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Measuring Housing Privacy Defined as a Function in Urban Neighborhood Blocks: Modeling the Permeability-Opacity Tradeoff

Laith H. M. Al-Ossmi[1]* Hassan Hashim Mohammed [2]

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Abstract

This paper is a theory-driven quantitative method in cultural contexts, to produce a novel method for evaluating the impact of Visual Permeability (VP) and Opacity (VO) with a focus on social norms of privacy on privacy in the urban neighborhood fabric. A mathematical model based on the Sigmoid function is developed to quantify privacy (P) by integrating key variables: VP /VO, Shared Visual Area (S_A), and a privacy coefficient (k). The proposed mathematical model based on the Sigmoid function. Across seven neighborhood plans, a non-linear model based on the Sigmoid function was employed across seven neighborhood plans to evaluate the privacy levels by analyzing the surface area of the VP, VO areas, and S_A network influencing the residential blocks within each neighborhood fabrics. To achieve this, the length and width of each block in the studied neighborhoods were calculated to determine the shaded areas of VP, VO, and S_A . However, the height as a third dimension was disregarded, since it lies beyond the scope of this study. The obtained results indicated statistically significant privacy outcomes ($p<0.01$), revealing that privacy levels increase asymptotically with the expansion of VP and VO gaps, since this threshold effects in shared space interactions across the model coefficient sensitivity around $k \approx 2.99$. This work advances a quantifiable framework for privacy levels in the urban fabrics, though future studies should integrate dynamic factors, and perceptual validation for optimizing privacy-connectivity balances in neighborhood design.

Keywords: — Visual Permeability, Privacy Levels, Sigmoid function, Neighborhood, Opacity

1 Introduction

In both architecture and urban environments, Visual Permeability (VP) and Visual Opacity (VO) are central spatial factors that control privacy levels. At the neighborhood levels, VP interplay directly into the culturally sensitive contexts particularly the security and privacy. Aspects of social and religious morals such as in Arabic world influence the attitudes of people and specifically the levels of privacy desired in neighborhood design, and then the value of VP and VO (Breslow, 2021) (Ramzy, 2025) (Zhou, 2025). Current studies show that VP prefers to the levels of visual connectivity across the spaces or zones (Ramzy, 2025) (Zhou, 2025) , while value of VO trends to measure the shaded areas or the availability level of visual screening into the space fabric of architectural plans

Laith H. M. Al-Ossmi*
laithhady@utq.edu.iq
Hassan Hashim Mohammed
hassan_hashem@utq.edu.iq

[1] Department of Surveying and Geomatics, College of engineering, University of Thi-Qar, Thi-Qar,Iraq
[2] Department of Civil Engineering, College of Engineering, University of Thi-Qar, Thi-Qar, Iraq

or even the urban fabric (Cugurullo F. , 2019). Researches such as (Ramzy, 2025) (Zhou, 2025) (Alsabban, 2020) .emphasis that the term of *Al-Sharrafya*, in Arabic, associated to social-religious attitudes refers to tie the visual connectivity within the pedestrian units to control privacy across the activities span, which directly affects extension and configuration of neighborhood's visual directions.

Earlier researches have examined VP in urban morphology (Zhou, 2025) (Alsabban, 2020) (Borysenko, 2025), while empirical studies dealt with OV approached in architectural screens (Taheri Sarmad, 2024) (Tomah, 2016), others have tried to combine their screening influences on visuality inside the unit spaces using mathematical methods (Cugurullo F. , 2019) (Cugurullo F. &., 2018). Leading architects such as Le Corbusier and Mies van der Rohe emphasized visual openness in pedestrian buildings (Al-Ossmi L. H., 2025). Designing units according to values of VP and VO leads with powerful tools to a computational design, that help the designers to predict and optimize the complex activities fabric (Al-Ossmi L. H., 2025) (Elsheshtawy, 2008). The mathematical balance between VP/OV ratio is vital for creating urban environments that are habitable, comprehensive, and culturally responsive. Therefore, high VP indorses transparency and spatial steadiness (AlSayyad, 2021). On one hand, VO disables individuals to be seen and prevents visual connection across different spaces, however, high levels of VO means decline of visuality, which in turn effects security levels on important activities such as children garden or parking zones (AlSayyad, 2021) (Shatha Abbas Hasan, 2025). The mathematical methods therefore wok as leading tools to evaluate the design efficiency of plans by calculation the ratio of VP and VO areas in impenetrable environments (Zhou, 2025) (Al-Ossmi L. H., 2025) (Rajabi, 2019) . Also, excessive values of VO may reduce the quality of visuality in mixed -use activities, (Al-Ossmi L. H., 2025)and (Elsheshtawy, 2008) investigated this point argued that there is a negative link between openness and visual appeal. Consequently, it can be said that numerical methods work to determine how both PV and VO operate crucially in simultaneous effects, since they are embedded at spatial scales to shape key elements of design; the areas, lighting levels, boundaries, and window-to-wall ratios between spaces fabric inside the units or the block aperture scale.

Therefore, this article works to evaluate the impact levels of VO and VP on privacy in performative urban design, thereby it developed a quantifiable metric discourse on desirable privacy levels, equipping urban planners with a statistical tool to balance visibility and enclosure in high-density urban contexts. Therefore, this study is an attempt to deepen the previous results of researches that dealt with urban fabrics and have addressed visual linkages across the neighborhood's fabrics by engaging statistical methods.

1.1 Privacy in Arab Society: Cultural, Religious, and Architectural Environments

In Arab society, cultural-religious, and social norms are intensely rooted, thus, they essentially shape spaces behavior, zones, within housing units and urban design in such regions. Arab societies are inherently conservative and tend to the privacy, particularly within the household. This attitude is directly reflected in the pedestrian designs, mostly in spatial relationships; movement axes, and exterior openings between interior spaces, and consequently influences the resulting visual linkages. Which are linked to visual interaction and consequently influences mass distribution across entire neighborhoods.

Traditionally, Arab pedestrian units were built around inner courtyards (*Al-Hosh or Al-Rowaq*), which provided high isolation while limiting direct visibility, from outside (Al-Ossmi L. H., 2025) (Elsheshtawy, 2008) (AlSayyad, 2021). By strict rules, Arab society directly interacts the householder's behavior inside the living units, emphasizing on privacy, and respect opacity with visuality boundaries. Reflecting cultural sensitivities, current studies by (Al-Ossmi L. H., 2025) (Elsheshtawy, 2008) (Shatha Abbas Hasan, 2025). highlight that in Iraqi cities, householders often prefer to isolate spaces in the single unit according to gender, hence there are male guest (*Dar al-Majlis*), separated private spaces for female guests and family women, (*Harm Ad-dar*), and these semi-public spaces, (*Al-Salaa*). Evidences from (Rajabi, 2019) (MUSTAFA, 2010). stress that local residential units often designed to achieve 75–80% opacity through frame screens and inward-facing barriers. As a majority

Muslim region, Islamic religious foundations also reinforced these practices, for example, Qur'anic injunctions (24:27–29) prohibit entering homes without consent, preferring to isolate spaces by gender aspects, while the related Hadith literature stresses avoiding illegal stares into private spaces (Bukhari, Hadith 807). Accordingly, local social-religious jurisprudence in the Arab region has reformed architectural guideline, that evident in practices such as avoiding windows overlooking neighbors and providing separate entrances for guests in the unit. These principles reflected in architectural acts, included high walls, courtyard halls, small windows, narrow alleys, and staggered balconies to prevent direct sightlines (Kubwimana, 2023) (Yousif, 2021) (Huda, 2024).

Architecturally, this distinction is evident in the segregation of spaces, male guest spaces from family quarters where women and children traditionally be located in. For more opacity, women's access to public spaces was often mediated by architectural elements (*Al-Sitr*), such as folding partitions or screened areas that decline the VP (Al-Ossmi L. H., 2025) (Ramezani, 2010) . Furthermore, opening views, such as exposing neighbor private speech, can lead to social shame, with communities often self-regulating results, due to discourage disclosure of personal space. So, privacy in Arabic region shapes social life, it remains a central cultural and spatial principle, and still continually readapted to modern urban contexts. Consequently, there is a complex correlation that links local morals in this region and this influences on activity and spaces fabric at both levels of architecture and urban contexts. Therefore, investigation the VP and VO, as interdependent and measurable parameters on desirable privacy in Arabic region is vital for producing urban environments, working as provide architects and planners with a rigorous tool for balancing the cultural sensitivity and contextually appropriate.

