating building height, building volume, and vertical obstructions, factors that are especially important in dense urban environments where two-dimensional representations cannot fully capture pedestrian-level visual experience. Therefore, the contribution of 3D ISOVIST in this study lies not merely in its technical implementation but in its capacity to translate

urban building massing into measurable indicators of pedestrian-level visual openness and obstruction.

Additionally, ISOVIST has been reported to have a strong relationship with human behavior and psychological interaction with the environment from both theoretical and empirical perspectives [31]. Accordingly, various methods have been developed to quantify ISOVIST. Among them, GIS-based approaches using digital elevation models (DEMs) have been widely adopted in urban planning and design to evaluate visibility and spatial relationships across urban environments [32]. However, raster-based GIS methods are constrained by pixel resolution and representative height values, limiting their ability to accurately represent complex three-dimensional urban environments [33]. These limitations become increasingly pronounced in high-density cities, where building height and volumetric configurations play a critical role in shaping pedestrian-level visibility. To overcome these limitations, recent studies have increasingly adopted parametric modeling techniques, which enable more flexible geometric representation and support dynamic evaluation of urban design alternatives [34,35].

Rhinoceros and its Grasshopper plug-in provide a parametric modeling environment that enables real-time three-dimensional visibility analysis. Unlike conventional GIS workflows, parametric modeling allows urban forms to be directly modified while simultaneously updating visibility measures, making it well suited for design-oriented analysis. In particular, the DeCodingSpaces Toolbox has expanded the application of 3D ISOVIST by calculating indicators of pedestrian-level openness and enclosure from detailed three-dimensional urban geometry [36]. Compared with conventional 2D ISOVIST, which represents visibility on a planar surface, 3D ISOVIST better reflects actual human visual experience by incorporating building height and volumetric obstruction. This advantage is particularly important in high-density cities such as Korea, where building height regulations strongly influence pedestrian-level visibility and urban spatial quality. Consequently, 3D ISOVIST provides a more appropriate analytical framework for evaluating the visual implications of urban morphology and development intensity.

### 3. Methodology

#### 3.1. Study Area

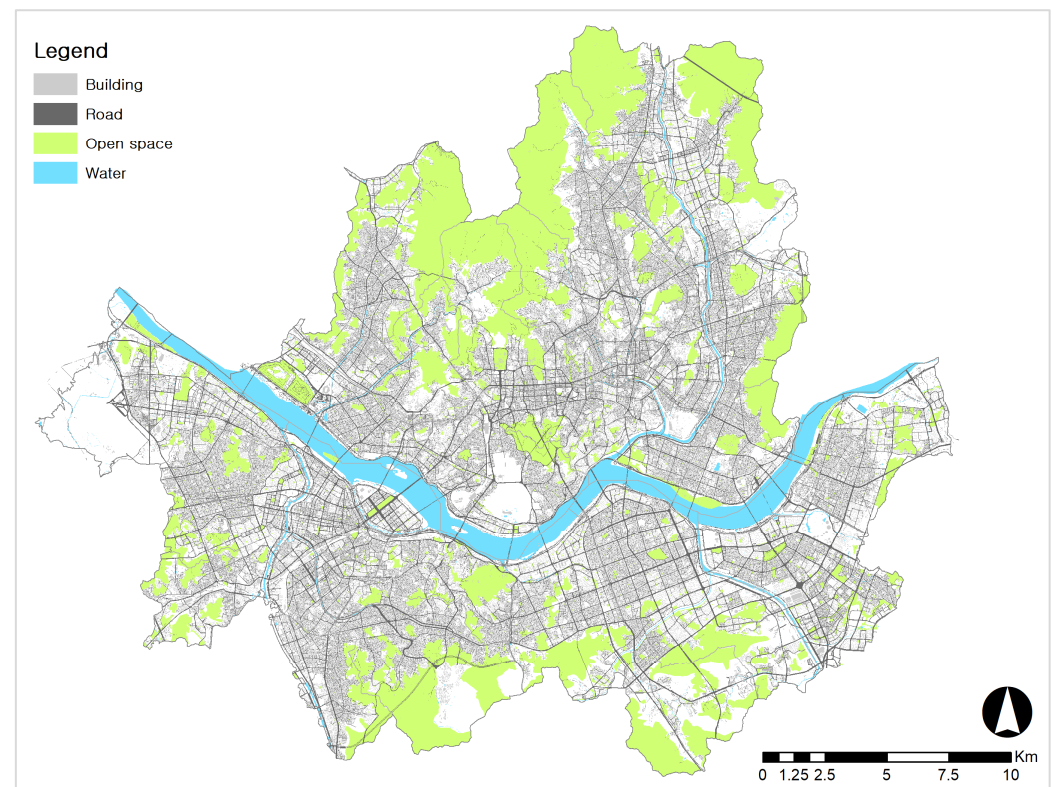
This analysis area focused on Seoul, Korea. Notably, Seoul and its surrounding regions have experienced significant population concentration stemming from rapid urbanization over recent decades. Urban development projects in Seoul have caused a drastic change in the urban environment. To address the degradation of living conditions attributed to aging housing and apartment complexes, there is anticipation for redevelopment projects involving total demolition and reconstruction. Such initiatives are triggering and enlarging ongoing transformations within urban spaces (Figure 1).

Given the confluence of geographical, spatial, and demographic factors characterizing Seoul, it necessitates particular attention in the realm of urban planning and design. The rationale behind choosing Seoul as the spatial focus for this study is delineated as follows:

First, the capital city of Seoul has been under pressure from population concentration and continuous urban development. Parallel to this, the high-density development method is preferred due to the limited urban area and the lack of new sites. Therefore, it was expected to present significant implications for understanding the relationship between compact city development and its impact on residents.

Second, Seoul is a city in which the traditional planning system and the post-industrial urban planning system coexist. In terms of land use, the use areas are mixed. This allows spatial differences and various usage characteristics of urban development methods to be

analyzed. As a result, a comprehensive understanding of building area and height related to development density and reliability of analysis results can be expected.



**Figure 1.** Study area—city of Seoul.

### 3.2. Data

This study deals with the effect of the changing urban density due to urban development projects on visibility in the urban landscape. For this purpose, the building footprints with height dataset, provided by the National Geographical Service, was used to form the three-dimensional urban space. This study focused on visibility as an index to measure changes in the landscape according to urban development projects and the resulting landscape changes. In addition, it is necessary to efficiently consider the density characteristics of urban space, both regionally and micro-scale. Therefore, this study focuses on building height and building coverage as visibility-oriented morphological variables that directly influence three-dimensional visual obstruction and spatial openness. These variables are not intended to represent a comprehensive urban design typology, but rather to define building height–coverage configurations for analyzing pedestrian-level geometric visibility at a citywide scale.

