

This is the accepted manuscript (postprint) of the following article: Liu, Y., Lu, Y., Li, M., Wei, D., Liu, D., & Biljecki, F. (2026). Vitality-oriented urban forms are associated with poorer indoor window views in Hong Kong. *Habitat International*, 178, 104016.

<https://doi.org/10.1016/j.habitatint.2026.104016>

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Vitality-oriented urban forms are associated with poorer indoor window views in Hong Kong

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Abstract

Some urban form characteristics, e.g., dense street network, diverse pedestrian destinations, can promote vitality, because they support walking, social interaction, and public life. Yet these characteristics mainly focus on pedestrians rather than indoor occupants, although people spend around 90% of their time indoors. Using 1,352,550 simulated window views across Hong Kong, this study examines whether vitality-oriented urban form indicators, including floor area ratio, road network density, point-of-interest entropy, and building-age entropy, are associated with model-predicted window-view quality. Multilevel mixed-effects models were used, complemented by height-interaction models (height refers to the vertical elevation), contextual heterogeneity tests, and multi-scale comparisons. The results show that road network density, point-of-interest entropy, and floor area ratio are negatively associated with window-view quality ($\beta = -0.111$, -0.082 , and -0.054 , respectively; all $p < 0.001$), whereas the building-age association is very small ($\beta = -0.004$). Moreover, window height is positively associated with window-view quality ($\beta = 0.396$), and all four height-interaction terms are positive ($\beta = 0.026$ – 0.055). Window-view quality was lowest in high-development-intensity Tertiary Planning Units, and associations with road network density and point-of-interest entropy were more negative in old urban areas. Across buffers, the road-density and floor area ratio associations remain negative in the predicted-score models. In the human-rated subsample, the height and two entropy associations remain directionally consistent, whereas the other two are sensitive to outcome measurement. The findings call for more vertically and contextually differentiated urban design strategies that consider indoor visual welfare alongside street-level vibrancy.

Keywords:

Window-view quality, urban vitality, built environment, high-density cities, 3D urban analytics

1. Introduction

Urban vitality has been one of the central lenses through which urban designers and city managers create a good urban environment (Gómez-Varo et al., 2022; Jacobs, 1961). Mixed land use, dense street networks, continuous street frontages, and abundant activity are commonly advocated as key vitality-oriented urban form characteristics that support walking, social interaction, and public life (Dogan & Lee, 2024). As a result, such urban forms are often treated not only as explanatory factors for street-level public

life, but also as broader indicators of urban design quality (Han et al., 2022; Zhu et al., 2025b).

This inference, however, is built largely upon the perspective of street users. Urban environments are also experienced through daily window views from inside buildings (Liu et al., 2026; Wei et al., 2026). For residents behind the window, the external urban environment is experienced as visual stimuli rather than a public space to be used (Chang & Schiavon, 2026; Yao et al., 2024). This difference matters because urban forms commonly associated with urban vitality may not improve the visual quality of indoor occupants. More specifically, a vitality-oriented urban environment may entail shorter viewing distances, stronger obstruction, and heavier visual burden for indoor occupants. Yet it has rarely been examined before.

Some researchers point out that indoor visual experience is directly shaped by urban design. For example, building arrangement, inter-building distance, street geometry, and façade character collectively determine what occupants can see, governing view depth, layering, and the presence of sky or vegetation (Chokhachian et al., 2020; Drobne et al., 2022; Kılıç & Yener, 2025). However, it remains unclear how these vitality-oriented urban forms relate to window-view quality. This issue is salient in high-density vertical cities. In such settings, compact street layout and dense buildings make adjacent façades more visually dominant in window views, often shortening viewing distance and increasing obstruction. Furthermore, height, which refers to the vertical elevation, may also alter window-view quality by affecting viewing distance, interface proportion, and obstruction (Lau et al., 2010; Caswell et al., 2025).

The difficulty in addressing this research gap is largely due to methodological limitations. Large-scale window-view data and their quality assessment have not been readily available for an urban area. The recent advances in three-dimensional city models, image generation, and computational assessment make it possible to study indoor visual environments systematically and at large scale (Li et al., 2022; Li et al., 2026).

Against this backdrop, this study uses Hong Kong as a case to examine how four vitality-oriented urban form indicators are associated with window-view quality, and whether these associations vary across window height, spatial contexts, and buffer sizes. In doing so, the study makes three contributions. First, it examines vitality-oriented urban forms from the perspective of indoor occupants, extending their assessment beyond street-level use. Second, it uses more than 1.3 million simulated window views,

offering large-scale evidence at a spatial resolution that street-based studies rarely achieve. Third, it shows how these associations vary vertically, contextually, and spatially within Hong Kong.

2. Literature review

2.1. Vitality-oriented planning tradition and key urban form dimensions

Urban vitality has long been a central concept in understanding and defining a good urban environment. Coined by Jacobs (1961), the term urban vitality has been widely used to describe the level to which urban space supports human interactions and everyday activities (Carmona, 2021; Jiang et al., 2025), as well as their continuity over time (Makki et al., 2025; Sampson & Raudenbush, 1999). This broader understanding was further developed by Whyte (1980), and Montgomery (1998), and more recently summarized by Dogan and Lee (2024), who describe vitality through three interrelated dimensions: intensity, referring to the volume and frequency of human presence and activity; diversity, referring to the range of users, functions, and activities that coexist within a place; and consistency, referring to the temporal continuity of activity across different times of day and days of the week.

This understanding of vitality has become the dominant framework through which empirical studies evaluate urban form quality. Across this tradition, this quality is primarily assessed via the lens of supporting interactions and activities in public spaces, such as walking, staying, social interaction, and the coexistence of different activities across time (Li et al., 2026; Mouratidis, 2021; Wu et al., 2022; Zou et al., 2025). Empirical studies have translated this idea into a range of measurable indicators, including pedestrian volume, walking activity, staying behavior, street-level social interaction, and, more recently, mobile-phone activity, social-media activity, point-of-interest (POI) density, and composite vitality indices (Chen et al., 2022, 2026; Han et al., 2022; Huang et al., 2023; Liu et al., 2025; Zhu et al., 2025b). Although the data sources vary, these studies all focus on the intensity and diversity of public-space use. In other words, these variables were developed to explain how urban form supports public-space use, rather than how urban form is experienced from indoors.

Across different cities, datasets, and methodological approaches, four built-form dimensions appear repeatedly in vitality-oriented research: urban density, street

network connectivity, land use diversity, and building age heterogeneity. Urban density, measured by Floor Area Ratio (FAR), is consistently identified as a strong predictor of vitality (Sung & Lee, 2015). By concentrating built volume, it generates the density of users and potential encounters on which public life depends (Li et al., 2026). Empirical studies also show that its effect is nonlinear, with optimal threshold ranges beyond which further intensification yields diminishing or even negative returns (Duan & Chen, 2026; Jacobs, 1961). Street network connectivity shapes how readily people can move through and between spaces. Denser networks shorten travel distances, multiply route choices, and attract commercial activity to streets (Delclòs-Alió & Miralles-Guasch, 2018). Evidence suggests that network density carries the largest explanatory power among spatial configuration variables in predicting vitality distribution (Paköz et al., 2022; Sung et al., 2013). Land use diversity, typically captured by land-use mix or POI diversity, draws users with different schedules and purposes to the same area. Empirical studies consistently find significant positive associations between POI entropy and pedestrian activity, staying behavior, and social interaction across diverse urban contexts (Delclòs-Alió & Miralles-Guasch, 2018; Gómez-Varo et al., 2022). Building age heterogeneity reflects Jacobs's argument that old and new buildings coexisting within the same fabric lower rents and incubate small businesses (Sung & Lee, 2015). Age-diverse blocks have been found to support higher concentrations of small-firm and creative-sector employment, and mixing buildings from different eras is positively associated with both urban vitality and neighborhood social relations (Dogan & Lee, 2024; Huang et al., 2023).

Accordingly, this study chooses one representative indicator for each of the four built-form dimensions. FAR is used to capture urban density because it reflects the physical concentration of built volume more directly than population-based measures (Gómez-Varo et al., 2022; Jacobs, 1961; Sung & Lee, 2015). Road network density is used to represent network structure because it describes the compactness and permeability of the street system (Delclòs-Alió & Miralles-Guasch, 2018; Paköz et al., 2022; Sung et al., 2013). POI entropy is used to represent functional mix because it is suitable for highly mixed urban settings where land-use zoning alone may understate fine-grained variation (Gómez-Varo et al., 2022). Building age entropy is used to represent building-age heterogeneity because Jacobs-inspired research highlighted whether buildings from different development periods coexist within the same urban fabric (Dogan & Lee, 2024; Huang et al., 2023; Sung & Lee, 2015). In this way, the

four indicators used in this study are derived from a recurring structure in the vitality literature. At the same time, because these indicators were originally developed to explain street-level public life, it remains necessary to examine whether they are associated with the quality of urban environments as experienced from indoors.