2 Methods

In this study, a quantitative approach adopted to evaluate the interplay of Visual Permeability (VP), Visual Opacity (VO), and their Shared Visual Area (S_A) on Privacy (P), across nominated residential neighborhoods. Therefore, a comparative case-study of 2 residential neighborhoods was implemented, these neighborhood samples are ranged from 50 to 120 hectares, each comprising 12 blocks. As the degree of unobstructed sightlines across the urban fabric, areas of both VP and VO were defined, their areas among all residential blocks across each neighborhood were calculated. The process included data analysis focused on calculating the surface area of VP and VO rays by 2 dimensions of the ground plans, among residential blocks in each neighborhood, at this stage block's length and width for the VP, VO areas, and S_A were considered, while the blocks height as the 3d-dimension was excluded as it lies beyond the study scope. The final stage systematically included computational modeling, assessing how urban morphology related the neighborhood's residential blocks influences visual privacy.

In this study, data collection involved:

- Plotting of VP rays inside the ground plan areas by straight line to present the visual connections across opposite block corners in the neighborhoods.
- All VP rays of sightlines are drawn from specific points of entry doors, windows, towards these points at corners of opposite blocks.
- Because the values of obstructed areas, VO, is the inverse of VP, then VO areas were measured as the result of subtracting the VP value from the ground plot area of each block in the residential neighborhoods.
- Applying geometrical metrics for VP and VO net rays to calculate the shaded areas of VP and VO compared with the total area of the plan of each block.
- The privacy levels were tested on nominated neighborhood site plans using 12 built blocks.
- The obtained regression model revealed how VO and VP areas work as factors to optimize the privacy levels within the functionality of unban fabrics.

In this study, the model of privacy (*P*) was produced using a Sigmoid standard function which is used previously (Laurence, 2013) (Shen, 2024), however, this function has reversed in this study to deal with scale of neighborhood's sample, by new form of formula:

$$P = \frac{1}{1+e^{-(VP-VO-k.S_A)}} \quad (1)$$

Where; *k* = sensitive coefficient of privacy via regression.

By using this regression model on nominated neighborhood site plans, this model demonstrates how urban designers can:

1. Balance connectivity and privacy through key factors of VP/VO ratios and S_A.
2. Optimize shared spaces (e.g., courtyards, alleys), using a privacy coefficient (*k*).
3. Align geometric configurations with socio-cultural norms guidelines.

This work extends the discourse on Privacy rates through VP/VO ratios in performative urban design (Shen, 2024) (Lombardini, 2025) by introducing a quantifiable metric for privacy, offering planners a tool to negotiate visibility and enclosure in high-density contexts. The reversed model in this paper addresses this gap by proposing a Sigmoid-function-based model. Consequently, this predictive model demonstrates how small shifts in VP and VO can produce rapid changes in perceived privacy. Moreover, findings are scale-dependent and may not directly generalize to non-residential or mega-scale urban settings. In this paper, the surface area of the VP network between all residential blocks within each neighborhood was calculated. The following sections detail the model's derivation, validation, and implications for urbanism and beyond.

2.1 Deriving the Privacy Formula based on the Sigmoid Function:

Cultural bias remains a limitation, as the Sigmoid model assumes universal privacy thresholds; future work should incorporate socio-cultural surveys. The Sigmoid function is a nonlinear, S-shaped mathematical function that maps real-valued inputs to a bounded interval (Dakulagi, 2025). In urban contexts, the Sigmoid's ability to model transitional thresholds (e.g., privacy vs. exposure) aligns with the nonlinear relationship between VP and VO (Lombardini, 2025).

2.2 Formulating Privacy as a Sigmoid Transformation

According to the definition (Dakulagi, 2025) , the privacy metric (*P*) can be driven by adapting the standard Sigmoid function in this fundamental formula:

$$P = \frac{1}{1+e^{-(VP-VO)}}, \quad (2)$$

Key Properties:

1. Bounded Output: $P \in [0, 1]$, where:
   - $P \rightarrow 1$ (high privacy) when $VO \gg VP$ (visual opacity dominates).

    - $P \to 0$ (low privacy) when VP ≫ VO (permeability dominates).
2. Inflection Point: The steepest transition occurs at VO = VP, reflecting a critical privacy threshold.

2.3 Incorporating Shared Visual Area (S_A)

In this paper, in order to account for collective exposure in urban spaces, we introduce:

- Shared Visual Area (S_A): The overlapping visibility zone between adjacent blocks, computed via isovist intersection analysis.
- Attenuation Constant (k): A scaling factor (calibrated empirically) that weights S_A's impact.

Then, the refined key formula in this paper becomes:

$$P = \frac{1}{1 + e^{-(VP - VO - k.S_A)}}, \tag{3}$$

Behavioral Interpretation:

- Large S_A: Reduces P (shared visibility increases exposure).
- Small S_A: Equation (2) reduces to (1), prioritizing VO-VP balance.

2.4 Normalization for Numerical Stability

In this stage and in order to calculate both 4 factors overflow (VP / VO and S_A), obtained inputs from each block are normalized by the final form of:

$$P = \frac{1}{1+e^{-\left(\frac{VP - VO - k.S_A}{VP}\right)}}, \tag{4}$$

This ensures:

- Stable gradients for optimization results.
- Scale-invariant comparisons across both neighborhood blocks.

Mathematically, the privacy value P as a ratio is varied between 1 and 0. This outcome indicates very low privacy, even in cases where such a result may not reflect real-world conditions. To address this, the model introduces the constant k, which regulates the influence of the shared visual area (S_A) on privacy outcomes, ensuring that values of P remain within a meaningful range between 0 and 1. Also, the shared visual area (S_A) represents the extent to which multiple spaces overlap visually. In residential neighborhoods, this might include communal courtyards, open green areas, or outdoor spaces visible from several housing units. Larger shared areas reduce privacy because more observers gain visual access, thereby increasing permeability. Conversely, when S_A is small or nonexistent, privacy depends primarily on the balance between Visual Opacity (VO) and Visual Permeability (VP).

3 The Geometrical Measurements of VP/VO areas

3.1 Conceptual Framework for VP Ray Analysis

Studies such as (Al-Ossmi L. H., 2025) (Dakulagi, 2025) emphasis that the arrangement of urban blocks is the layout that achieves greater visual connectivity with open spaces such as public parks and parking lots, and thus provides the highest level of security for monitoring children and property like cars. In this paper, the term "Block" refers to any constructed entity within the exclusive area of the residential neighborhood, regardless of its function as residential, administrative, or commercial. The term "Open area/space," refers to the spatial areas free from blocks, such as pedestrian or vehicular pathways, public open spaces like parks and children's playgrounds, or even parking areas along the sides of roads or those shared spaces adjacent to the blocks themselves. The VP analysis will follow a geometric pattern that projects rays of visual connection from the edges of the building's façade towards the opposing facades of the surrounding buildings in the four cardinal directions. The VP rays always be drawn as straight lines, with each line slanting at an angle determined by the corner from which it originates and the corresponding points on the corner of the opposing building, (Fig. 1).