### 3.3. Research Framework

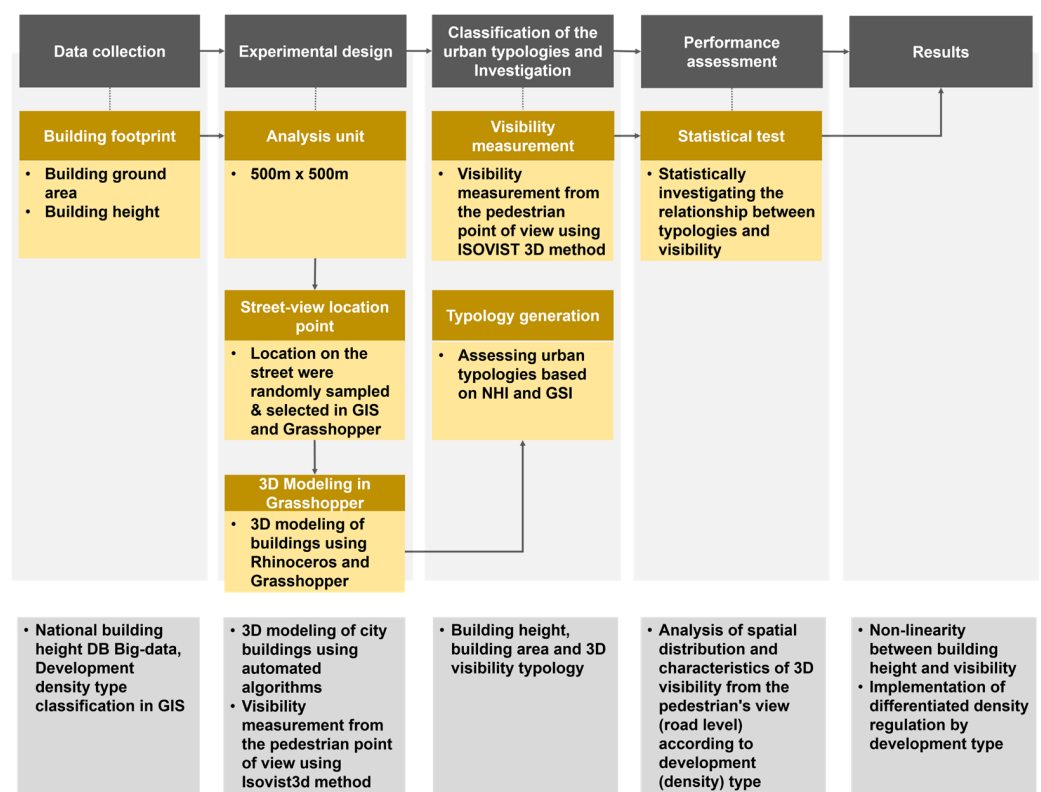
The research process is structured across several stages to achieve the study objectives. First, building footprint and height data were obtained from the National Building Height Database and processed for the simulation. The resulting dataset enables the classification of urban development typologies based on building height and area and provides the foundation for subsequent visibility analyses.

Before conducting the 3D ISOVIST simulation, three spatial parameters were distinguished: the analytical aggregation unit, the maximum observation distance, and the building-geometry context. Previous research has suggested that characteristic urban landscape elements can be perceived at distances of up to approximately 500 m [37]. Accordingly,

the maximum ISOVIST observation distance was set to 500 m. The 500 m  $\times$  500 m grid was used as an aggregation unit for summarizing and comparing local visibility conditions across Seoul, rather than as a natural boundary of pedestrian experience. However, because observation points near the grid boundary may be influenced by buildings outside the target grid, building geometry was extracted from a larger 1500 m  $\times$  1500 m context consisting of the target grid and its eight surrounding grids. This approach reduced boundary effects while maintaining a fixed 500 m observation radius. Consequently, the 500 m grid served as the reporting unit, the 500 m radius defined the visibility range, and the 1500 m  $\times$  1500 m context was used only as the building-geometry input for ray tracing.

Based on these spatial settings, Seoul was divided into 500 m  $\times$  500 m grid cells for analysis. Ten random pedestrian observation points were generated on roads within each grid cell using ArcGIS (Esri, Redlands, CA, USA). An automated Grasshopper script was then used to construct three-dimensional building models and perform 3D ISOVIST simulations for each observation point. The resulting visibility measures were aggregated to the grid level for subsequent statistical analysis.

The next step involves classifying urban forms based on building characteristics and examining how variations in urban morphology influence 3D visibility. Finally, a statistical validation was conducted to evaluate the reliability of the 3D visibility simulation model. This verification examines the relationships among model accuracy, building height, building area, and 3D visibility. Furthermore, the study investigates the relationship between urban form and 3D visibility through comprehensive analysis (Figure 2).



**Figure 2.** Framework of research process.

### 3.4. Parametric Model and 3D Simulation

In this study, the 3D ISOVIST method was employed to investigate urban visibility. This approach was selected because it is particularly suitable for evaluating pedestrian-level visibility across large urban areas. Unlike Google Street View (GSV), which relies on pre-existing imagery and may have limitations in spatial coverage and data availability,

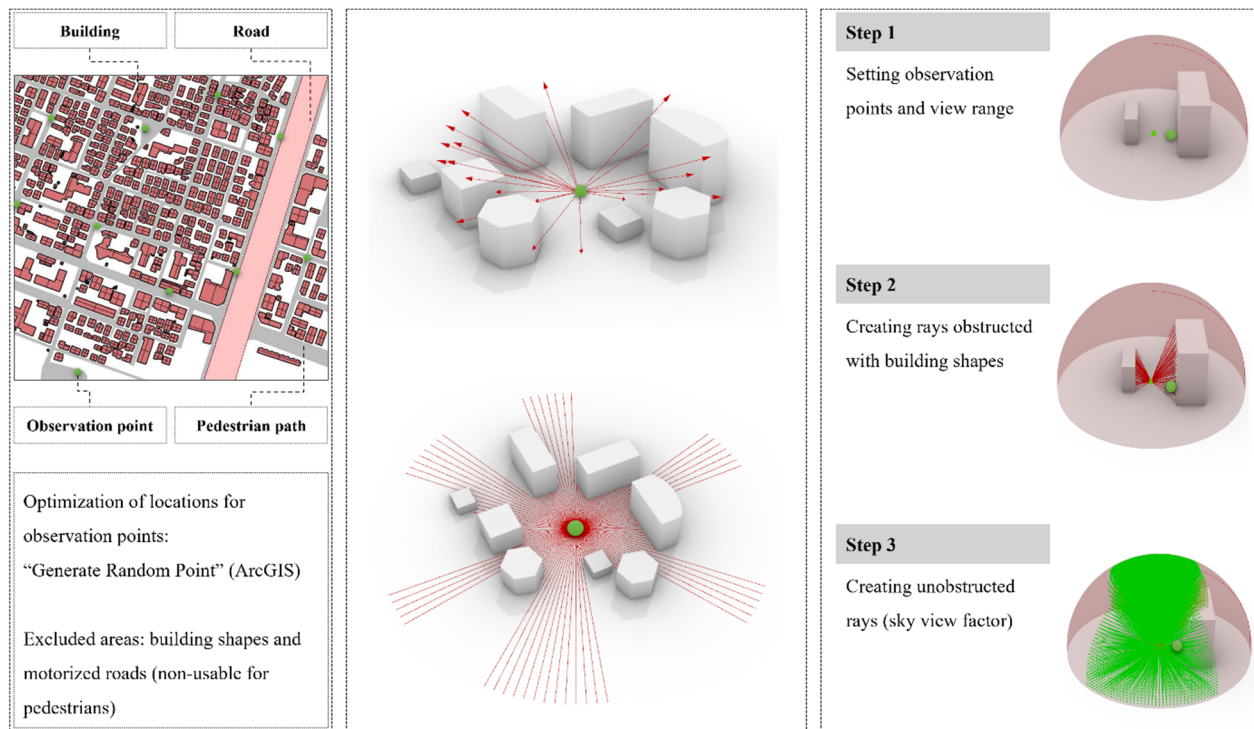
the 3D ISOVIST method provides a comprehensive assessment of visibility by considering both direct line-of-sight and perceptual fields of view. Its flexibility enables analyses across diverse urban contexts, including informal neighborhoods with narrow streets and complex urban environments. Moreover, the quantitative nature of the ISOVIST approach ensures reproducible results. Therefore, the 3D ISOVIST method was adopted because of its adaptability, comprehensiveness, and ability to generate visibility measures.