2.2. Window-view research and indoor visual qualities

Window-view research offers a different perspective on urban environment quality from indoors (Abd-Alhamid et al., 2023). Instead of emphasizing movement, staying, and social interaction in public space, this literature focuses on how the outdoor scene is visually experienced through the window. Existing studies commonly assess window-view quality through content, openness, visible distance, obstruction, privacy, and natural elements, and relate these conditions to visual comfort, restoration, stress reduction, cognitive performance, and overall satisfaction (Du et al., 2022; Kent & Schiavon, 2020; Ko et al., 2020, 2022; Lu et al., 2026). In this framework, a high-quality window view is defined by whether the external setting provides visual access, sufficient depth, limited obstruction, visual privacy and aesthetics.

At the same time, most window-view studies treat the outside environment mainly as visual exposure rather than as an outcome of urban design. A large part of the literature asks which types of views are preferred, which view characteristics are more restorative, and how view quality can be measured more accurately (Chang & Schiavon, 2026; Tara et al., 2021; Wang et al., 2025a). Even studies using geometric indicators, virtual reality, or automated assessment methods largely remain concerned with evaluating the view itself (Fung & Lee, 2012; Kim et al., 2022; Li et al., 2022, 2025; Yeom et al., 2020). As a result, window-view research has done more to describe desirable view conditions than to explain which urban design configurations produce them.

This distinction matters because urban form characteristics associated with urban vitality may not be associated with equally favorable indoor views. Compact development, dense street networks, functional mix, and heterogeneous building stock can coincide with shorter viewing distances, greater obstruction, and lower visual privacy. This divergence between street-level activity and indoor visual experience has not been examined systematically at the window level.

2.3. Height, context, and scale in high-density vertical cities

This gap is especially salient in high-density vertical cities, where compact urban geometry shapes both urban vitality and indoor visual conditions. Evidence from Hong Kong further suggests that domestic window experience is closely conditioned by high-rise development patterns and associated planning and building configurations (Lau et al., 2010). Importantly, this relationship is not simply planar. Studies of 3D visible space and urban openness show that openness varies substantially with viewpoint height and surrounding configuration, meaning that the same urban form is not experienced in the same way across floors (Sun et al., 2026). Scenario-based studies in high-density cities further suggest that relatively small changes in plot ratio and building height can alter visibility and related environmental conditions in context-specific ways (Guo et al., 2020). Recent work on vertical accessibility likewise shows that floor level and vertical circulation reshape how mixed-use density is actually experienced, and that 2D assessments may misrepresent everyday urban conditions in vertically stratified environments (Chen et al., 2026). Taken together, these studies suggest that the relationship between vitality-oriented urban form and window-view quality in high-density vertical cities should not be understood as fixed or planar. Rather, it is intrinsically conditioned by height, context, and scale.

This issue has long been difficult to examine at scale, not because it lacked relevance, but because large-scale evaluation of window-level view quality is time consuming. Recent advances in three-dimensional urban data, image-based machine learning, and automated window-view assessment now make it possible to evaluate indoor visual environments systematically across large urban areas (Li et al., 2022; Ying et al., 2025). In this sense, high-density vertical cities are therefore important settings for examining how these urban forms relate to window-view quality at different heights. In sum, the key research questions of this study are: (1) Are urban form indicators associated with urban vitality associated with window-view quality? (2) Do these associations vary with window height? (3) Do they differ across urban contexts and measurement scales?

3. Methods

3.1. Study area and analytical units

This study focuses on Hong Kong, a high-density and high-rise city, where compact urban form and mixed land use make it an appropriate setting for examining vitality-oriented urban form, height, and window-view quality. The study area covers Hong Kong's major built-up areas and includes 163 Tertiary Planning Units (TPUs), 3,027 subdistrict units, 43,535 buildings, and 1,352,550 window samples (Figure 1).

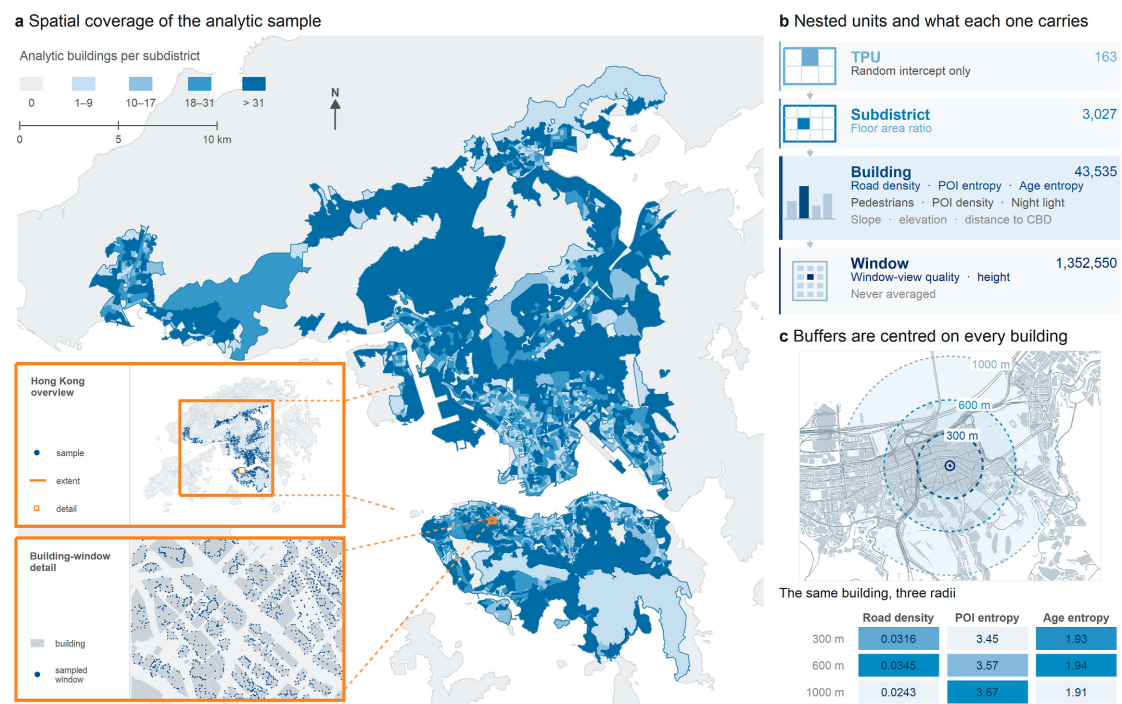


Figure 1. Study area, analytical units and buffer design.

(a) Subdistricts are shaded by the number of buildings entering the analysis. The main map shows the study area; an enlarged map shows the building and window details.

(b) The four nested units of analysis and the variables at different units. Three of the four urban form indicators are measured inside building-centered buffers; floor area ratio is measured at the subdistrict level. Window-view quality and window height are measured at the individual window level (i.e., not aggregated).

(c) Buffers of 300, 600, and 1000 m centred on one building, with the indicator values obtained at each radius.

TPUs are larger administrative planning areas defined by the Planning Department,

covering relatively homogeneous land use and development patterns. Each TPU contains multiple subdistrict units, which are finer spatial subdivisions reflecting more localized built environment conditions. Variables are measured at different spatial units and then matched to individual windows. Window-view quality and window height are first measured at the window level. Road network density, POI entropy, building-age entropy, the three vitality variables (street-view pedestrian volume, POI density and night-time light), slope, and elevation are computed within buffers centred on each building centroid, with 300 m used in the main analysis. FAR is constructed at the subdistrict-unit level, and distance to the central business district (CBD) is assigned from each building. Each window inherits these morphological, vitality and control variables from its building and is assigned to its containing TPU. After complete-case filtering, the analytical sample contains 1,352,550 windows from 43,535 buildings in 163 TPUs. Models are fitted directly to the window observations, with TPU random intercepts accounting for higher-level clustering.

3.2. Data, variables, and measurement

This section explains how the main variables are measured and brought into the analysis. It introduces window-view quality, vitality-oriented urban form, and height, then presents the contextual variables and buffer settings used to examine heterogeneity and scale effects and finally describes the preprocessing steps before modelling. Figure 2 provides an overview of how window-based view measures are linked to surrounding urban conditions in the analysis.