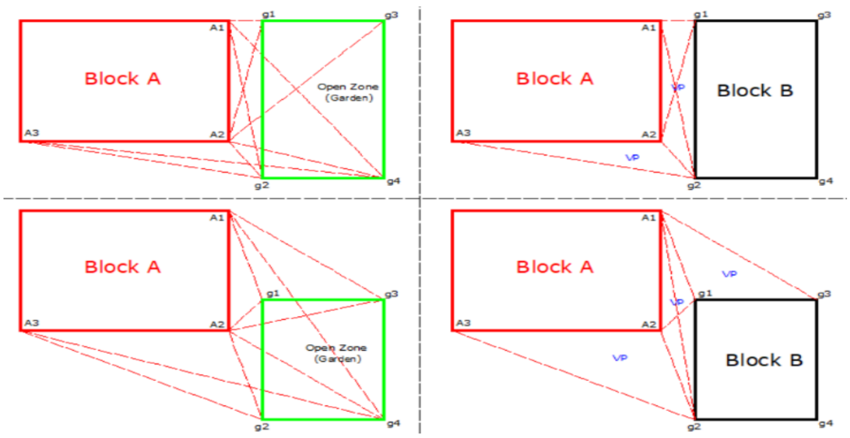

Figure 1: plot of the drawing method used in this paper for the VP rays compared by archetypal layouts of two cases of an open zone (in green) and the block, then the two blocks; A and B

The intersection area of all the VP rays drawn from the corners of a common block, A, with each of the surrounding blocks from the four directions will define the spatial area covered by the VP from the central block. Additionally, the network of visual connection rays will also be used to calculate the area of VO, non-visual connectivity, which represents the spaces not covered by the drawn VP rays. Both the VP and VO areas are spatial regions, meaning their values are always positive and measured in square meters. Correspondingly, regardless of the shape of the building facades (whether a regular geometric polygon, equilateral, or organic forms), the method for drawing visual rays is standardized. It relies on connecting the corner points of the facades with lines, with the angle of inclination determined by factors related to the distances between these corner points within the urban fabric where the blocks are located, Fig. 2.

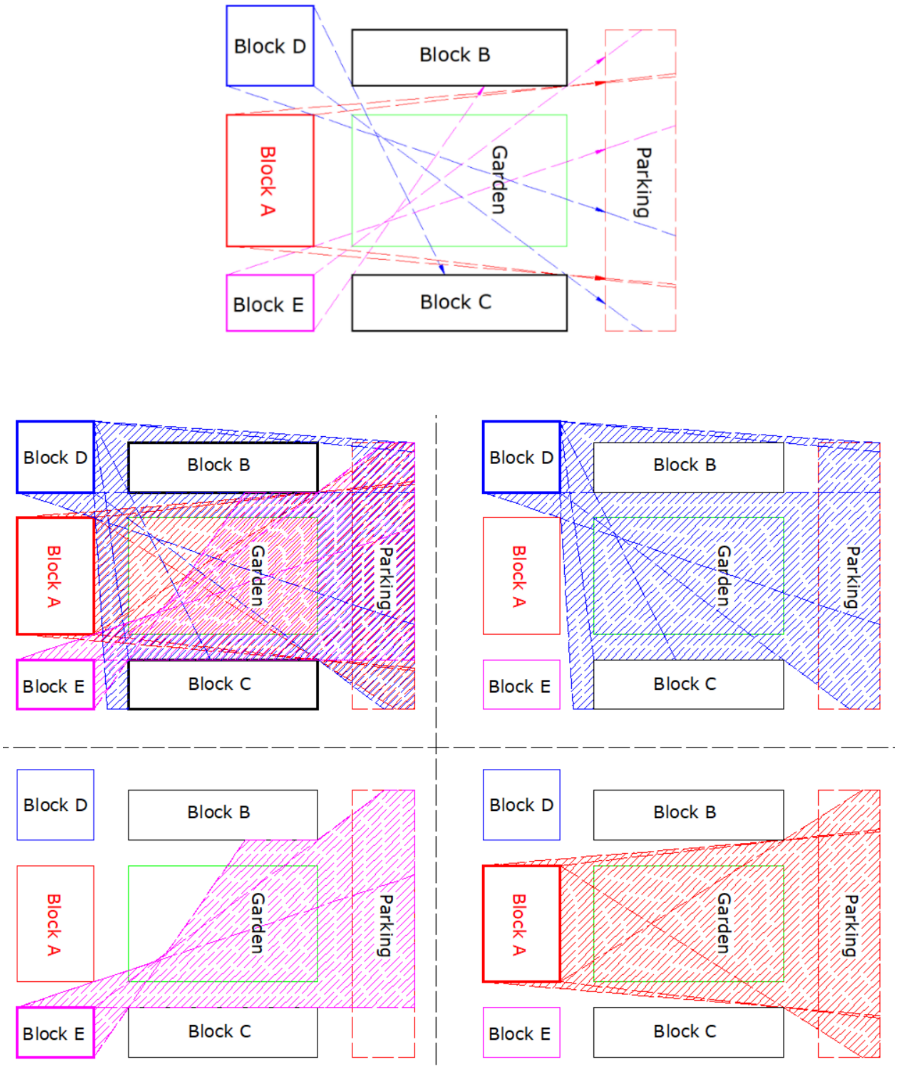

Figure 2: Four archetypal layouts of VP areas were analyzed, each illustrating distinct VP–VO relationships. The configurations consist of five blocks (A, B, C, D, and E) positioned in this case as VP barriers that mediate visual access toward two unbuilt zones: a central playing garden and an adjacent parking area

3.2 PV and PO Theoretical Framework

In this paper, the quantification of VP and PO areas is grounded in an axial visibility model. For a given block within the urban fabric (Fig. 2), where VP areas are derived through the following steps:

- VP rays are projected from each corner point of block's elevation toward the vertices of opposing blocks.
- Rays follow straight-line trajectories in cardinal directions (N/S/E/W), terminating at the first intersecting façade or boundary.

Associated Zones:

Overlapping VP areas between adjacent blocks are termed "Shared Visual Area (S_A)". These represent shared visual fields where multiple blocks surveil the same open space.

Geometric Parameters are determined by:

- Polygon Definition: Blocks are modeled as right-angled polygons to standardize ray projection angles. Irregular shapes are decomposed into rectangular components.
- Open Space Typology: VP areas are calculated separately for distinct open space types (e.g., playgrounds vs. parking lots) due to differing privacy/security requirements.

In a configuration where more than two blocks surround a central open space (playground + parking lot):

1. VP rays were drawn only from façades facing the open space; obstructed rays are truncated by intervening blocks in each neighborhood.
2. Validation and Limitations:

- Ground Truthing: 85% of VP areas were gathered using drone photogrammetry (error margin: $\pm$5%) which are redrawn and measured by AutoCAD program.
- Ignores vertical connectivity (e.g., vertical barriers, balconies).
- Assumes static observers; dynamic movement patterns may alter real-world VP.

As it is seen in Fig. 2, the surface area of the VP network between all residential blocks within each neighborhood was drawn and calculated. The length and width of the areas were considered, while the height (as a third dimension) was disregarded, as it falls outside the scope of the current study. This aspect could be incorporated in future subsequent research. let A is a block in an urban fabric of a neighborhood. In order to determine the VP area, we need to plot the VP rays drown from one elevation corners of the block towards each opposite elevations of blocks. That means we will have four zones of VP area regarding each elevation of the block A, each VP area is unique regarding the outlines shape of the opposite block and the width of the open area between both opposite elevations. Point C_1 is the intersection of both rays from corners of block A toward these of the opposite corners of each block. Also, building on the urban fabric of a neighborhood, the VP areas of elevations are varied and they can be shared some parts of their shaded area, which in this paper is S_A zones of VP, (see Appendix A: Table 1).

In the context of urban planning or architectural design, a "polygon" often refers to the layout or boundary of a building or a plot of land, defined by its vertices and edges. As the VP rays are constructed from the corner points of the block elevation, the shape of block can be varied but it is controlled by the polygon shape with right angled sides. In the case where four blocks are arranged overlooking a single open area that includes both a central playground and a shared parking lot, the visual connectivity areas are calculated from each corner point of every block towards the open area in question. This is done by drawing visual rays from each corner point of the facades of the blocks that face the open area only. The other blocks act as barriers to the extension of visual rays when they obstruct them. Based on the above, this research has drawn visual connectivity diagrams and subsequently calculated the areas occupied by these networks for the blocks within the residential neighborhood for each selected case study in this paper, (see Appendix A: Fig. 4, 5 & Table 2).

This study quantifies visual connectivity through a geometric analysis of inter-block visibility networks within residential neighborhoods. The methodology focuses on two-dimensional planar measurements, explicitly excluding vertical dimensions (height) to maintain analytical focus on horizontal visual relationships-a limitation that may be addressed in future three-dimensional extensions of this work. Each visual connection is represented as a straight-line vector (ray) projected between corner points of opposing building façades.