To measure 3D ISOVIST, this study employed the DeCodingSpaces Toolbox for Grasshopper, developed by the Architectural Computer Engineering team at Bauhaus-Universität Weimar (Weimar, Germany) [38]. The toolbox allows users to define viewing direction, angle, and extent while calculating visible volumes of buildings, land, and sky. A three-dimensional urban environment was constructed using building footprint and height data. The city model was generated using Rhinoceros 7 and Grasshopper (Robert McNeel & Associates, Seattle, WA, USA), which provide a parametric modeling environment. The DeCodingSpaces Toolbox was then applied to simulate visibility and derive 3D ISOVIST measures for the study area.

To understand the visibility calculations, it is necessary to briefly explain the underlying ISOVIST algorithm. In this study, visibility was measured using a ray-tracing approach, a widely used technique in ISOVIST analysis. The ray-tracing method generates a spherical boundary around an observation point and projects rays toward the boundary while treating buildings as obstacles. Visibility is quantified by identifying which rays are intercepted by obstacles and which remain unobstructed. In this study, the observation range was fixed at 500 m to represent the maximum pedestrian-level viewing distance adopted in the analysis. However, to minimize edge effects and account for surrounding buildings outside the target observation area, the computational simulation was performed over a larger 1500 m modeling extent. This ensured that buildings beyond the 500 m observation range were appropriately represented during the ray-tracing process without artificially overestimating visibility near the boundary of the analysis area. The primary input parameters included observer location, building surfaces, viewing direction, viewing range, and the number of generated rays. Building geometries were treated as obstacles within the model. The generated rays were classified into two categories: obstructed rays that intersect building surfaces and unobstructed rays that remain visible to the sky (Figure 3).

On the other hand, this study quantifies the visibility of the landscape from the viewpoint of pedestrians, namely the open space outside buildings and roads. Therefore, setting a measurement point in the external space is necessary. However, analyzing visibility in all spaces harms the efficiency of research. In addition, the urban landscape in everyday life is experienced at an indeterminate point rather than a fixed point. Accordingly, a point that is the basis of the visibility analysis was randomly generated in the 500 m × 500 m grid, which is the unit of analysis, and visibility was measured at the generated point. For this, 10 points were randomly generated in each analysis unit using Grasshopper's "Populate Geometry" component. To represent realistic pedestrian viewpoints, the random sampling was restricted to pedestrian-accessible open spaces, such as roads and other ground-level open areas, while buildings and inaccessible spaces were excluded. Next, visibility analysis was performed for the 10 points. Specifically, for the visibility analysis, 0–360° horizontally, 0–180° vertically, and an observation range (i.e., maximum line-of-sight distance) of 500 m were specified (Figure 3).

The viewing range defines the maximum observation distance for visibility analysis. Ray length represents the average visible distance from the pedestrian's viewpoint, with longer ray lengths indicating greater visual openness. In addition, the ray fraction measures the proportion of unobstructed rays, providing an indicator of the degree of openness and enclosure within the urban environment.



**Figure 3.** Concept of 3D ISOVIST and visibility analysis. (The arrows and lines indicate the directions and extent of the lines of sight from the observation point).

The ray length, as an average metric derived from the pedestrian’s viewpoint, serves as an indicator of the depth of the observable area. Consequently, a longer ray length implies a broader visible region, thereby reflecting a greater expanse within the pedestrian’s field of view. Furthermore, ray-based visibility metrics were used to characterize different aspects of the visual environment, including sky viewing ratio, building viewing ratio, ground viewing ratio, mean viewing distance, and viewing distance variance. These indicators collectively capture the composition, openness, and spatial heterogeneity of the urban landscape from the pedestrian perspective (Table 1). Together, these indicators enable a comprehensive assessment of urban visibility by capturing both the spatial composition of the visible scene and the depth characteristics of the surrounding environment.

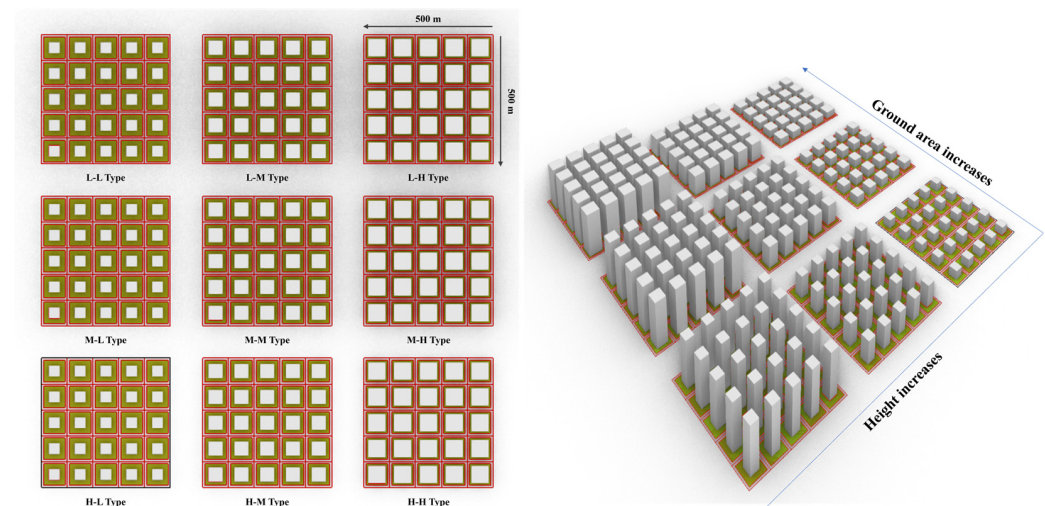
**Table 1.** Description of visibility indicators.