Outcomes: window-view quality and three vitality proxies

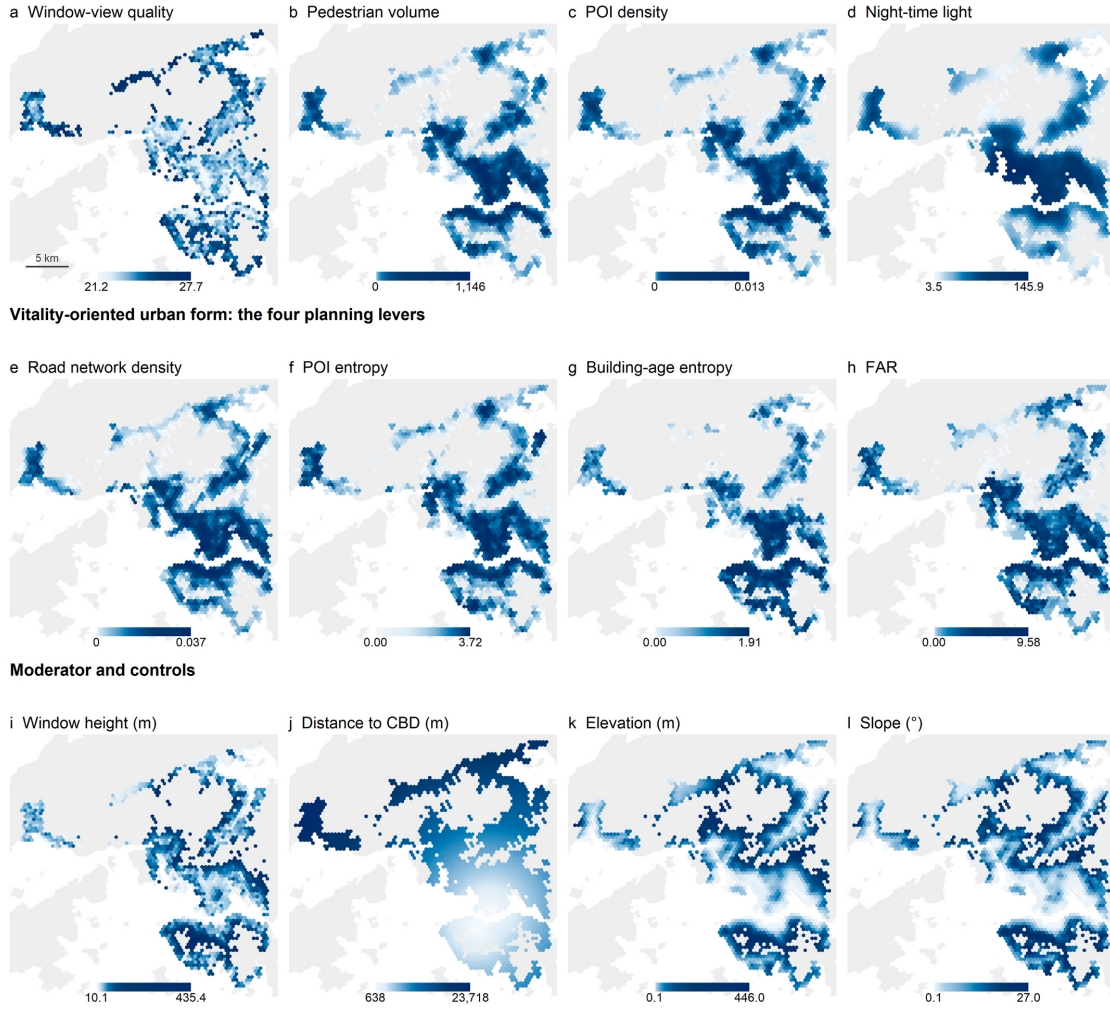


Figure 2. Spatial distribution of the outcome, vitality variables, urban form indicators, the moderator and controls.

Values are averaged into 400 m hexagons for display only; all variables enter the models at the window level with building-centred 300 m buffers. Panels a and i are aggregated from window observations, the remaining panels from building centroids. Colour breaks follow within-panel deciles after 1st-99th percentile winsorization, and each colour bar is labelled with its own minimum and maximum. Grey denotes the built-up study extent without sampled buildings or windows.

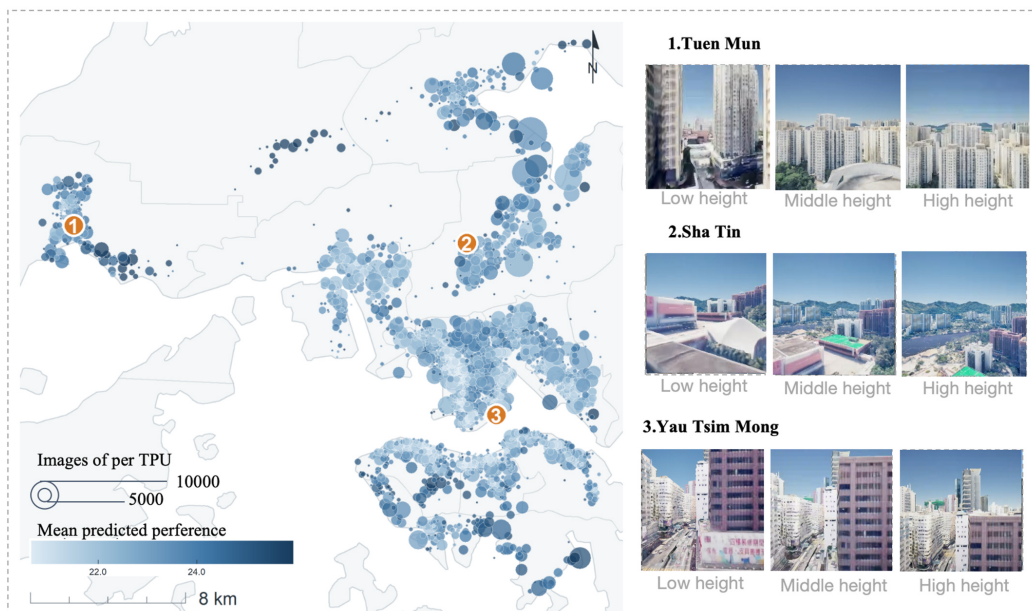
3.2.1. Window-view quality

The dataset comprises 1,391,174 simulated window-view images (Figure 3a). Each image represents an outward-facing view rendered in Cesium from a virtual viewpoint placed on a building façade, rather than a field-captured photograph.

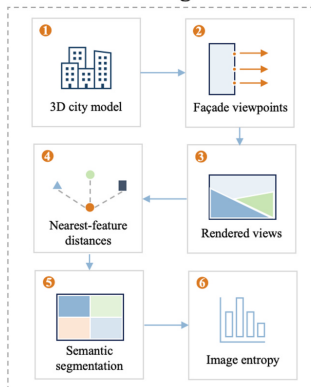
Viewpoint coordinates and headings were derived from building footprints and height attributes, with the camera-oriented perpendicular to the façade and set to a 60-degree field of view. Based on previous experimental and sensitivity analyses (Li et al., 2022; Li et al., 2026), a sampling strategy was adopted to reduce computational load while preserving accuracy. Views from the centres of the bottom, middle, and upper floors were rendered at façade locations along building perimeters (Wei et al., 2026). Building footprints and height attributes were obtained from the Lands Department's Building Framework Spatial Data Theme, and the environmental layers were obtained from Google and have been continuously updated around 2018 to cover the urban area of Hong Kong.

a. Citywide window-view coverage

TPU bubble area indicates image count; fill indicates mean predicted preference



b. Window-view generation



c. Spatial representativeness of the human-rated subset

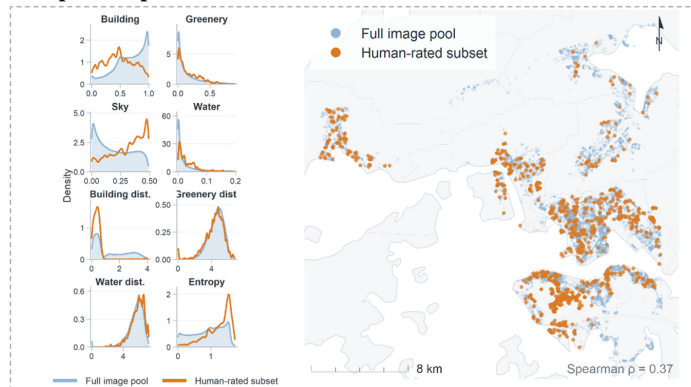


Figure 3. Coverage, generation, and representativeness of the window-view dataset.

(a) TPU-level distribution of the 1,391,174 simulated window-view images across Hong Kong. Bubble area indicates the number of images and fill indicates mean predicted preference. Numbered examples show low-, middle-, and high-elevation views rendered from the same façade locations. (b) Workflow for virtual viewpoint generation and extraction of viewpoint height, nearest-feature distances, semantic composition, and image entropy. (c) Spatial and feature-distribution overlap between the full image pool and the 1,000-image human-rated subset. Feature curves are normalized within each sample, and distance variables are log-transformed.

Each image was represented by eight random-forest inputs (Figure 3b). A Segment Anything Model fine-tuned on the CIM-WV dataset (Li et al., 2024) assigned each pixel to building, greenery, sky, road, or water. The three distance variables were the minimum planar Euclidean distances, in metres, from the viewpoint to the nearest waterbody boundary, greenery boundary, and non-host-building boundary. They represent the proximity of natural elements and potential near-field obstruction. Image entropy was calculated from the grayscale histogram as $H = -\sum_{i=0}^{255} p_i \log_2 p_i$, where p_i is the normalized frequency of gray level i . Higher entropy indicates greater luminance heterogeneity and was used as a proxy for visual complexity rather than a direct measure of disorder.

From the full image pool, 1,000 images, representing 0.072% of all images, were selected for human preference assessment using stratified random sampling across the 18 administrative districts. Their spatial and feature distributions were compared with those of the full pool (Figure 3c). An online pairwise-comparison survey involving 889 respondents evaluated each image approximately 27 times. TrueSkill converted the repeated pairwise choices into one human-derived latent preference score per image (Herbrich et al., 2006). These scores were used to train a random forest based on the four semantic proportions, three nearest-feature distances, and image entropy. Five-fold cross-validation yielded $R^2 = 0.41$, and the fitted model was applied to the full pool of 1,391,174 images. Thus, the dependent variable in the main regression is the model-predicted preference score, not a direct human rating.