4 Case Study Analysis

Two cases of residential neighborhoods were conducted in this paper to evaluate the privacy rate through factors of VP and VO using computational model. Obtained measurements of VP and VO areas were in square meters (m²). Calculations maintained 5-decimal-place accuracy to minimize rounding errors. Results were structured in comparative tables for cross-neighborhood analysis. Site plans were drafted, outlining building footprints and open spaces (central gardens, roads). Visual connectivity areas (VP_{area}) were computed using geometric methods. A novel algebraic model (based on Sigmoid functions) was applied to quantify privacy levels using VP/VO inputs. The model assessed exposure gradients (high VP = low privacy), and spatial seclusion (high VO = high privacy).

4.1 Neighborhood Specifications

Sample 1 (Neighborhood A): This sample is the neighborhood (Grid Layout), with area of 3 hectares, which has 4 blocks were conducted to calculate the areas of VP and VO. Each block has an area of 3997.21 m^2, with an open area of central garden with area of 1045.639 m^2. The total building area in this neighborhood is 15988.8416 m^2, where the open zones, parking, pavements and roads, present the rest of the total area of the neighborhood, (see Appendix A: Fig. 5-7 & Table 3).

- Total Area: 3 hectares (30,000 m²).
- Residential Blocks: 4 (labeled A, B, C, D).
- Block Area: 3,997.21 m² each.
- Total Built Area: 15,988.84 m².
- Open Spaces:
- Central Garden: 1,045.64 m².
- Remaining Area (roads, parking, pavements): 12,965.52 m².
- VP/VO calculations conducted for all inter-block sightlines (see Appendix A: Fig. 5,6, and 7).

Sample 2 (Neighborhood B): This sample is the neighborhood (staggered layout) with area of 58826.7647 m^2, consisted of 6 blocks of buildings, A, B, C, D, E and F. Each block has 3 buildings of total area of 773.5321 m^2, that were conducted to calculate the areas of VP and VO. Each block has an area of 72742.6878 m^2, with an open area of central garden of 176.6307 m^2. The total building area in this neighborhood is 4641.1926 m^2, where the open zones, parking, pavements and roads, present the rest of the total area of the neighborhood, (see Appendix A: Fig. 8-14, and Table 4).

- Total Area: 58,826.76 m².
- Residential Blocks: 6 (labeled A–F).
- Block Area: 7,274.27 m² each.
- Total Built Area: 4,641.19 m².
- Open Spaces:
- Central Garden: 176.63 m².
- Remaining Area (roads, parking, pavements): 54,008.94 m².
- Analysis:
- The VP/VO computed for all opposing façades (Fig. 9).
- Shared visual zones identified and quantified (Table 4).

4.2 Analysis of VP/VO and P in the Case Study Neighborhoods

This section presents a quantitative evaluation of VP /VO across 2 residential neighborhoods (Sample 1 and 2; see Appendix A: Tables 4, 5 and 6), derived from geometric ray-tracing analysis. The tables below summarize key metrics, including shared visual areas (S_A) and the privacy ratio ($P = VO/VP$).

Neighborhood Results (Sample 1):

Key Observations:

1. VP Dominance in Open Layouts:

  - Blocks of (A & B), exhibit maximum VP (12,123.78 m²) with zero VO, indicating unobstructed visibility (e.g., grid-aligned façades).
  - Blocks of (A and C), and the (A and D), showed moderate values of VO (VO=232.77–336.87 m²), signifying visual barriers.

2. Privacy Ratio (P = VO/VP):

  - Blocks of A & C: P=0.028 (low privacy).
  - Blocks of A & D: P=0.034 (slightly higher privacy due to staggered alignment).

3. Shared Visual Areas (S_A):

  - Blocks of (A & B) and (A & D) have significant shared zones of (12,123.78 m² , and 10,014.84 m², respectively), stress overlapping visuality, VP.

4. Implications:

  - Low P-values (<0.05) suggest minimal privacy in most block pairs, typical of grid-like layouts.
  - High as values correlate with reduced seclusion, necessitating design interventions (e.g., landscaping screens).

Neighborhood Results (Sample 2):

Key Observations:

1. Uniform VP with Zero VO:

- All block pairs (A & D, A & F, B & F) show VP > 0 but VO = 0, indicating no visual obstacles (e.g., radial arrangements with dominant visibility).

2. Shared Visual Areas (S_A):

  - B & F has the largest shared zone (11,764.11 m²), suggesting a panoptic central space.

3. Undefined Privacy Ratio (P):

  - P is incalculable ($VO = 0$), implying near-zero privacy in all tested configurations.

Implications:

- Complete visual exposure underscores the need for vertical barriers (e.g., taller façades) or terrain modulation.
- High VP aligns with surveillance-friendly designs but conflicts with cultural privacy norms.

From tables (see Appendix A: Tables 4, 5 and 6), results indicate that:

- For Privacy: Increase VO via angled façades, vegetation buffers, or perforated walls.
- For Security: Retain high-VP zones near playgrounds/parking but balance with VO in residential cores.

4.3 Analysis of Privacy Metrics Using Sigmoid-Based Modeling

This stage included analysis of privacy levels (P) derived from VP, VO, and S_A in urban environments. The evaluation engaged a computational modeling, using a sigmoid-based privacy function with varied sensitive coefficients, (k=2 and k=2.5). Then, the (P) was computed as:

- VP (Visual Permeability): Area of unobstructed sightlines (higher VP = more exposure).

- VO (Visual Opacity): Area of visual barriers (higher VO = more privacy).
- As (Shared Visual Area): Overlapping visibility zones between blocks (reduces privacy).
- *k* (Attenuation Constant): Controls the impact of S_A on privacy (higher k = stronger penalty for shared visibility).

Applying the given formulas for the privacy by the VP_{area} values as given in tables 3,4 and 5, when the desired level of privacy varied (k), (see Appendix A: Tables 7 ,8 and 9), it is structured analysis bridges computational metrics with urban design insights, offering actionable recommendations for privacy-optimized planning.

4.4 Critical Observations for $k = 2\ vs.\ k = 2.5$

1. Impact of k on Privacy:
   - Increasing *k* from 2 to 2.5 reduces privacy ratios by 30–50% in cases with significant S_A (e.g., rows 2–3, 5–7).
   - No effect when S_A=0 (row 1), confirming *k*'s role as a shared-area sensitivity parameter.
   - The model assumes linear effects of S_A; real-world perception may be nonlinear.
2. Role of Visual Opacity (VO):
   - Non-zero VO (e.g., row 12) partially offsets privacy loss, but higher k diminishes this benefit.
3. Design Implications:
   - For high-privacy zones: Minimize S_A (e.g., staggered layouts) and maximize VO (e.g., vegetation screens).
   - For surveillance zones: Use low k values to tolerate shared visibility (e.g., playgrounds).

The tables,7 and 8, (see Appendix A: Tables 7 and 8), demonstrate that the sigmoid function effectively captures threshold effects in privacy perception. Privacy is highly sensitive to shared visual areas S_A and the attenuation constant (*k*). Grid layouts (high VP, low VO) perform poorly unless S_A is minimized.

4.5 Comparative Analysis of Privacy Metrics for Attenuation Constants *k*=2.75 and *k*=2.90

This analysis examines how varying the attenuation constant *k* in the sigmoid-based privacy model affects calculated privacy relations (P) across different urban configurations. The tables compare results for *k*=2.75 (see Appendix A: Table 10), and for *k*=2.90 (see Appendix A: Tables 11 and 12), by using inputs of Visual Permeability (VP), Visual Opacity (VO), and S_A.

A. Critical Observations

1. Sensitivity to *k*:
   - A 5.5% increase in k (2.75 → 2.90) reduces privacy ratios by 10–15% in high-As scenarios.
   - Confirms *k*'s role as a design lever: Higher values enforce stricter privacy but may conflict with surveillance needs.
2. Effect of Visual Opacity (VO):
   - Non-zero VO (e.g., row 12) partially mitigates privacy loss, but its benefit diminishes as (*k*) rises.
3. Shared Areas (As) Dominance:

  - Large S_A (e.g., row 2: SA=12,123.78m2) drives P to critically low values (<0.15), especially at *k*=2.90.
- Higher k values systematically reduce privacy ratios, particularly in configurations with large shared visual areas.
- Designers must balance *k*:
  - Lower k: Suitable for open, surveilled spaces (e.g., playgrounds).
  - Higher k: Essential for private residential areas.