| Indicator                 | Description                                                                                                                       |
|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Sky viewing ratio         | Proportion of the three-dimensional field of view occupied by the unobstructed sky area.                                          |
| Building viewing ratio    | Proportion of the three-dimensional field of view occupied by building surfaces and other vertical obstacles.                     |
| Ground viewing ratio      | Proportion of the field of view occupied by ground, street, or other horizontal surfaces.                                         |
| Mean viewing distance     | Average unobstructed ray length from the observation point. Higher values indicate greater visual openness and depth.             |
| Viewing distance variance | Variability of ray lengths, representing unevenness in the visible field. Higher values indicate more heterogeneous visual depth. |

## 4. Results

### 4.1. Classification of Built-Up Types and Simulation Results

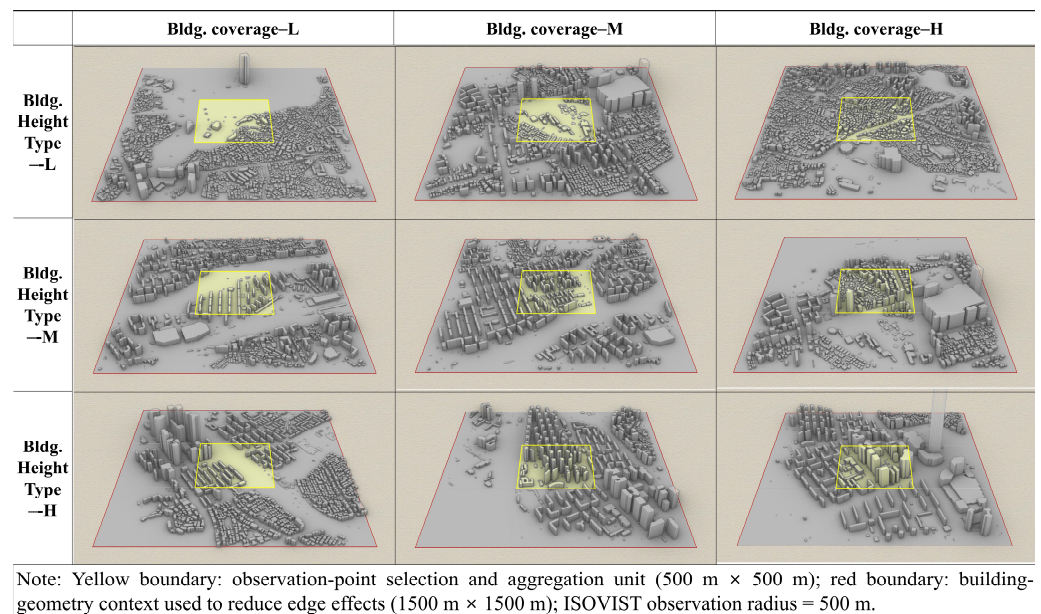
The three-dimensional characteristics of the built environment resulting from urban development affect pedestrian visibility at street level. To examine these effects, urban form was systematically classified according to building height and building coverage ratio. Both variables were categorized into low, medium, and high groups using the natural breaks (Jenks) classification method. The resulting categories were subsequently combined to create nine urban density typologies representing distinct height–coverage configurations (Figure 4).



**Figure 4.** Conceptual classification of built-up area types.

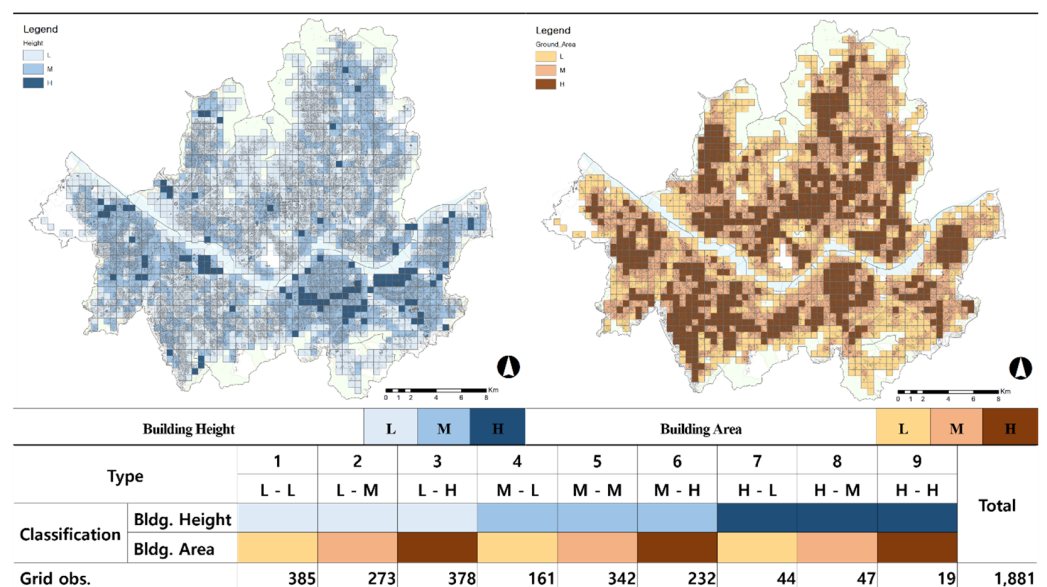
ArcGIS 10.8 (Esri, Redlands, CA, USA) was used to categorize development density based on building area and height. For this purpose, the case area of Seoul was divided into 500 m × 500 m grid units, and among them, 2209 grids completely included in Seoul were selected. Next, the number of buildings included in each grid unit was calculated because it was judged that the visibility analysis was meaningless if the building, which was the result of urban development noted in this study, was below a certain level. As a result of calculating the number of buildings, the average was 357, and the standard deviation was 341. Thus, the Grid containing only 16 or fewer buildings, the difference between the average and the standard deviation, was excluded from the analysis. Finally, 23 grids that did not include roads were excluded from the analysis. And eventually, 1881 grids were determined as spatial analysis units for ISOVIST analysis.

Next, development types were classified based on the characteristics of buildings within the final 1881 selected grid cells, following criteria adopted from previous urban morphology studies [39]. Urban form classifications are typically derived from quantitative data, thereby reducing researcher subjectivity and bias. In this study, building height, building area, and the number of buildings were used to characterize urban form. The national Building Height Database, which provides detailed information on building height and footprint area, served as the primary data source. Accordingly, average building height and building coverage ratio were calculated for each spatial unit and classified into low, medium, and high categories. The final urban form typologies consisted of L–L, L–M, L–H, M–L, M–M, M–H, H–L, H–M, and H–H, representing combinations of building height and building coverage ratio across the study area (Figure 5).



**Figure 5.** Classification case of building height and building area.

After classifying the development type, modeling and rendering were performed in Rhinoceros and Grasshopper. Table 1 shows three-dimensional environment examples of units for each typology. As a result of classification, there were 385 L–L Types, 273 L–M Types, 378 L–H Types, 161 M–L Types, 342 M–M Types, 232 M–H Types, 44 H–L Types, 47 H–M Types, and 19 H–H Types in Seoul. They are classified by type (Figure 6).