After covariate linkage and complete-case filtering, 1,352,550 predicted scores entered the main analyses; 866 of the rated images entered the outcome-measurement robustness analysis.

3.2.2. Vitality-oriented urban form

Drawing on vitality-oriented street design theory, this study constructs urban form measures from four dimensions: urban density, network structure, functional mix, and building-age mix. These are represented by FAR, road network density, POI entropy, and building age entropy, respectively (Figure 2). It should be noted that these variables do not measure urban vitality directly but serve as proxies for built-form characteristics commonly associated with vitality in the literature.

Subdistrict-level FAR is used to measure urban density, capturing the local concentration of built volume. Road network density, POI entropy, and building age entropy are calculated within buffers centered on each building centroid (300m in the main analysis, 600m and 1000m for the multi-scale check). Specifically, road network density is measured as the total road length within the buffer, indicating the structural compactness of the street network. POI entropy is calculated from the distribution of POI categories within the buffer and captures both functional mix and environmental content complexity. Building-age entropy is calculated using the same formula over 10-year construction-age groups of buildings within the buffer.

The main analysis uses a 300 m buffer to construct road network density, POI entropy, and building age entropy. These measures are recalculated using 600 m and 1000 m buffers for scale robustness tests and to identify the spatial range of their associations.

3.2.3. Moderator: height

Window height is retained for each individual window and entered as a continuous variable in the interaction models. It is measured as the viewpoint's absolute vertical position from the camera's three-dimensional z-coordinate, in metres above the Hong Kong Principal Datum (mPD) rather than above local ground level. It therefore combines terrain elevation with the window's vertical position inside its building.

3.2.4. Control and contextual variables

Three continuous controls are included because location and terrain may be associated with both urban form and window-view quality. Distance to CBD is the Euclidean distance from each building to the nearer of Central and Tsim Sha Tsui.

Elevation and slope were derived from the Lands Department's territory-wide 5 m-grid Digital Terrain Model, obtained through the Common Spatial Data Infrastructure Portal (Lands Department, 2024). For each building-centred buffer, mean elevation and mean slope were calculated as coverage-weighted raster means. Slope and elevation are the mean terrain values within the 300 m building-centred buffer in the main analysis. Each window inherits these controls from its building.

In addition to street environmental characteristics, window-view quality may also be shaped by the broader urban context in which each sample is located. To examine contextual heterogeneity in the associations of vitality-oriented street variables, this study considers three groups of contextual variables. Planning zone reflects differences in development stage and planning background and includes old urban areas, urban extensions, and new towns. Urban system divides samples into Hong Kong Island, Kowloon, and the New Territories. Morphological context represents more stable development constraints and institutional differences in the built environment. It is defined using TPU-level FAR and grouped into low-, medium-, and high-development-intensity categories. It should be distinguished from urban density used in the main models, whereas urban density is the subdistrict-level FAR entering the regression as a continuous urban form predictor; urban development intensity is a categorical TPU-level variable that captures the broader and more stable institutional development context in which each subdistrict is embedded.

3.2.5. Urban vitality proxies

To verify that the form indicators track urban vitality, we use three variables, each capturing a recognized facet of urban vitality (Tu et al., 2020). All three are computed within the same building-centred buffers as the urban form indicators. Street-view pedestrian volume captures street-level pedestrian activity in the Jacobsian theory (Sung & Lee, 2015; Wu et al., 2023). We retrieved 2025 Google Street View images at sampled points along the street network and detected pedestrians with the You Only Look Once (YOLO) object detector (Jocher et al., 2023; Liu et al., 2023, 2025; Redmon et al., 2016); the variable is measured by the mean pedestrian count per image within the buffer. POI density captures the density of functional supply (Chen et al., 2022). Using points of interest from an online map service, it is computed as the number of POIs per unit area within the buffer. Night-time light captures the intensity of night-

time activity (Wu, Zhao & Ye, 2023). We used the 2024 Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite (NPP–VIIRS) annual composite at 500 m resolution (Chen et al., 2021), taking the mean radiance within the buffer. Each vitality proxy was regressed on the four form indicators at the building level, using the same controls and TPU random-intercept structure. This analysis tests whether the selected urban form indicators are associated with three vitality variables.

3.2.6. Buffer settings and scale definition

To examine scale dependence and test robustness, road network density, POI entropy, and building age entropy are measured using 300 m, 600 m, and 1000 m buffers centered on each building centroid. These distances were chosen to represent nested spatial contexts in built environment and transport studies, smaller buffers capture immediate surroundings, whereas buffers around 1000 m reflect a broader walking or cycling environment (Cervero et al., 2009; Wang et al., 2021). In this study, the 300 m buffer represents the local street-interface scale, where nearby façades, ground-level functions, and visual obstruction are most likely to affect window views. The 600 m buffer captures the surrounding neighborhood fabric, including street networks, functional mix, and building-stock composition. The 1000 m buffer captures a broader urban-context scale. The main models use the 300 m measures, while the 600 m and 1000 m measures are used for cross-scale robustness tests and for identifying the spatial extent of the observed relationships.

3.2.7. Data preprocessing

Before modelling, all continuous variables are standardized as z-scores to facilitate comparison across variables and buffer scales, and categorical variables are dummy coded. Missing values are removed listwise. All variables are matched to individual windows, and window-view quality and window height are kept at the window level, while the buffer measures and subdistrict-level FAR are attached to each window from its building and subdistrict. After excluding invalid cases, the final analytical sample includes 1,352,550 windows.

3.3. Model specification

The sequential analytical design, including the baseline mixed-effects model, the height-moderation models, the contextual heterogeneity models, and the multi-scale buffer analysis, shows how the relationships between vitality-oriented urban form and window-view quality are tested under different analytical conditions.

3.3.1. Baseline and height-moderation models

To identify the basic relationships between vitality-oriented urban form and window-view quality while accounting for potential spatial clustering, this study employs linear mixed-effects models. An intercept-only null model is first estimated, and the intraclass correlation coefficient (ICC) is calculated to test whether window-view quality shows significant between-TPU clustering. If the TPU-level variance is non-negligible, TPU random intercepts are included in subsequent models. A TPU random intercept therefore absorbs unobserved district-level conditions, shared by all windows in the same unit. No additional random intercept is specified at the building level, for two reasons: the four urban form indicators are constant within a building, so the building level supplies no further variation for identifying their coefficients; and a three-level model with 43,535 building groups and more than 1.3 million observations is computationally infeasible. Dependence among windows of the same building is instead addressed by clustering standard errors at the TPU level. Because the design is cross-sectional, spatial dependence is tested but no temporal autocorrelation test applies.

The null model is:

$$WQ_{ij} = \beta_0 + \mu_j + \varepsilon_{ij}$$

where WQ_{ij} denotes the window-view quality of window i in TPU j , μ_j is the TPU-level random intercepts, and ε_{ij} is the window-level error term.

Based on this, a baseline main model is estimated to include FAR, road network density, POI entropy, and building age entropy as fixed effects, together with distance to CBD, slope, and elevation as controls, to examine their overall associations with window-view quality:

$$WQ_{ij} = \beta_0 + \sum_{k=1}^4 \beta_k X_{k,ij} + \sum_{m=1}^3 \gamma_m Z_{m,ij} + u_j + \varepsilon_{ij}$$

where WQ_{ij} is the window-view quality of window i in TPU j ; $X_{k,ij}$ denotes the four urban form indicators, road network density, POI entropy, building-age entropy, and FAR. $Z_{m,ij}$ denotes distance to the CBD, slope, and terrain elevation; u_j is the TPU random intercept; and ε_{ij} is the window-level residual. Each vitality variable was also regressed on the four building-centred form indicators using an analogous building-level mixed-effects specification. This auxiliary model is used to support the interpretation of the indicators.

To test the moderating role of window height, a joint interaction model was estimated in which window height interacted simultaneously with all four urban form indicators. The general form is:

$$WQ_{ij} = \beta_0 + \sum_{k=1}^4 \beta_k X_{k,ij} + \beta_H H_{ij} + \sum_{k=1}^4 \delta_k (X_{k,ij} \times H_{ij}) + \gamma_1 CBD_{ij} + \gamma_2 Slope_{ij} + u_j + \varepsilon_{ij}$$

where H_{ij} denotes window height and δ_k represents the interaction between window height and each of the four urban form indicators. Terrain elevation is omitted from this model because of its high correlation with window height.

For significant interactions, simple slope analysis and conditional marginal effects analysis are conducted. Simple slopes are estimated at the window height, one standard deviation above the mean, and one standard deviation below the mean. Conditional marginal effects are then calculated across the full range of height values, together with their 95% confidence intervals. To complement the continuous interaction, we additionally estimate the associations separately for low, middle, and high floors. Windows are grouped by their vertical position within the same building, and the baseline main model is re-estimated within each group under the same controls, standardization, and TPU random intercepts (Supplementary Figure S1). Model adequacy is assessed through variance inflation factors, marginal and conditional R^2 , and Moran's I for the model residuals. Because residual spatial clustering remains detectable at this sample size, TPU-clustered robust standard errors are also reported as a check on inference.