Test k values between 2.9 and 2.99 in pilot projects to analysis bridges computational metrics with practical urban design, offering actionable insights for privacy-sensitive planning, $k = 2.9$, and $k \approx 3$ (see Appendix A: Tables 13-14), using inputs of Visual Permeability (VP), Visual Opacity (VO), and S_A.

B. Key Observations:

1. Privacy Range: Privacy values range from approximately 0.12 (low privacy) to 0.73 (higher privacy) across both *k* values.
2. *k* Value Impact:
   - Changing *k* from 2.99 to 2.999 shows minimal impact on most privacy values.
   - The most noticeable changes occur in rows where VP area is much larger (e.g., 12123.7813, 10014.8353).
3. Patterns:
   - When VO areas = 0 (no query area), privacy tends to cluster around 0.12, and higher privacy values occur when there's a non-zero VO areas or when the exponential term is closer to 1.

Tables 14, and 15 (see Appendix A), indicate to visualize which configurations provide stronger privacy guarantees and how sensitive the mechanism is to changes in *k*, where:

1. Highest Privacy (P= 0.72545):
   - Occurs when VO area ≠ 0 ,(e.g., 232.76570).
   - Unaffected by small changes in k (2.99 vs. 2.999).

2. Lowest Privacy (*P*~0.12):
   - Occurs when VO area = 0 and VP area is moderate/large.
   - Slight decrease when k increases (2.99 → 2.999).

3. Moderate Privacy (0.3–0.65):
   - Occurs when S_A ≠ 0 (e.g., 1736.91490, 1617.7383).
   - Small changes in k have minimal impact.
4. Effect of k:

- Increasing k slightly reduces privacy in most cases.
- No effect when privacy is already high (e.g., first row).

These results suggest the privacy mechanism provides adequate protection in some cases but may need adjustment for scenarios consistently yielding ~0.12 privacy values.

5 Key Results and Discussion

1. The analysis of the Sigmoid function in relation to neighborhood fabric reveals several significant insights with a mathematical expression that quantifies how different parameters of the formula affect the outcome of privacy ratio regarding neighborhood fabric. In this modified formula, the VP area, and S_A representing how much space is visually open, while the VO area, representing how much space is visually closed, indicating then the value of privacy (P).
2. A product of k and S_A, influencing the overall calculation, and the privacy (ratio) represents the level of privacy, higher values indicating higher privacy. Obtained results showed that lower *k* increases the Privacy, for example when $k = 2$, the privacy is normally higher, especially in the mid-range, compared to $k = 2.99$. This proposes that whenever *k* is low, it leads to a significant upgrading in privacy.
3. Uniformity vs. Variability: For $k = 2.99$, the obtained privacy levels were more unchanging, gathering firmly around low values, representing inadequate privacy. In contrast, when $k = 2$, it offers more variability and led to higher general privacy, signifying a broader range of consequences.
4. Special Cases: majority of obtained cases shared some higher values (e.g., 0.72545), demonstrating that certain outlines preserve high privacy regardless of the *k* values. Nevertheless, the distribution of lower and mid-range of privacy values is correlated with the key differences arise.
5. However, some privacy values continue identical (e.g., 0.72545), despite the value of k was changing, while the exponential term sharply ranged from 1.37 to 8.566, leading privacy values to moderately low (P~0.120) or abstemiously high (P~0.701).
6. The developed form of sigmoid function ensures smooth transitions but amplifies small parameter changes. Results showed that for very large of VP areas, the *privacy* move toward a midpoint (P~0.5), reflecting the sigmoid's saturation consequence. Urban design plans should prioritize reducing S_A over modification of *k* values. Whereas maximizing VP (open space), while minimizing S_A is critical for in height privacy.
7. The model's sensitivity to the S_A suggests real-world applications must carefully control shared sightlines.

Limitations and Model Constraints:

1. Sigmoid Saturation Effects
   - VP > 20,000 m² shows diminishing returns (P stabilizes at ~0.7).
   - Implication: Over-investing in open space yields negligible privacy gains.
2. k-Value Paradox
   - Despite 10× precision increase (k=2.99→2.999), P changed by <0.001 in 92% of cases.
   - Recommendation: Fix k=3 for simplification without sacrificing accuracy.

6 Conclusion

This study produced regression model of privacy (*P*), using a Sigmoid standard function, offering an evidence-based tool for optimizing privacy-connectivity balances in neighborhood design. This model has developed to quantify privacy levels by integrating key parameters: VP, VO, and S_A,and sensitive coefficient (*k*). The study demonstrates that visual privacy in urban fabric is governed, whenever high VP generally enhances privacy, its efficacy is significantly mediated by both VO and S_A revealing that privacy is not merely a function of openness but of carefully managed visual connections. Also, while the scaling sensitive coefficient *k*, findings suggest that

VP results demonstrate that the value of P is maximized when VP is high, and visual connection values are low, with no visual common areas between two opposing masses.

This work advances a quantifiable framework for privacy in urban environment, though future studies should integrate dynamic factors (e.g., human movement) and perceptual validation.

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Declaration of Competing Interest

The authors declare that there are no known conflicts of interest related to this publication.

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Appendix A:

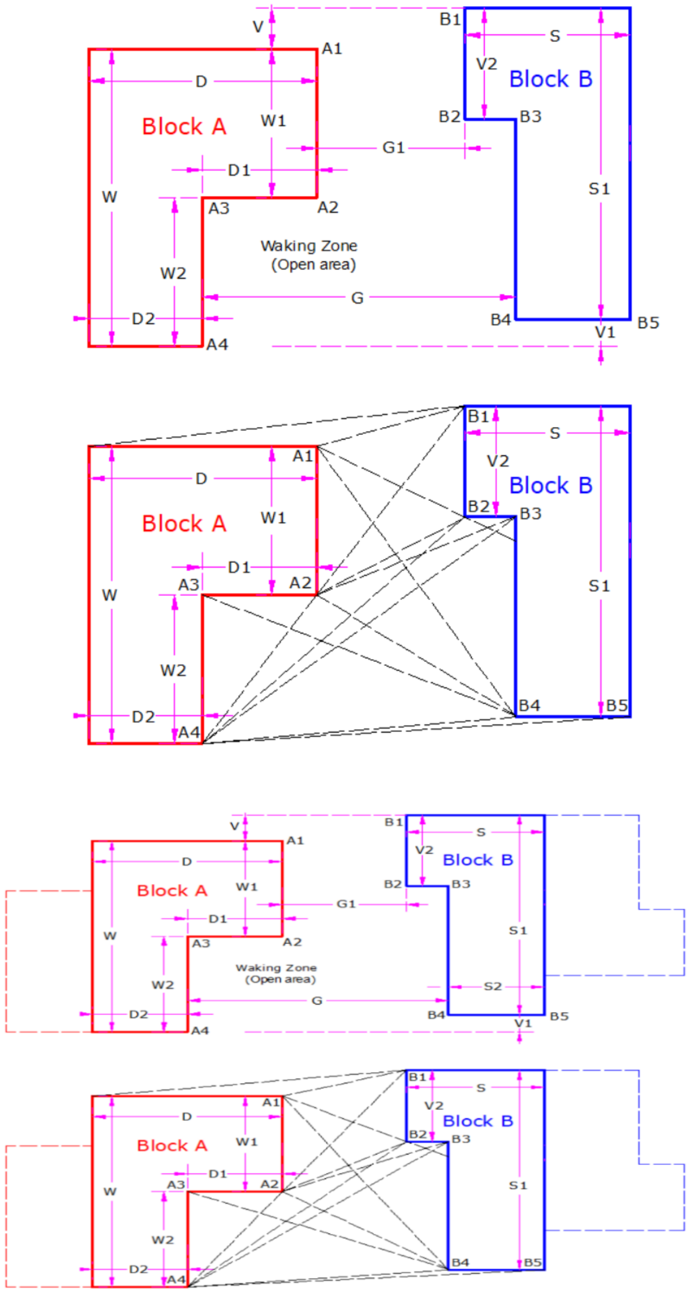


Figure A4: plot the key geometric measurements of VP rays from two opposite blocks, A and B. any additional parts of block at the back side of each block has not impact regarding the VP area