**Figure 6.** Classification of building height and building coverage.

According to the distribution of the typologies by (500 m × 500 m) grid space units in Seoul, H–H types were observed in Jongno, Yeouido, and Gangnam, the main downtown areas of Seoul, and L–L types of development were observed in Pyeongchang-dong, Seongbuk-dong, Sillim-dong. In addition, L–L and L–M types were observed in areas outside of Seoul where development restrictions were applied due to the green belt, and H–L, H–M, and H–H types were observed in areas south of the Han River (Figure 6).

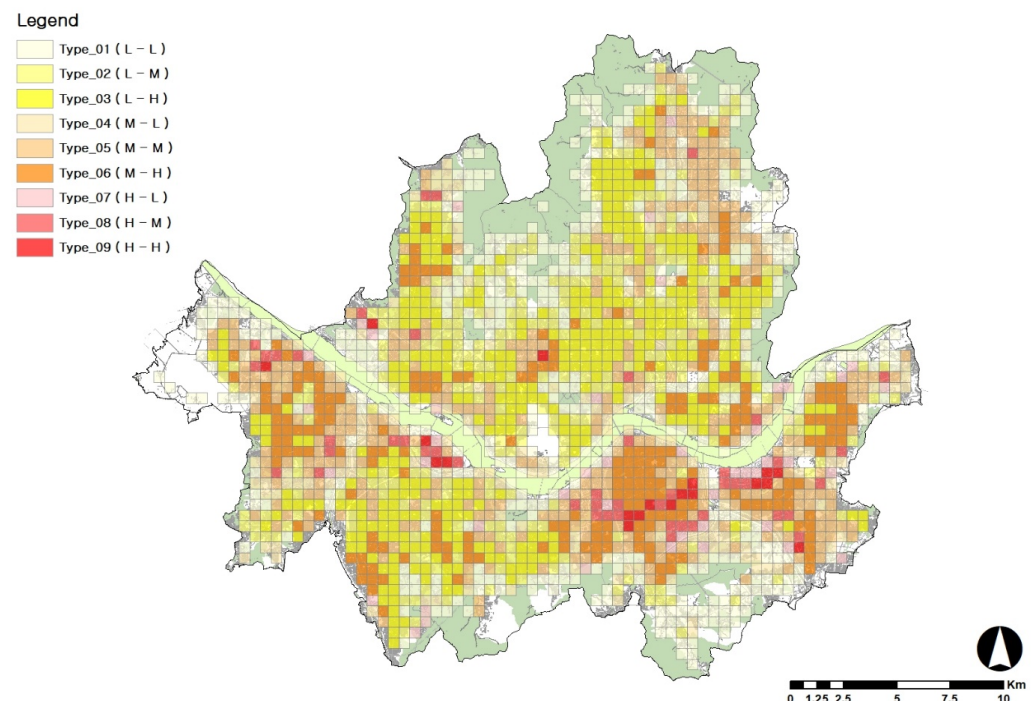
As a result of 3D ISOVIST simulation, the sky view ratio value of Type-1 (L–L) is 0.431, the sky view ratio value of Type-2 (L–M) is 0.340, and the sky view ratio value of Type-3

(L-H) is 0.292, which is the same development area. Therefore, in the case of the type, it can be seen that the ratio of the visible area decreases as the height of the building increases. Likewise, the Sky View Ratio value of Type-3 (L-H) is 0.292, Type-6 (M-H) is 0.282, and Type-9 (H-H) is 0.275. It can be seen that the visible area ratio decreases as the area increases (Table 2 & Figure 7).

**Table 2.** 3D ISOVIST results by nine built-up area types.

| Built-Up Area Types<br>(Height–Coverage) | Viewing Ratio |                     | Viewing Distance |          |
|------------------------------------------|---------------|---------------------|------------------|----------|
|                                          | Sky           | Obstacle (Building) | Mean             | Variance |
| Type-1 (L-L)                             | 0.431         | 0.075               | 219.198          | 242.301  |
| Type-2 (L-M)                             | 0.340         | 0.166               | 175.096          | 229.510  |
| Type-3 (L-H)                             | 0.292         | 0.213               | 150.909          | 221.184  |
| Type-4 (M-L)                             | 0.395         | 0.111               | 204.846          | 237.623  |
| Type-5 (M-M)                             | 0.329         | 0.176               | 173.056          | 227.338  |
| Type-6 (M-H)                             | 0.282         | 0.223               | 147.589          | 218.553  |
| Type-7 (H-L)                             | 0.387         | 0.119               | 203.821          | 236.418  |
| Type-8 (H-M)                             | 0.325         | 0.180               | 174.322          | 226.061  |
| Type-9 (H-H)                             | 0.275         | 0.231               | 152.395          | 214.208  |

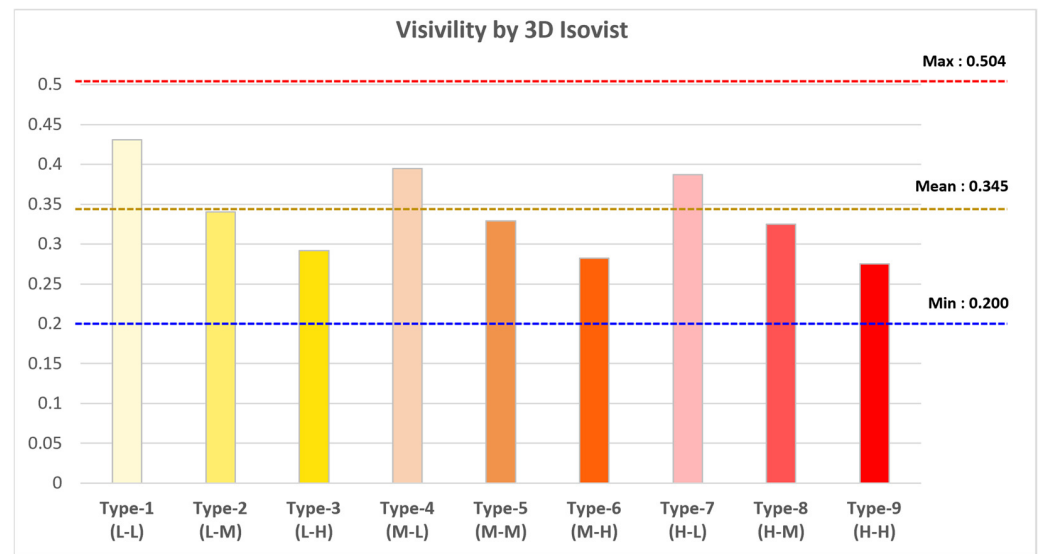
Note: The viewing ratio is composed of sky, obstacle/building, and ground visibility. Since only sky and obstacle ratios are reported in the table, the remaining proportion represents ground visibility.