3.3.2. Contextual heterogeneity models

To test whether the associations of vitality-oriented urban form on window-view quality vary systematically across urban contexts, the three groups of contextual

variables are introduced as grouping conditions, and interaction terms between contextual variables and the urban form indicators are estimated.

The general form of the contextual heterogeneity model is:

$$WQ_{ij} = \beta_0 + \beta_1 V_{ij} + \beta_2 C_{ij} + \beta_3 (V_{ij} \times C_{ij}) + \beta_4 CBD_{ij} + \beta_5 Slope_{ij} + \beta_6 Elevation_{ij} + u_j + \varepsilon_{ij}$$

where V denotes urban form variables and C denotes a contextual variable. The main effect of the contextual variable represents the baseline difference in window-view quality relative to the reference category, while the interaction term indicates how the associations of the vitality variable differ from that in the reference group.

Reference categories are specified for all contextual variables. Specifically, New town is used as the reference category for planning zone, the New Territories for urban system, and high development intensity for development context.

3.3.3. Robustness analysis

To test robustness and identify the spatial range of the associations of vitality-oriented street variables, road network density, POI entropy, and building age entropy are recalculated using 300 m, 600 m, and 1000 m buffers, and their relationships with window-view quality are re-estimated within the same mixed-effects modeling framework.

The general form of the multi-scale model is:

$$WQ_{ij}^{(s)} = \beta_0^{(s)} + \sum_{k=1}^4 \beta_k^{(s)} X_{k,ij}^{(s)} + \beta_H^{(s)} H_{ij} + \sum_{k=1}^4 \delta_k^{(s)} (X_{k,ij}^{(s)} \times H_{ij}) + \gamma_1^{(s)} CBD_{ij} + \gamma_2^{(s)} Slope_{ij} + u_j^{(s)} + \varepsilon_{ij}^{(s)}$$

where s denotes the 300 m, 600 m, or 1000 m specification. Road network density, POI entropy, and building-age entropy are recalculated at each buffer size, whereas FAR retains the same subdistrict-level value. The corresponding main model omits window height and the interaction terms.

At each buffer scale, both main models and height-interaction models are estimated. Coefficient direction, statistical significance, and effect size are compared across scales for road network density, POI entropy, building age entropy, and their interactions with height. In addition, conditional effects are estimated at the mean of height, one standard deviation above the mean, and one standard deviation below the

mean to identify scale-dependent moderation patterns.

To assess whether outcome prediction altered the estimated associations, we re-estimated the baseline and height-moderation models in the 866 rated images with complete covariates. The sample, controls, standardization, and TPU random-intercept specification were held constant, and the resulting coefficients and 95% confidence intervals were compared.

4. Results

4.1. Urban form indicators, vitality proxies, and window-view quality

Window-view quality is spatially clustered before modelling (building-level Moran's $I = 0.619$, $p < 0.001$), and the null-model ICC is 0.236. The null-model variance components are $\tau_{00} = 0.236$ and $\sigma^2 = 0.764$. A likelihood-ratio test supports the TPU random intercept, $\chi^2(1) = 66,780.4$, $p < 0.001$. Multicollinearity is acceptable, as elevation and window height are strongly correlated ($r = 0.82$) and are therefore never entered into the same model (Supplementary Table S1). The mixed model reduces residual Moran's I to 0.238 at the building level and 0.095 at the TPU level; both remain statistically detectable, so TPU-clustered standard errors are also reported and give the same conclusions for the main associations (Supplementary Table S1–S4).

We first assess whether the four urban form indicators are associated with different dimensions of urban vitality (Figure 4a). All four are positively associated with pedestrian volume ($\beta = 0.109$ – 0.489 , all $p < 0.001$), while their associations with POI density and night-time light are generally positive but not uniform. These results support interpreting the four measures as vitality-oriented form indicators.

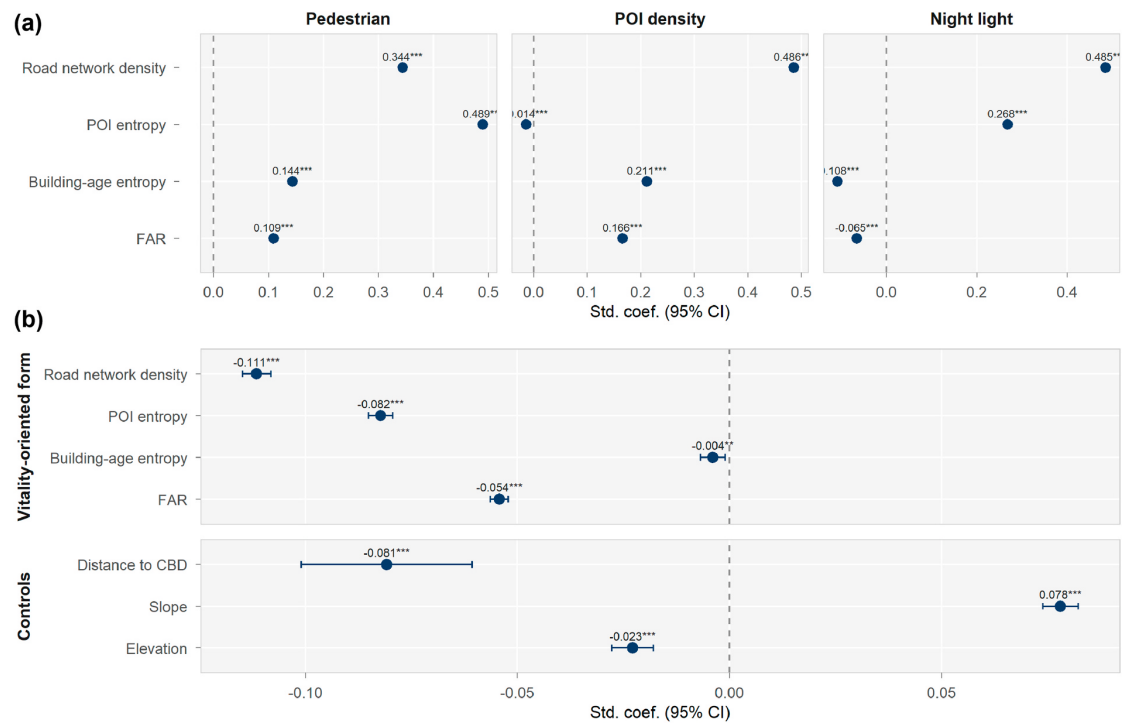


Figure 4. Associations of the four form indicators with vitality variables and window-view quality.

(a) Building-level standardized associations with pedestrian volume, POI density, and night-time light. (b) Window-level standardized associations with model-predicted window-view quality, with controls shown (N = 1,352,550). Points and horizontal bars denote coefficients and 95% confidence intervals.

The same set of urban form indicators, however, are negatively associated with window-view quality (Figure 4b). Road network density, POI entropy, and FAR are all significantly negative ($\beta = -0.111$, -0.082 , and -0.054 ; all $p < 0.001$), while building-age entropy is very small ($\beta = -0.004$). The controls behave as expected window-view quality falls with distance to the CBD ($\beta = -0.081$) and rises on steeper terrain ($\beta = 0.078$), where surrounding development is sparser. Together, these results show that urban forms associated with vitality coincide with poorer indoor window views.

4.2. Associations between urban form and window-view quality change with window height

Adding window height and its interactions with the four urban form indicators reveals a clear height moderation effect for window height (Table 1; Figure 5). Window height has a strong positive main effect ($\beta = 0.396$, $p < 0.001$). All four interactions

with height are positive and significant: road network density $\times$ height (0.042), POI entropy $\times$ height (0.044), building-age entropy $\times$ height (0.055), and FAR $\times$ height (0.026), all $p < 0.001$, all four slopes relating each urban form indicator to window-view quality shift in a more positive direction as window height increases.

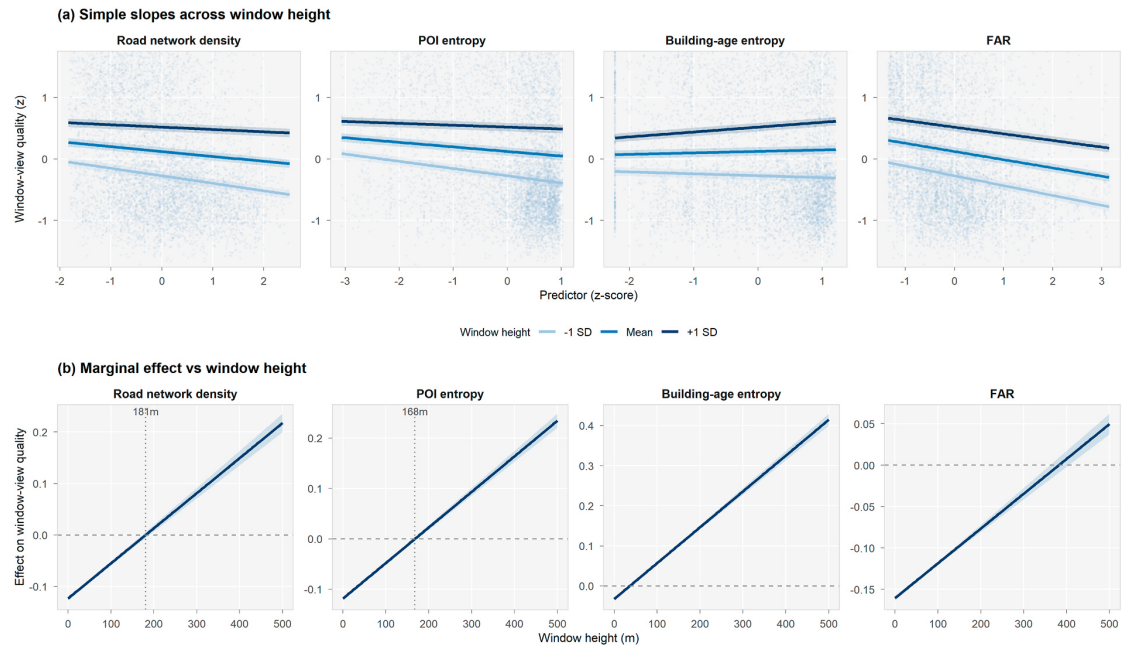


Figure 5. How window height changes the associations between urban form indicators and window-view quality.