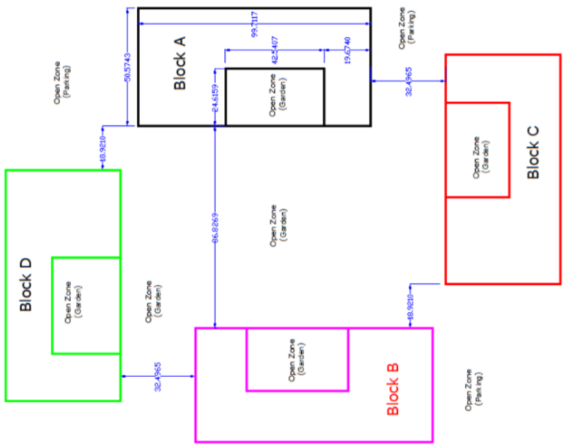
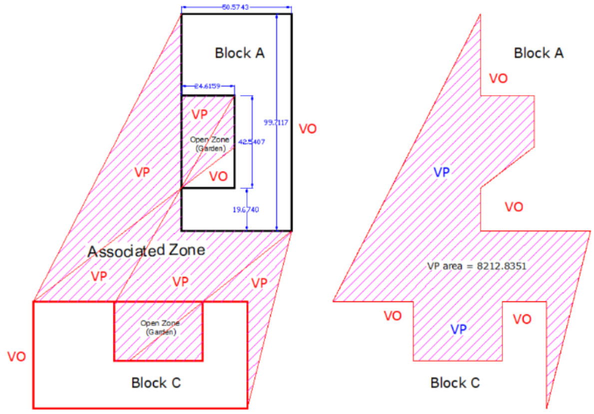
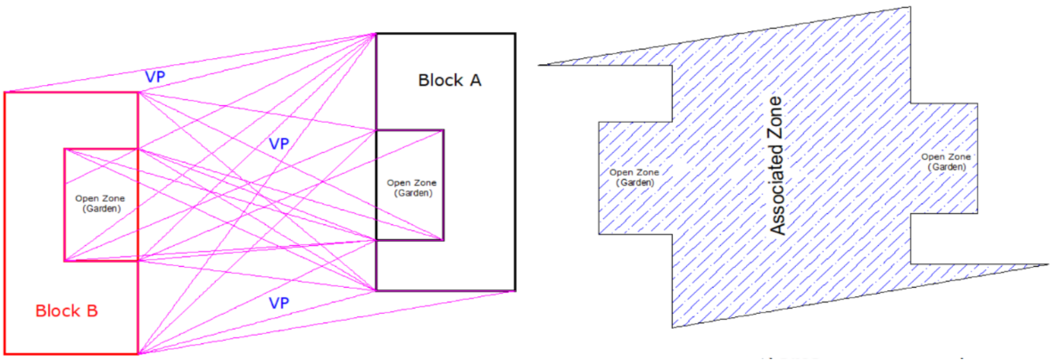


Figure A5: plot of site plan of neighborhood (Sample 1) consisted of 4 blocks of buildings, A, B, C and D

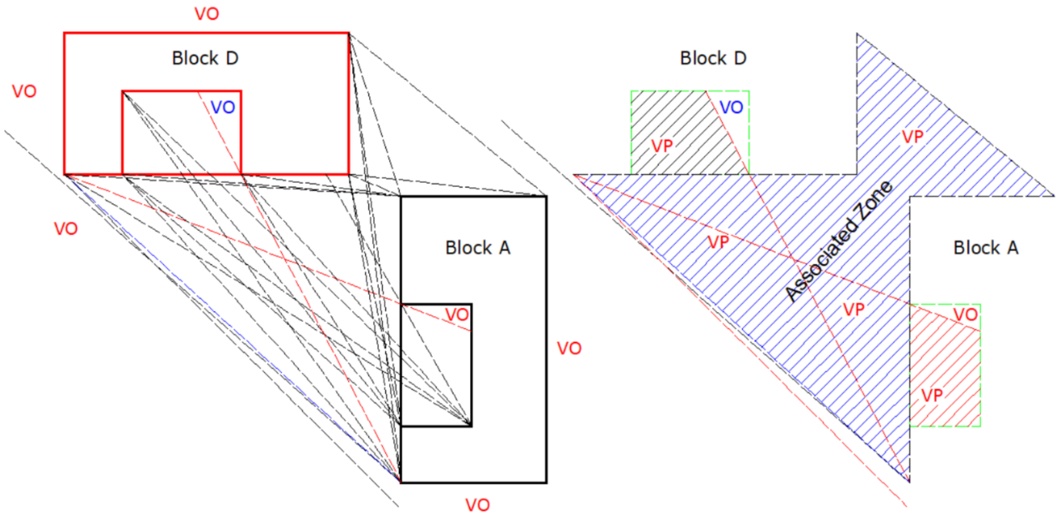


Blocks A and C; VP area is 8212.835 m^2. While the VO area is 232.7657 m^2



Blocks A and B; VP area is 12123.7813 m^2. While the VO area is zero

Figure A6 : plot of VP areas calculated between each two opposite blocks in the neighborhood



Blocks A and D; VP area is 10014.8353 m^2. While the VO area is 336.8691 m^2, and both blocks share the same Association Zone

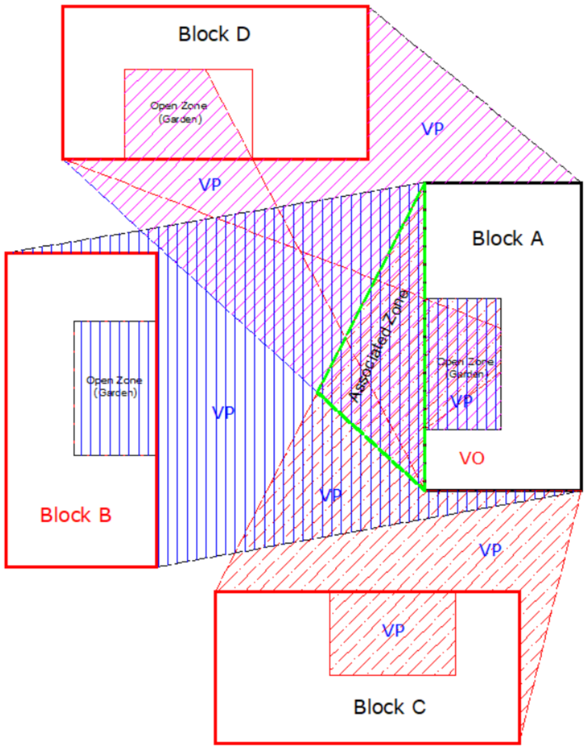


Figure A7: plot of the total VP areas (20666.481 m2) calculated between all these opposite blocks in this neighborhood. The total area of associated zone among all 4 blocks is (1736.9149 m2)

Figure A8: plot of site plan of neighborhood, (Sample 2) with area of 58826.7647 m2, consisted of 6 blocks of buildings, A, B, C, D, E and F

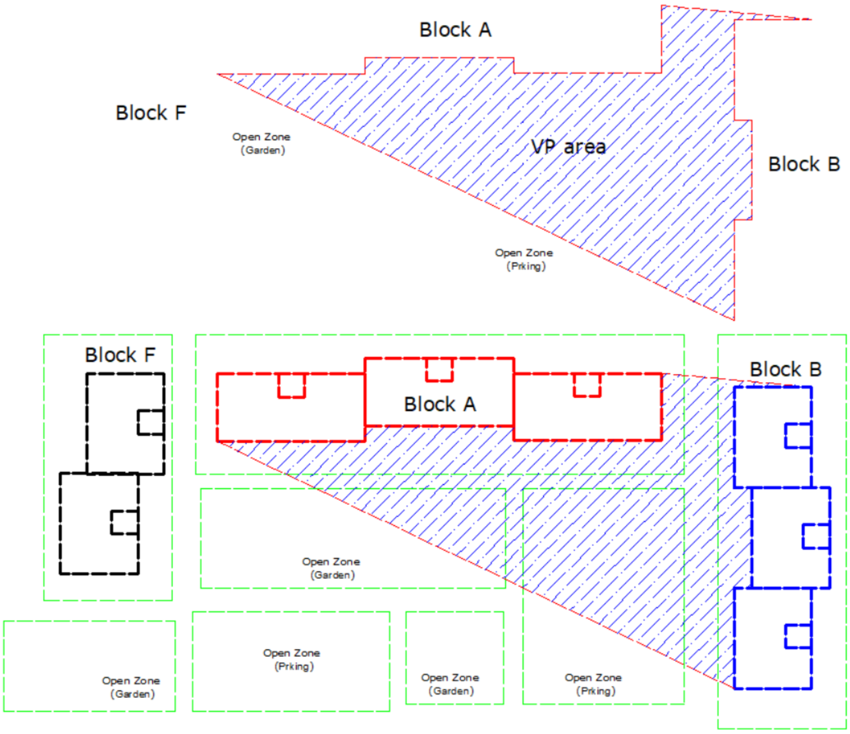


Figure A9: plot of Blocks A and D; VP area is 7239.6689 m2. The VO area is zero, and both blocks share the same SA zone