**Figure 7.** Spatial distribution by type of urban development.

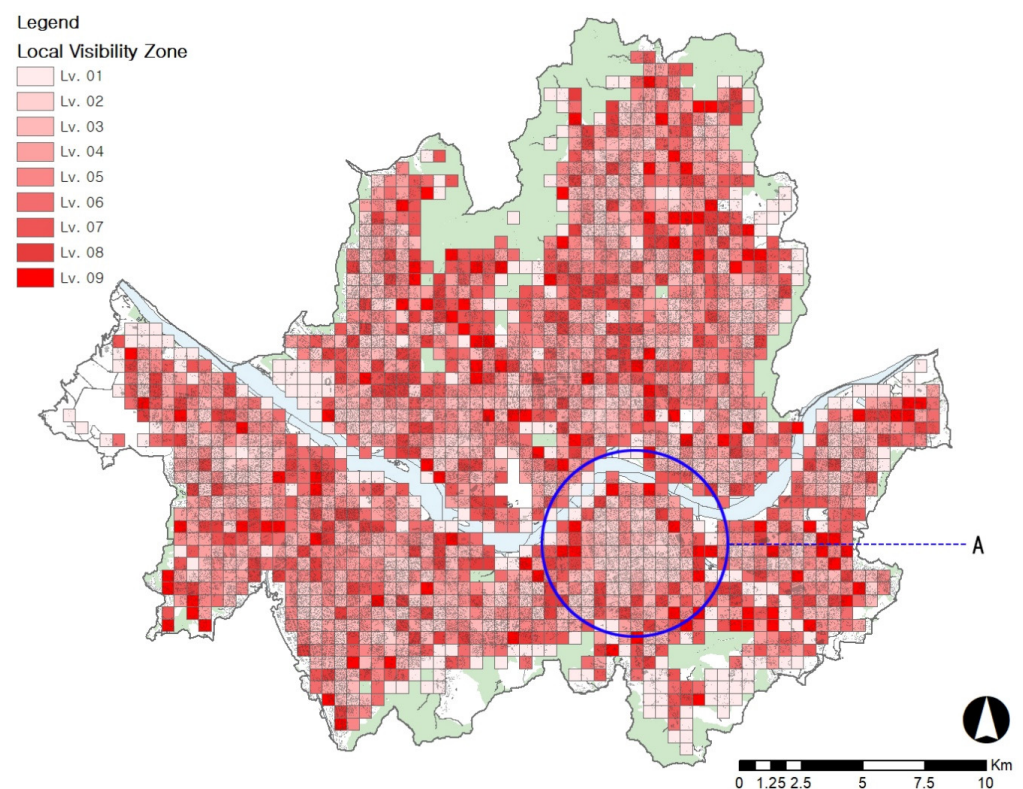
Regarding the visibility ratio by development type, it can be confirmed that the visibility ratio changes according to the height of the building when the development area is the same. Specifically, when the development area belongs to the L group, it can be seen that the visibility ratio decreases as the building height increases from L-type to H-type. However, when the building height is L-type, the visibility ratio decreases as the building

area increases. Furthermore, it can be seen that the visibility ratio in the L-type building area is above the average visibility of all areas in Seoul (Figure 8).



**Figure 8.** Viewing rate by development type.

Next, the calculated 3D ISOVIST values were aggregated by spatial analysis unit, and K-means clustering was applied to delineate Local Visibility Zones (LVZs) (Figure 8). The clustering results reveal that visibility is generally highest in river and mountainous areas, while urbanized and residential districts exhibit lower visibility levels. Area A (Figure 9), encompassing Seoul's primary business and commercial center, demonstrated particularly high visibility, especially along the northern riverfront.



**Figure 9.** Concept of Local Visibility Zone (LVZ).

#### 4.2. Relationship Between Urban Form Variables and Simulated ISOVIST Visibility

This study generated pedestrian-level visibility indices using Rhino and Grasshopper's modeling and simulation environment. Before examining visibility differences across urban form typologies, regression analyses were conducted to investigate whether the simulated ISOVIST values exhibited systematic relationships with major urban form variables, including building height, building area, and building volume. Particular attention was given to potential nonlinear and interaction effects, which were subsequently incorporated into the analytical framework. The main variable values used in modeling and simulation, such as building height, building area, and building gross floor area, were considered for verification. Each variable's nonlinearity and interaction effects were additionally considered and applied to verify the model.

The regression analysis indicated that the simulated ISOVIST values were systematically associated with the selected urban form variables, with Model A-2 providing a slightly better fit than Model A-1 (adjusted  $R^2 = 0.696$ ). Additionally, the regression results showed that the visible area decreased as building height increased. On the other hand, as the building area determining the building footprint increased, the visible area also increased. In general, because building height and building area tend to be inversely related under fixed site conditions, an increase in building footprint is often accompanied by a reduction in building height, resulting in greater visible area. Accordingly, total building volume, which captures the combined effects of building height and building area, was additionally included in the regression model. The results further indicated that greater building volume was associated with reduced visible area, suggesting that both building height and building mass should be considered when evaluating pedestrian-level visibility.

On the other hand, for buildings that result from city development activities, the development scale is controlled by the building-to-land ratio and floor area ratio. Therefore, it is used as a tool for sustainable development by suppressing the excessive development of land. Generally, increasing the Building Coverage Ratio (BCR) and decreasing the Floor Area Ratio (FAR), or decreasing the building-to-land ratio and increasing the floor-to-floor ratio, are preferred so that various building volumes can be created at the same development scale while producing different urban form characteristics.

These results reflect the policy of suppressing excessive development by minimizing the building area and increasing the height or maximizing the building area and scale. In the case of downtown business and commercial districts, land use benefits were maximized by maximizing the floor area ratio. Because building height, building area, and building volume are inherently interrelated under these development conditions, the regression model was specified to account for both nonlinear and interaction effects. Accordingly, a squared term for building height was included to capture its nonlinear relationship with visibility, and an interaction term between building area and total building volume was incorporated to examine their combined influence on the simulated ISOVIST visibility.

Two regression specifications were estimated to examine the relationship between urban form and visibility. Model A-1 included the direct effects of building height, building area, total building area, and total building volume on visibility. Building height was additionally entered as a squared term to capture potential non-linear effects. Model A-2 further incorporated an interaction term between building area and total building volume to examine whether the influence of building footprint varies according to overall building mass. The inclusion of the interaction term slightly improved model performance, increasing the adjusted  $R^2$  from 0.689 to 0.696.

As a result of the analysis, it was found that as building height increased, ISOVIST values initially decreased and then increased. Consistent with this pattern, building height exhibited a negative coefficient ( $\beta = -0.009$ ,  $p < 0.001$ ), whereas its squared term was

positive ( $\beta = 1.73 \times 10^{-4}$ ,  $p < 0.001$ ), indicating a significant non-linear relationship between building height and visibility. Furthermore, the interaction between building area and total building volume was negative and statistically significant ( $\beta = -2.99 \times 10^{-9}$ ,  $p < 0.001$ ), suggesting that the positive effect of building area diminishes as building volume increases. Consequently, developments characterized by both large footprints and high volumes tend to constrain pedestrian visibility more strongly than would be expected from their independent effects alone (Table 3). Overall, these regression results confirm meaningful relationships between simulated ISOVIST visibility and urban form characteristics, providing a basis for the subsequent typology-based analyses.