(a) Conditional slopes of each form indicator at low (-1 SD), mean, and high ($+1$ SD) window height. (b) Conditional association of each indicator with window-view quality across the observed height range, with 95% confidence bands; the dashed line marks zero. Positive interaction coefficients indicate that the estimated associations become more positive as window height increases.

Table 1 Moderating effects of height on the associations between vitality-oriented street variables and window-view quality

	Height moderation
Vitality-oriented urban form	
Road network density	−0.080*** [−0.083, −0.077]
POI entropy	−0.074*** [−0.077, −0.071]
Building-age entropy	0.024*** [0.021, 0.027]
FAR	−0.134*** [−0.136, −0.132]
Window height	0.396*** [0.393, 0.398]
Height interactions	
Road network density × Height	0.042*** [0.039, 0.044]
POI entropy × Height	0.044*** [0.042, 0.046]
Building-age entropy × Height	0.055*** [0.053, 0.057]
FAR × Height	0.026*** [0.024, 0.028]
Controls	
Distance to CBD	−0.128*** [−0.148, −0.108]
Slope	−0.035*** [−0.039, −0.032]
Intercept	0.122*** [0.053, 0.191]
N (windows)	1,352,550
ICC	0.208
Marginal R ²	0.155
Conditional R ²	0.330

Notes: Standardized coefficients; 95% confidence intervals in brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Estimated at the window level with TPU random intercepts (restricted maximum likelihood). Elevation is dropped from the moderation model owing to collinearity with window height ($r = 0.82$). A likelihood-ratio test supports the TPU random intercept ($\chi^2(1) = 66,780.4$, $p < 0.001$; unconditional ICC = 0.236). Residual spatial autocorrelation falls from Moran's $I = 0.619$ in the raw outcome to 0.238 at the building level and 0.095 at the TPU level; TPU-clustered robust standard errors give the same conclusions (Supplementary Table S4).

The simple-slope plots make this visible (Figure 5a), for every indicator the negative slope is steepest at low floors (−1 SD) and flattens toward high floors (+1 SD). The marginal-effect curves show where each negative association reaches zero (Figure 5b): road network density reaches zero at about 181 m and POI entropy at about 168 m, building-age entropy turns positive already at low floors (about 36 m), and FAR stays negative until about 380 m. In short, windows at greater heights have better predicted views, and the negative associations between the urban form indicators and window-view quality become weaker.

The within-building floor-group analysis provides complementary evidence: the POI-entropy and FAR associations weaken from low to high floors, FAR becomes positive at high floors, and road network density remains negative across floor groups;

the building-age pattern is less consistent (Supplementary Table S5 and Figure S1).

4.3. Heterogeneity across urban scenarios

After adjustment for distance to CBD and terrain, baseline window-view quality does not differ significantly across geographic regions or planning zones. In contrast, medium- and low-development-intensity TPUs have higher baseline window-view quality than high-intensity TPUs ($\beta = 0.146$ and 0.603).

The associations show clearer contextual variation (Figure 6a). Relative to the New Territories, Hong Kong Island has more negative associations for road network density, POI entropy, and building-age entropy ($\Delta\beta = -0.047$, -0.036 , and -0.035) but a less negative FAR association (0.086); Kowloon shows the same pattern for POI entropy, building-age entropy, and FAR (-0.048 , -0.043 , and 0.087), while its road-density difference is not significant (-0.006). Relative to new towns, old urban areas have more negative road-density, POI-entropy, and building-age associations (-0.013 , -0.033 , and -0.099) and a less negative FAR association (0.108); urban extensions have more negative road-density and POI-entropy associations (-0.042 and -0.057), no clear building-age difference (0.004), and a less negative FAR association (0.032). Relative to high-intensity TPUs, low-intensity TPUs have less negative road-density, POI-entropy, and building-age associations (0.124 , 0.068 , and 0.095) but a more negative FAR association (-0.129); medium-intensity TPUs show a slightly more negative road-density association (-0.019), less negative POI- and building-age associations (0.077 and 0.082), and a more negative FAR association (-0.077).

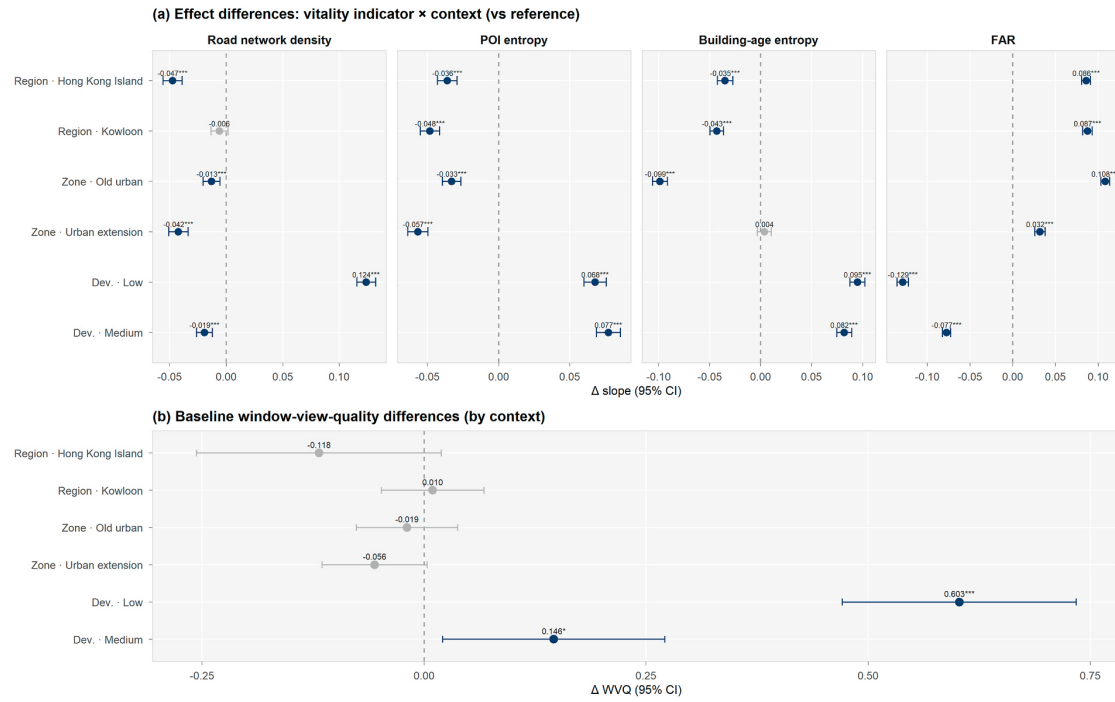


Figure 6. Contextual variation in window-view quality and in its associations with urban form indicators.

Panel (a) shows differences in form–view slopes across contextual groups, and panel (b) shows differences in baseline window-view quality. Results are reported for geographic region, planning zone, and development intensity.

4.4. Multi-scale and outcome-measurement robustness

Figure 7 shows multi-scale robustness. Road network density is negatively associated with window-view quality at all three scales and becomes more negative as the buffer expands ($\beta = -0.112, -0.191$, and -0.218 at 300 m, 600 m, and 1000 m). POI entropy is negative at 300 m ($\beta = -0.082$), close to zero at 600 m ($\beta = -0.012$), and slightly positive at 1000 m ($\beta = 0.017$), indicating that its negative association is local. Building-age entropy changes sign across scales ($\beta = -0.003, 0.018$, and -0.052), so no stable scale pattern is inferred. FAR remains negative throughout ($\beta = -0.054, -0.064$, and -0.070).