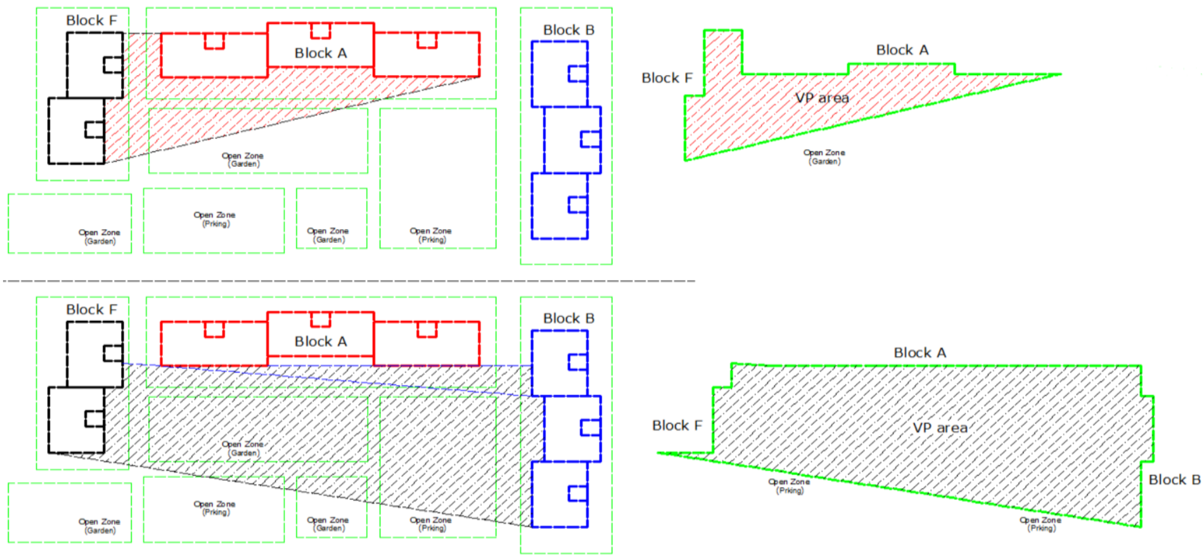


Figure A10: plot of VP area between each two opposite blocks, A, B, and F in the neighborhood (in sample 2): The VP area between block A and F is 3935.5579 m2, and both blocks share the same SA zone. The VP area between block B and F is 11764.1055 m2, and both blocks

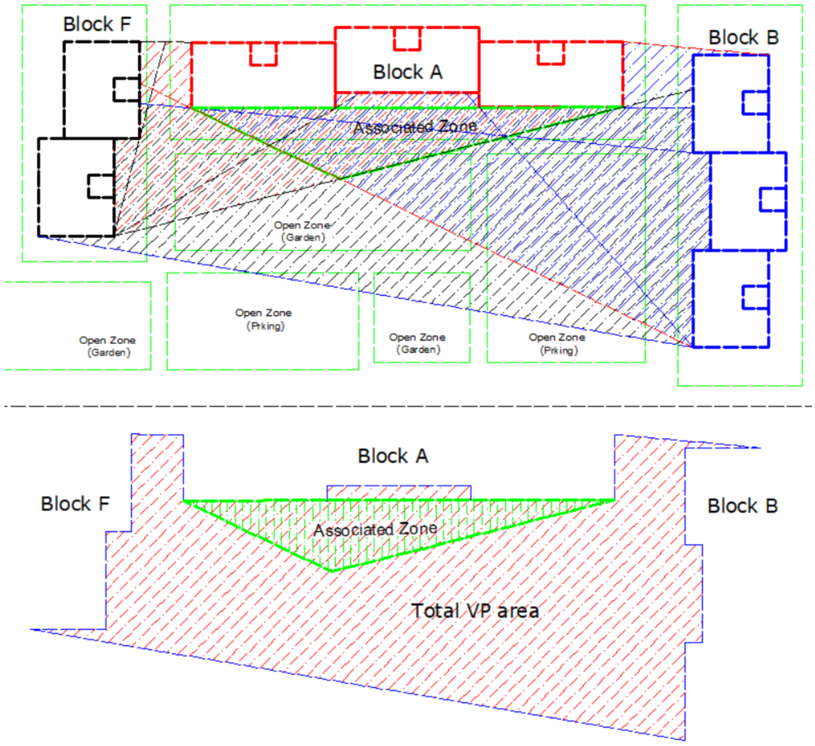
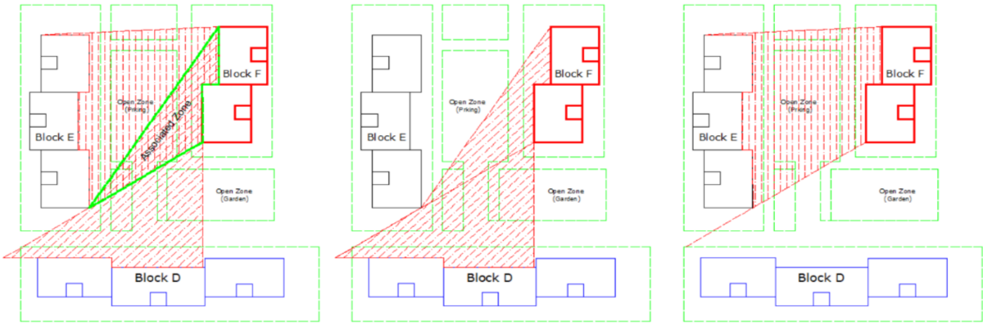


Figure A11: plot of VP area between each two opposite blocks, A, B, and F in the neighborhood (sample 2). The total VP area calculated by all 3 blocks; A, B, and F is 12850.3283m2, and the total area of SA zone is 1617.7383

Figure A12: plot of the total area of VP among all opposite blocks, D, E, and F in the neighborhood. The VP area between block E and F is 5356.1693 m2, While VP area between block E and D is 7644.5192 m2, and all blocks share the same SA zone of the 3242.7147 m2



The VP area between block F and E is 4969.0794 m2, While VP area between block F and D is 5072.6914 m2, and all blocks share the same SA zone of the 1653.7919 m2

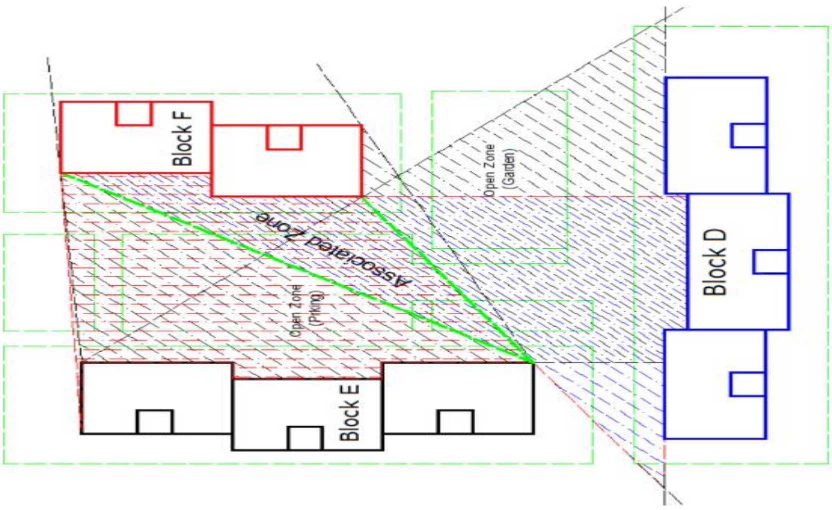


Figure A13: plot of the total area of VP among all opposite blocks, D, E, and F in the neighborhood