**Table 3.** Statistical validation of the model.

| Variable             |                                           | Variable Description                                 | Model A-1              |     |        | Model A-2              |     |        |
|----------------------|-------------------------------------------|------------------------------------------------------|------------------------|-----|--------|------------------------|-----|--------|
|                      |                                           |                                                      | Coef.                  |     | t      | Coef.                  |     | t      |
| Independent Variable | Height                                    | Average building height                              | −0.008                 | *** | −12.18 | −0.009                 | *** | −13.78 |
|                      | Height Square                             | Average building height squared (non-linear)         | $1.38 \times 10^{-4}$  | *** | 7.75   | $1.73 \times 10^{-4}$  | *** | 9.40   |
|                      | Building Area                             | Average building area (ground floor)                 | $8.85 \times 10^{-5}$  | *** | 16.40  | $1.29 \times 10^{-4}$  | *** | 15.79  |
|                      | Total Building Area                       | Total building area (ground floor)                   | $-1.34 \times 10^{-6}$ | *** | −34.72 | $-1.33 \times 10^{-6}$ | *** | −34.98 |
|                      | Total Building Volume                     | Total building volume (volume)                       | $-2.72 \times 10^{-8}$ | *** | −4.18  | $-1.95 \times 10^{-8}$ | *** | −2.97  |
|                      | (Building Area) × (Total Building Volume) | Interaction of building area & total building volume |                        |     |        | $-2.99 \times 10^{-9}$ | *** | −6.51  |
|                      | _cons                                     |                                                      | 0.483                  | *** | 113.50 | 0.484                  | *** | 114.87 |
| Number of obs.       |                                           |                                                      | 1881                   |     |        | 1881                   |     |        |
| F(6, 1874)           |                                           |                                                      | 833.59                 |     |        | 717.03                 |     |        |
| Prob > F             |                                           |                                                      | 0.000                  |     |        | 0.000                  |     |        |
| R-squared            |                                           |                                                      | 0.690                  |     |        | 0.700                  |     |        |
| Adj R-squared        |                                           |                                                      | 0.689                  |     |        | 0.696                  |     |        |
| Root MSE             |                                           |                                                      | 0.040                  |     |        | 0.040                  |     |        |

Note: \*\*\*  $p < 0.001$ .

#### 4.3. Analysis of ISOVIST Characteristics by Urban Development Type

The analysis was performed using the (Medium-rise) × (Medium-developed) type as a criterion variable, and all types except the (High-rise) × (Medium-developed) type were found to correlate with visibility. First, it was found that the visibility of the (Medium-rise) × (Low-developed) type increased compared to the (Medium-rise) × (Medium-developed) type, the criterion variable, but the visibility of the (High-rise) × (High-developed) type decreased. This means that the visibility decreases as the building development area increases because the building height type is the same as the middle rise. Next, the visibility of the (Low-rise) × (Medium-developed) types increased compared to the (Medium-rise) × (Medium-developed) types. However, (High-rise) × (Medium-developed) was found to be statistically insignificant. Therefore, when the development area type is the same as the medium type, it can be seen that the Low-rise type has better visibility than the Medium-rise type. Also, when the height of the building is the same as the Low-rise type, the change in visibility according to the shift in the development area type of the building was examined. Visibility increased in the (Low-rise) × (Low-developed) types but decreased in the (Low-rise) × (High-developed) types. However,

visibility decreased for (High-rise)  $\times$  (Low-developed) types and increased for (High-rise)  $\times$  (High-developed) types.

Meanwhile, we paid attention to the (Medium-rise)  $\times$  (High-developed) type and the (High-rise)  $\times$  (Low-developed) type. This is attributed to the prevalent residential typology in Korea, which predominantly comprises apartment complexes. Specifically, the height of a building is closely tied to the floor area ratio (FAR), while the building area is intricately linked to the building coverage ratio. This correlation arises from the potential reflection of individuals' intentions to maximize the use of space permitted by law on constrained development sites. Therefore, as the height of the building increases, the coverage ratio decreases. Considering this, it can be seen that the visibility of the (Medium-rise)  $\times$  (High-developed) type decreased, but the visibility of the (High-rise)  $\times$  (Low-developed) type increased. This means that increasing the building height and reducing the development area can increase visibility at the pedestrian eye level. This is closely related to the nonlinearity of the building height and visibility confirmed in the model verification stage (Table 4).

**Table 4.** Development Type and Visibility Regression Model.

|                      | Variable                                                      | Type         | Coef.   |     | t      |
|----------------------|---------------------------------------------------------------|--------------|---------|-----|--------|
| Independent Variable | Low-rise $\times$ Low-developed                               | Type-1 (L-L) | 0.102   | *** | 28.82  |
|                      | Low-rise $\times$ Medium-developed                            | Type-2 (L-M) | 0.011   | *** | 2.76   |
|                      | Low-rise $\times$ High-developed                              | Type-3 (L-H) | −0.037  | *** | −10.46 |
|                      | Medium-rise $\times$ Low-developed                            | Type-4 (M-L) | 0.065   | *** | 14.42  |
|                      | Medium-rise $\times$ Medium-developed<br>(Reference variable) | Type-5 (M-M) |         |     |        |
|                      | Medium-rise $\times$ High-developed                           | Type-6 (M-H) | −0.047  | *** | −11.73 |
|                      | High-rise $\times$ Low-developed                              | Type-7 (H-L) | 0.057   | *** | 7.57   |
|                      | High-rise $\times$ Medium-developed                           | Type-8 (H-M) | −0.004  |     | −0.55  |
|                      | High-rise $\times$ High-developed                             | Type-9 (H-H) | −0.054  | *** | −4.87  |
|                      | _cons                                                         |              | 0.329   |     | 128.52 |
|                      | Numbers of obs.                                               |              | 1881    |     |        |
|                      | F(6, 1874)                                                    |              | 305.040 |     |        |
|                      | Prob > F                                                      |              | 0.000   |     |        |
|                      | R-squared                                                     |              | 0.566   |     |        |
|                      | Adj R-squared                                                 |              | 0.564   |     |        |
|                      | Root MSE                                                      |              | 0.047   |     |        |

Note: \*\*\*  $p < 0.001$ .

## 5. Discussion

The established relationship between urban form and spatial configuration with human visual perception has been extensively documented in prior research [26,40]. For this reason, many researchers and urban designers have focused on the impact of urban form on visual perception [2,41,42], advocating for the preservation of the visual landscape of the city by restricting its vertical expansion [43]. Notably, there is a noticeable contrast between urban planners' and policymakers' negative perceptions and opposition towards the vertical expansion of cities and the opposing views held by landowners and urban developers. Specifically, planners and policymakers argue that restricting building height enhances the visibility of urban spaces. On the other hand, urban developers and landowners claim that if the development capacity of a given land can be fully reflected in

building height, openness may increase instead [44]. The conflicting perspectives on the relationship between urban development density and visibility suggest reconsidering the complex interplay between physical factors shaping urban spaces.