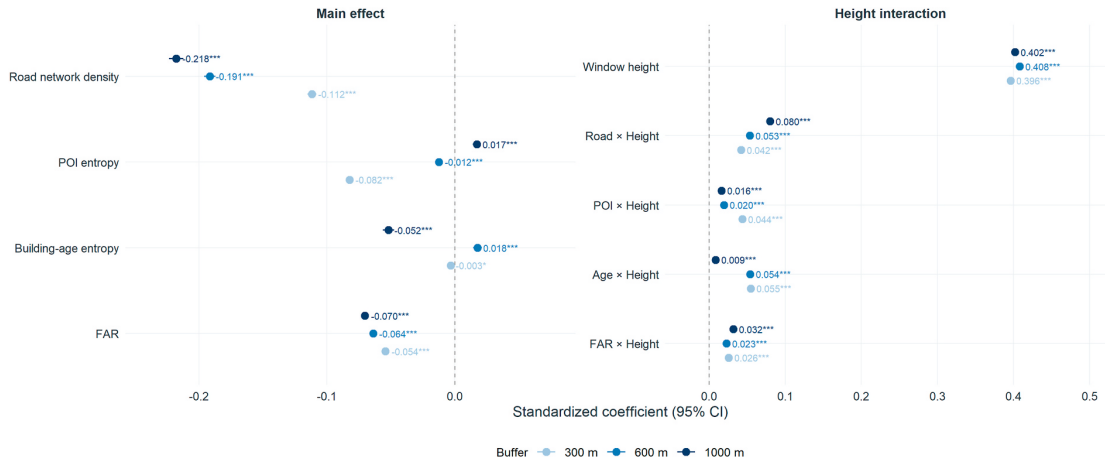


Figure 7. Multi-scale robustness of the main and window-height interaction coefficients.

Standardized coefficients and 95% confidence intervals are shown for the 300 m, 600 m, and 1000 m specifications.

Window height remains strongly positive across scales ($\beta = 0.396\text{--}0.408$), and all height interactions remain positive. The road-density interaction strengthens with buffer size ($\beta = 0.042, 0.053$, and 0.080), whereas the POI interaction weakens ($\beta = 0.044, 0.020$, and 0.016). The building-age interaction is similar at 300 m and 600 m but much smaller at 1000 m, while the FAR interaction is comparatively stable. The negative road-density association is therefore broad in spatial range, whereas the negative POI-entropy association is concentrated in the immediate surroundings.

Re-estimating the models on 866 human-rated windows produces wider confidence intervals because of the smaller sample (Figure 8). Window height remains positive and significant ($\beta = 0.286, p < 0.001$), compared with 0.396 in the full sample. POI entropy and building-age entropy retain their negative direction ($\beta = -0.090$ and -0.053) but are not significant. Road network density is close to zero ($\beta = 0.005$), while FAR changes from negative to significantly positive ($\beta = 0.083, p = 0.038$). The road-, POI-, and building-age-by-height terms remain positive but are imprecisely estimated, whereas $\text{FAR} \times \text{height}$ changes sign. The height association is therefore robust to outcome measurement, while the road-density and FAR estimates require greater caution.

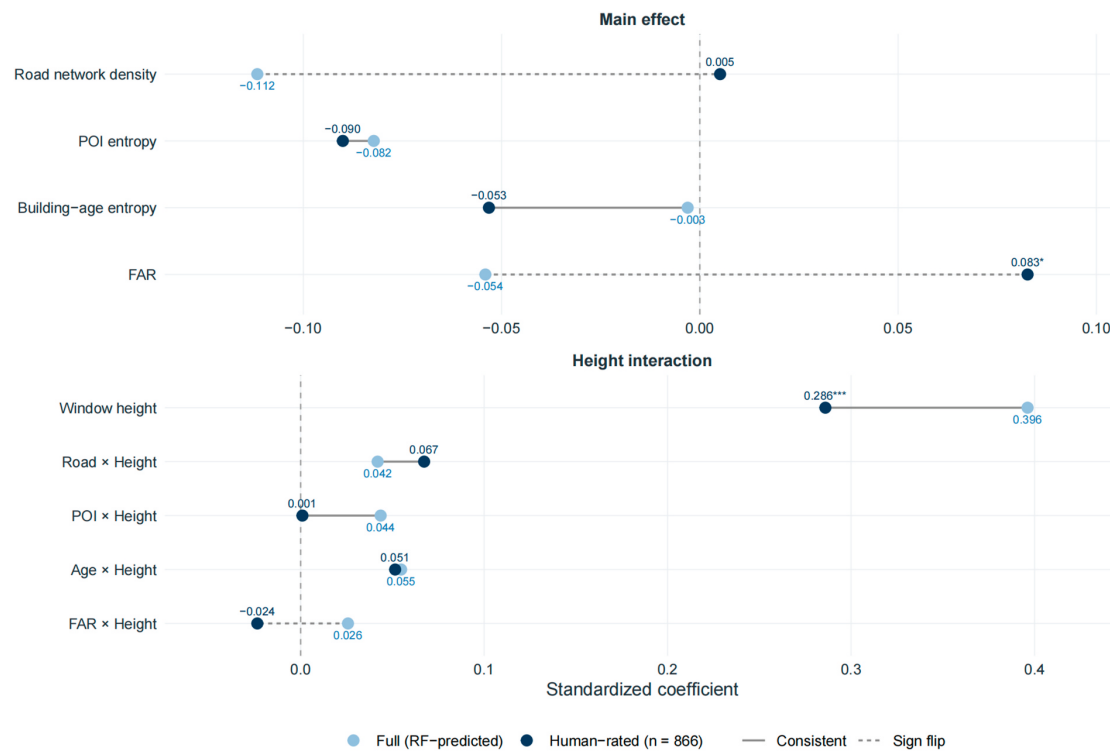


Figure 8. Outcome-measurement robustness, model-predicted versus human-rated window-view quality.

Standardized coefficients for the baseline and height models, estimated from the full sample of predicted window-view quality ($N = 1,352,550$) and from the human-rated subsample ($n = 866$), joined by a line. A solid line marks a consistent sign across the two outcomes; a dashed line marks a sign change (road network density, FAR, and $FAR \times Height$). Stars mark significance in the human-rated sample (* $p < 0.05$, *** $p < 0.001$). Both models use TPU random intercepts. Window height and the negative direction of the mix measures hold across outcomes, whereas road-density and FAR change sign and are interpreted with caution.

5. Discussion

The discussion is organized into four parts. It begins by outlining the broader theoretical implications of the study, then turns to the mechanisms linking urban form to window-view quality, followed by the planning implications of these relationships across different urban conditions. It ends by reflecting on the main limitations of the study and directions for future research.

5.1. Beyond public space: extending the assessment of vitality-oriented urban form to indoor window view

This study adds an indoor perspective to Jacobs-inspired ideas of vitality-oriented urban planning theory, which emphasizes accessibility, activity, and vibrancy in public spaces (Dogan & Lee, 2024; Jacobs, 1961). Our study shows urban forms linked to urban vitality are negatively associated with indoor visual conditions. In Hong Kong, denser road networks, greater functional mix, and higher FAR coincide with poorer predicted window views, especially at lower window heights. Urban vitality should therefore not be treated as the sole measure of environmental quality.

This also broadens the scope of window-view research. Most existing studies treat window views mainly as visual scenes (Elsadek et al., 2024; Ko et al., 2022). They focus on image composition, semantic elements, and their links with preference, restoration, or well-being (Chang & Schiavon, 2026; Wang et al., 2025b). Our study suggests that window views are associated with urban form characteristics commonly promoted by planning, emphasizing that street-level design should be evaluated together with its impact on indoor visual conditions. In other words, a window view is not only something to be perceived, but also something spatially produced.

Taken together, these points indicate a necessary shift in urban design theory. The effects of urban design are not evenly shared across all users or settings. In high-density cities, urban design strategy activating street life is also linked to less favorable visual conditions indoors. These associations may also change across different heights and spatial contexts. Urban design should therefore evaluate street-level activity and indoor visual quality together, while recognizing that their relationship changes with height and context.

5.2. Possible pathways underlying the observed vitality-oriented form and window-view quality associations

5.2.1. Distinct pathways across road network density, POI entropy, and building age entropy

Our results suggest that different urban form variables may relate to window-view quality via different pathways. This distinction follows Jacobs's original formulation:

mixed primary uses, short blocks, aged buildings, and sufficient concentration were proposed as mutually reinforcing conditions for diverse street life, not as interchangeable measures of overall environmental quality. Later empirical tests likewise show that their associations vary across outcomes and urban contexts (Huang et al., 2023; Jacobs, 1961; Sung et al., 2013; Sung & Lee, 2015). Our results extend this argument indoors by revealing marked differences in association magnitude, spatial range, contextual variation, and measurement robustness.

First, street network density shows a stable negative association across spatial scales, and the association becomes stronger at larger buffers. In Jacobs-inspired research, short blocks and connected streets support route choice, pedestrian circulation, and street contact (Ewing & Cervero, 2010; Sung et al., 2013; Sung & Lee, 2015). From a window, however, the same fine-grained network may also coincide with more block edges, tighter facing-building relationships, and shorter distances to urban features. This interpretation is consistent with window-view studies showing that greater building spacing and longer viewing distance are associated with lower oppressiveness and higher visual satisfaction (Chung et al., 2019; Kent & Schiavon, 2020; Wang & Munakata, 2024). In this sense, a fine-grained street network may support accessibility and vitality at street level, while also generating a heavier visual burden indoors. Because the road-density estimate falls close to zero in the human-rated subsample, both the strength and the presence of this association remain uncertain.