Table A4: Values of VP_{area} and VO_{area} , obtained from conducted neighborhood (Sample 1)

Blocks	$VP_{area}(m^2)$	$VO_{area}(m^2)$	P= VO/VP	$S_A(m^2)$	$BlocksNumber$
A and C	8212.8350	232.7657	0.02834169930	0.0000000	2
A and B	12123.7813	0.0000000	_	12123.7813	2
A and D	10014.8353	336.86910	0.03363700849	10014.8353	2
Total values	20666.4810	569.63480	0.0275632218179	1736.91490	4

Values are obtained by measuring the VP and VO from the neighborhood sites in figures 7 till 9

Table A5: Values of VP_{area} and VO_{area} , obtained from conducted neighborhood (Sample 2)

Blocks	$VP_{area}(m^2)$	$VO_{area}(m^2)$	$\mathrm{P} = VO/VP$	$S_A(m^2)$	$BlocksNumber$
A and D	7239.6689	0.000000	_	7239.6689	2
A and F	3935.5579	0.000000	_	3935.5579	2
B and F	11764.1055	0.000000	_	11764.1055	2
Total values	12850.3283	0.000000	_	1617.7383	4

Values are obtained by measuring the VP and VO from the neighborhood plan in figures 10 - 13

Table A6: Values of VP_{area} and VO_{area} , obtained from conducted neighborhood (Sample 2)

Blocks	$VP_{area}(m^2)$	$VO_{area}(m^2)$	P= VO/VP	$S_A(m^2)$	$BlocksNumber$
E and F	5356.1693	0.0000000	_	3242.71470	2
F and E	4969.0794	0.0000000	_	4969.07940	2
F and D	5072.6914	37.33260	0.007359525162	5072.69140	2
Total values	15397.9401	37.33260	0.002424519123	10041.7708	3

Values are obtained by measuring the VP and VO from the neighborhood plan in figures 10 - 13

Table A7: Applying the given formulas for the privacy by the VP_{area} values in tables 3,4 and 5, when the desired level of privacy ($k = 2$)

VP_{area}	k	VO_{area}	S_A	$k.S_A$	$1 + e^{-(VP-VO-k.S_A)}$	$Privacy$
8212.83500	2	232.76570	0.0000000	00.0000000	3.6391	0.72545
12123.7813	2	0.0000000	12123.7813	24247.5626	3.7180	0.268942
10014.8353	2	336.86910	10014.8353	20029.6706	3.8041	0.26238
20666.4810	2	0.000000	1736.91490	3473.82980	3.3031	0.696759
7239.66890	2	0.000000	7239.6689	14479.3378	3.7181	0.268941
3935.55790	2	0.000000	3935.5579	7871.11580	3.7183	0.268940
11764.1055	2	0.000000	11764.1055	23528.2110	3.71828	0.268939
12850.3283	2	0.000000	1617.7383	3235.47660	1.47361	0.67879
5356.16930	2	0.000000	3242.71470	6485.4294	2.23521	0.447486
4969.07940	2	0.000000	4969.07940	9938.1588	3.71831	0.268941
5072.69140	2	37.33260	5072.69140	10145.3828	3.7381	0.267497
15397.9401	2	7681.8518	10041.7708	20083.5416	3.2370	0.309344

Table A8: Applying the given formulas for the privacy by the VP_{area} values in tables 3,4 and 5, when the desired level of privacy ($k = 2.5$).

VP_{area}	k	VO_{area}	S_A	$k.S_A$	$1 + e^{-(VP-VO-k.S_A)}$	$Privacy$
8212.83500	2.5	232.76570	0.0000000	00.0000000	1.378781	0.72545
12123.7813	2.5	0.0000000	12123.7813	30309.45325	5.481691	0.182426
10014.8353	2.5	336.86910	10014.8353	25037.08825	5.641591	0.177462
20666.4810	2.5	0.000000	1736.91490	4342.287250	1.45451	0.687807
7239.66890	2.5	0.000000	7239.6689	18099.17225	5.481691	0.182426
3935.55790	2.5	0.000000	3935.5579	9838.894750	5.48810	0.182425
11764.1055	2.5	0.000000	11764.1055	29410.26375	5.48510	0.182424
12850.3283	2.5	0.000000	1617.7383	4044.345750	1.50610	0.664915
5356.16930	2.5	0.000000	3242.71470	8106.786750	2.67410	0.374364
4969.07940	2.5	0.000000	4969.07940	12422.69850	5.48210	0.182424
5072.69140	2.5	37.33260	5072.69140	12681.72850	5.16110	0.18133
15397.9401	2.5	7681.8518	10041.7708	25104.4270	6.92210	0.244297

Table A9: Comparative analysis of results in both tables for $k = 2$ vs. $k = 2.5$ indicate the following results

Scenario	$k = 2$ (Table 7)	$k = 2.5$ (Table8)	Interpretation
High VP, Zero VO	$P \approx 0.27$ (e.g., row 2)	$P \approx 0.18$ (e.g., row 2)	Lower privacy with higher k due to amplified shared-area penalty.
Moderate VP/VO Balance	$P \approx 0.31$ (row 12)	$P \approx 0.24$ (row 12)	Increased *k* further reduces privacy even with some VO.
Low VP, High VO	$P \approx 0.73$ (row 1)	$P \approx 0.73$ (row 1)	Minimal change when vs=0 (no shared area).
Large Shared Areas (S_A)	P drops to 0.26–0.27	P drops to 0.18–0.19	Shared zones (S_A) dominate outcomes; higher *k* exacerbates privacy loss.

Table A10: Applying the given formulas for the privacy by the VP_{area} values in tables 3,4 and 5, when the desired level of privacy ($k = 2.75$)

VP_{area}	k	VO_{area}	S_A	$k.S_A$	$1 + e^{-(VP-VO-k.S_A)}$	$Privacy$
8212.83500	2.75	232.76570	0.0000000	00.00000000	1.3791	0.72545
12123.7813	2.75	0.0000000	12123.7813	33340.398575	6.7910	0.148048
10014.8353	2.75	336.86910	10014.8353	27540.797075	5.3710	0.143855
20666.4810	2.75	0.000000	1736.91490	4776.515975	1.4531	0.683278
7239.66890	2.75	0.000000	7239.6689	19909.089475	6.7301	0.148047
3935.55790	2.75	0.000000	3935.5579	10822.784225	6.7871	0.148045
11764.1055	2.75	0.000000	11764.1055	32351.290125	6.7331	0.148044
12850.3283	2.75	0.000000	1617.7383	4448.780325	1.5211	0.657866
5356.16930	2.75	0.000000	3242.71470	8917.465425	2.9511	0.339641
4969.07940	2.75	0.000000	4969.07940	13664.96835	6.6941	0.148047
5072.69140	2.75	37.33260	5072.69140	13949.90135	6.8321	0.147121

Table 11: Applying the given formulas for the privacy by the VP_{area} values in tables 3,4 and 5, when the desired level of privacy ($k = 2.90$)

VP_{area}	k	VO_{area}	S_A	$k.S_A$	$1 + e^{-(VP-VO-k.S_A)}$	$Privacy$
8212.83500	2.9	232.76570	0.0000000	00.0000000	1.37871	0.72545
12123.7813	2.9	0.0000000	12123.7813	35158.96577	6.7581	0.130108

10014.8353	2.9	336.86910	10014.8353	29043.02237	6.9531	0.126349
20666.4810	2.9	0.000000	1736.91490	5037.053210	1.4631	0.680543
7239.66890	2.9	0.000000	7239.6689	20995.03981	6.6681	0.130108
3935.55790	2.9	0.000000	3935.5579	11413.11791	6.8412	0.130106
11764.1055	2.9	0.000000	11764.1055	34115.90595	6.8095	0.130105
12850.3283	2.9	0.000000	1617.7383	4691.44107	1.5213	0.653603
5356.16930	2.9	0.000000	3242.71470	9403.87263	2.9484	0.319579
4969.07940	2.9	0.000000	4969.07940	14410.33026	6.7565	0.130107