Still, the presence of high-rise structures is often associated with obstructed sightlines and the creation of a monotonous urban landscape, causing ongoing debates surrounding the regulation of building heights within the context of urban development density. In this regard, researchers have explored visibility in urban spaces by considering the complex interactions of urban buildings based on the physical environmental characteristics. They commonly discuss how building height, footprint, and orientation interact to determine visibility [45,46]. Furthermore, the concept of visibility underscores the significance of the observer's viewpoint, elucidating the human-scale experience of the urban landscape by examining the evolving visibility areas during pedestrian movements [4].

Also, in the context of urban landscape planning, our research introduces a novel perspective by integrating computational visibility analysis, mainly focusing on the pedestrian-level local visibility zone. By elucidating the relationship between visibility and urban design elements, such as building height and surface coverage, our study contributes valuable insights into enhancing the quality of urban environments from the standpoint of pedestrian experience. Beyond its methodological contribution, the findings may also provide useful insights for future studies examining the socioeconomic implications of urban form, including land-use distribution, accessibility, and housing market dynamics, where visibility represents one of several dimensions shaping urban environments [6]. Notably, while recent advancements in generative urban design tools predominantly prioritize considerations such as energy efficiency and spatial allocation, our findings underscore the importance of incorporating visibility parameters into these tools. By doing so, urban designers and planners can effectively optimize designs not only for functional efficiency but also for enhancing the perceptual qualities of urban spaces, ultimately fostering more sustainable and livable cities. Thus, our research serves as a critical step towards broadening the scope of generative urban design by generalization of how compactness impacts the visual experience to encompass holistic considerations of human experience and well-being within the urban fabric.

Another limitation is that this study measures geometric visibility rather than the full qualitative experience of the visible environment. Indicators such as sky view ratio, building visibility, and viewing distance describe the openness and spatial extent of the pedestrian visual field, but they do not determine whether the view is aesthetically positive, socially active, safe, or comfortable. An open view may reveal public space or landscape elements, but it may also reveal vacant land, parking areas, road infrastructure, or blank façades. Conversely, a more enclosed street may still provide a positive pedestrian experience when supported by active frontages, greenery, human-scale façades, and diverse land uses. Therefore, the ISOVIST indicators used in this study should be interpreted as a geometric layer of pedestrian visibility rather than as direct measures of urban quality.

This distinction is important because visual openness and urban quality do not follow a simple linear relationship. Dogan and Lee (2024) [47] demonstrated that 3D ISOVIST-based street enclosure has a nonlinear relationship with urban vitality, showing that both highly open and highly enclosed environments may be less supportive of urban activity. This suggests that pedestrian experience depends not only on how much space is visible, but also on the qualitative and functional characteristics of the visible environment. Therefore, the visibility indicators used in this study should be interpreted as a geometric layer of pedestrian visual conditions, rather than as direct indicators of urban quality, safety, sustainability, or vitality in future studies.

A further limitation concerns the simplified definition of urban form. This study characterizes urban morphology primarily through building height and building coverage because these variables directly influence geometric visibility and are consistently available across Seoul. However, this approach does not capture other dimensions of pedestrian experience, such as active frontages, vegetation, land-use mix, or pedestrian activity. Therefore, the proposed typologies should be interpreted as a simplified framework for evaluating the geometric effects of building massing rather than comprehensive urban design typologies. Future research should validate 3D ISOVIST results using alternative visibility-analysis methods, street-level observations, LiDAR or street-view data, and user perception assessments to better establish the relationship between simulated visibility and actual pedestrian experience.

Based on this research, one potential path for further research could involve exploring the socio-cultural aspects of urban visibility and its implications for community well-being. Specifically, future studies could investigate how variations in urban visibility impact social interactions, sense of community, and overall quality of life for residents. This could involve conducting qualitative research to gather insights from residents living in different urban environments with varying levels of visibility using an interview survey. Additionally, examining the role of urban design interventions, such as the creation of pedestrian-friendly spaces or the incorporation of green infrastructure, in enhancing visibility and fostering social cohesion could provide valuable insights for urban planners and policymakers. Overall, by considering the broader socio-cultural dimensions of urban visibility, future research can contribute to the development of more inclusive and livable urban environments.

## 6. Conclusions

In this study, two perspectives on urban development density were compared on a broad scale to enhance the public nature of urban landscapes from a pedestrian's viewpoint. To achieve this, the 3D ISOVIST technique was employed to quantify visibility, and an analysis was conducted on the relationship between architectural development density and visibility. The analysis focused on building height and area, which determine the scale of a building. To this end, the model's verification was performed first on the reliability of the 3D ISOVIST analysis tool and to understand the effect of individual variables on visibility. As a result of the analysis, the visibility decreased as the building height increased, but a non-linearity was found between the building height and visibility. This means that the height of a building becomes a factor that reduces visibility up to the critical value, but visibility may increase after the required value. In addition, it was found that there is a mutual relationship between the building area and the building volume through the interaction variable between the building area and the building volume. This means that building height and building area are complementary. It can be seen through the relationship between the FAR and the BCR.

Next, urban development types were classified into nine categories based on building height and floor area. This classification was inspired by the Local Climate Zone (LCZ), and an analysis was conducted on the relationship between each development type and visibility. As a result of the analysis, it was confirmed that when the building height is fixed at L, the visibility deteriorates as the building area increases. This means the building area is advantageous for visibility under the same building height conditions. As a result of the analysis, in terms of building height and size, type M-M showed better visibility than type L-M. This means that visibility in a space with a small building area is advantageous under the same building height condition. Next, type H-H had higher visibility than type H-L. This is in contrast to the previously analyzed L type with the same building height, where the visibility decreases as the building area increases.

This can be considered in the development of domestic apartment complexes. Specifically, Korea's primary building type of apartment complexes is divided into tower and plate types. This means visibility deteriorates as the building area increases under the same building height condition. This is because the joint space (stairwells, elevators, etc.) shared by tower-type buildings is more significant than that of plate-type buildings, which occupy a large building area. Additionally, in some cases, the regularity of the structure and shape (round rather than rectangular) was found to mitigate the adverse effects of building height and area on the visibility area. This means that the visibility of urban space can be improved when the arrangement and shape of buildings are used as parameters to enhance the visibility of high-density development. This study provides a quantitative perspective on how simple, controllable urban form variables influence pedestrian-level visibility, offering a basis for visibility-oriented urban form assessment rather than broader urban development recommendations.

These findings suggest that pedestrian-level visibility cannot be fully explained by building height alone but is jointly influenced by building coverage and spatial configuration. Accordingly, the proposed framework provides a quantitative basis for evaluating the visual implications of different urban form typologies from a visibility perspective. While the present study focuses exclusively on geometric visibility, future research integrating additional environmental factors, socioeconomic variables, and green landscape indicators could provide a more comprehensive understanding of urban landscape quality.

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