Second, POI entropy has a more local and context-dependent association. It is negative at 300 m, approaches zero at 600 m, and becomes slightly positive at 1000 m, suggesting that its negative association concerns the immediate street interface rather than stable area-wide geometry. Functionally mixed streets are often expressed through more differentiated ground-floor segments, entrances, shopfronts, and other street-facing elements; when these enter the foreground of a window view, they change the amount, layering, and complexity of visible content. This suggests that subdivided street edges attract visual engagement and window-view studies show that visible content, depth, layering, and visual complexity shape preference (Lin et al., 2022; Simpson et al., 2022; Wang et al., 2025a). The stronger negative POI association on Hong Kong Island, in Kowloon, and in urban extensions and old urban areas further suggests that the visual expression of functional mix is context dependent. POI entropy records category balance rather than interface quality, so this pathway remains an interpretation rather than a directly observed mechanism.

Third, FAR shows a height-conditioned rather than uniformly negative association with window-view quality. At lower windows, greater built volume can place more foreground building mass in the visual field, reducing sky exposure and view depth; at higher windows, the same surrounding density may be seen over rather than through nearby obstructions, recovering distance and openness. This interpretation is consistent with window-view studies showing that viewing distance, building spacing, foreground building proportion, sky exposure, and floor level shape view satisfaction and perceived oppressiveness (Caswell et al., 2025; Wang & Munakata, 2024). It suggests that indoor visual conditions are associated with FAR. In the human-rated subsample, the FAR association is positive rather than negative, so this pathway remains provisional and requires further testing.

By contrast, the building-age entropy association is the smallest and least stable of the four associations. It is close to zero in the baseline model, changes sign across buffer sizes and floor groups and is not significant under TPU-clustered standard errors or the human-rated outcome. This does not necessarily contradict Jacobs. Her “need for aged buildings” concerned affordable space, gradual redevelopment, economic diversity, and continuity of social relations, rather than a direct aesthetic preference for mixed building ages (Jacobs, 1961; King, 2013). Existing research has likewise shown that facade order, maintenance quality, and compositional characteristics shape how people evaluate buildings and streetscapes (Liang et al., 2024). Therefore, while building age mix may contribute to vitality, it shows no consistent association with window-view quality.

5.2.2. Why the associations vary with window height

Window height substantially changes the observed associations. The road-density, POI-entropy, and FAR slopes become less negative as height increases, while the building-age slope shifts from negative to positive. One possible explanation is that higher viewpoints contain less near-field façade obstruction, longer viewing distances, and greater sky exposure.

An explanation is that height changes how urban forms enter the indoor visual field. As height increases, nearby facades usually become less visually dominant, viewing distance expands, sky exposure increases, and the direct intensity of street-level visual complexity declines. As a result, the same urban configuration is not

experienced in the same way across heights. This interpretation is consistent with previous research showing that, in high-density high-rise settings, floor level, inter-building relationships, and visual elements shape perceived oppressiveness, outlook, and visual privacy (Chang & Schiavon, 2026; Chung et al., 2019; Wang & Munakata, 2024).

More broadly, this finding adds a vertical dimension to the discourse on the link between window-view quality and urban form. Much of the urban planning literature advocates density, land-use mix, and street structure primarily, implicitly treating urban experience as if it were relatively flat. Our results support a vertically stratified perspective, one that accounts for the volumetric complexity of the high-density city.

5.3. Planning and design implications under contextual variation

The associations between these form indicators and window-view quality are not evenly distributed, suggesting that interventions should respond to specific urban contexts. Baseline window-view quality is generally lower in high-intensity TPUs than in low- and medium-development-intensity TPUs, whereas geographic region and planning zone mainly alter the associations between vitality-oriented urban form and window-view quality. This context-sensitive approach accords with Hong Kong scenario studies showing that changes in plot ratio and building height have site-dependent environmental consequences and with reviews calling for geometry-specific, person-oriented planning in compact vertical cities (Caswell et al., 2025; Guo et al., 2020).

The urban forms associated with lower window-view quality also differ by context. Relative to the New Territories, Hong Kong Island shows more negative road-density, POI-entropy, and building-age associations, whereas in Kowloon the differences are concentrated in POI and building-age entropy. Relative to new towns, road density and POI entropy are more negative in urban extensions and old urban areas, with an additional building-age difference in old urban areas. Where road-density associations are stronger, planning should emphasize area-level permeability, building separation, and facing-building relationships; where POI-entropy associations are stronger, it should trigger detailed review of street-facing functions and interface organization rather than simply reducing functional mix. The less negative FAR association in these regional and planning settings further indicates that density should not be treated as a

stand-alone proxy for visual pressure. This interpretation is consistent with evidence linking building spacing and separation distance to perceived oppressiveness, while POI research cautions that entropy measures category balance rather than whether functions are complementary or well arranged (Chung et al., 2019; Wang & Munakata, 2024; Yue et al., 2017).

The three vitality-oriented street variables also work at different spatial scales, so responses should match their scale of influence. The road-density association is stronger at larger buffers and remains stable across scales, which suggests a need to examine it through area-level street structure, block permeability, and facing-building relationships. POI entropy, in contrast, is strongest at the 300m buffer, where its visual effects depend more on the immediate organization of ground-floor functions and street-facing content. Building-age entropy changes sign across scales and should be treated as a contextual flag rather than the basis for a fixed scale-specific intervention, whereas FAR remains negative across scales and is better addressed through subdistrict-level development control. This distinction between broad structural geometry and local interface conditions accords with 3D studies showing that urban openness depends on viewpoint and surrounding volumetric configuration, which two-dimensional summaries may miss (Chen et al., 2014; Zhu et al., 2025a).

Window-view quality also shows clear vertical differentiation. The continuous models show that the form-view slopes shift upward with window height at every scale, while the within-building floor-group analysis shows the clearest attenuation for POI entropy and FAR; road network density remains negative across floor groups. Low- to mid-heights should be treated as a priority. Even where higher residential placement is not feasible, design review should test building spacing, staggered layouts, setbacks, podium-tower transitions, and lower-level greenery; experiments specifically support spacing, staggered layouts, and greenery as relevant to high-rise window-view oppressiveness (Chung et al., 2019; Wang & Munakata, 2024). Hong Kong research further shows that residents evaluate domestic windows through view and privacy as well as daylight (Lau et al., 2010). More broadly, vitality-oriented urban design in vertical cities calls for a stratified approach, one that responds not only to differences across urban contexts and scales, but also to the uneven distribution of visual exposure across height.

5.4. Limitations

This study has several limitations. First, the findings are specific to Hong Kong's compact, high-rise morphology and should not be assumed to apply to other cities. Second, because the study is cross-sectional, the observed associations may reflect multiple processes, intensive development may constrain window views, locations with poorer views may be selected for more intensive development, or both may arise from shared locational and institutional conditions. The included controls reduce but cannot eliminate omitted-variable bias. We therefore interpret the estimates as associations rather than causal effects. Third, the dependent variable is a model-predicted window-view quality score rather than a direct subjective evaluation for every sample. Although this makes large-scale analysis possible, it may not fully capture all dimensions of indoor visual quality, such as restoration, privacy, or broader well-being relevance. Independent variables such as POI entropy also capture category balance rather than functional compatibility, street-facing interface quality, noise, traffic disturbance, or other nuisance exposures. These unmeasured conditions may affect both vitality-related form and window-view quality and may therefore contribute to residual confounding. Fourth, although the simulated window views capture direction-specific visual information, the regression models do not explicitly account for viewing orientation or local three-dimensional spatial configurations. These factors may contribute to unexplained variation in window-view quality and warrant further investigation. Finally, the outcome in the main analysis is a predicted score (five-fold cross-validation $R^2 = 0.41$; $r = 0.64$). The robustness check confirms the height association and the negative direction of the mix measures. Road network density falls close to zero, and FAR turns significantly positive under the human-rated outcome, so conclusions about these two indicators are limited to the predicted-score models.

These limitations contribute to future work. The urban form indicators are validated against three vitality proxies, pedestrian volume (a single-moment snapshot), POI density (supply rather than realized use), and night-time light (biased toward commercial activity), used jointly because no single measure captures a multidimensional concept (Tu et al., 2020); direct behavioural measures, such as mobile-phone positioning or sustained pedestrian counts, would strengthen the assessment of urban vitality. Multi-city comparison, longitudinal or quasi-experimental designs, and tighter integration of area-based context with window-specific visual

exposure are also promising directions.

6. Conclusion

This study examines the associations between vitality-oriented urban form and indoor visual quality. Using Hong Kong as a high-density vertical urban case, we find that denser road networks, greater functional mix, and higher FAR are linked to poorer model-predicted indoor window views, especially at lower window heights. In the human-rated subsample, the road-density association drops to near zero and the FAR changes to be positive. These patterns vary across urban contexts and spatial scales, supporting planning strategies that evaluate street-level activity and indoor visual quality together.

CRedit authorship contribution statement

Yi Liu: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Yi Lu:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Maosu Li:** Resources, Data curation, Writing – review & editing. **Di Wei:** Resources, Data curation. **Dongwei Liu:** Resources, Data curation. **Filip Biljecki:** Writing – review & editing.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary material

Supplementary data associated with this article are available in the online version of the published article at <https://doi.org/10.1016/j.habitatint.2026.104016>.

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