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Vertical Urbanism Beyond Mixed-Use Incidence: Functional Retention and Layer Transition in Hong Kong

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Abstract
Mixed-use districts have been characterized as high-density transit districts whose functions have been compartmentalized on podiums, concourses, decks, towers, and interiors connected with stations. In this paper, I look at the case of Central and Tsim Sha Tsui districts of Hong Kong to answer the following question: If the function mixture of whole buildings becomes visible on the ground, through what receiver pathway would it take place? What can we know about the vertical composition of transit-oriented urbanism from this pathway? The numbers will comprise four observations of district layers: central overall; central above-ground vertical; tims sha tsui overall; and tims sha tsui above-ground vertical. These numbers comprise pure live, pure work, pure visit, mixed function, and without point of interest of 2,566 buildings in Central and 771 buildings in Tsim Sha Tsui. The calculations involve functional visibility, mixed-use retention, Layered Functional Persistence Index (LFPI), layer closure reliability, closed visible composition, Jensen–Shannon divergence, layer transition work, receiver classification, and interface burden equivalence. In Central, there is weak vertical persistence due to the fact that mixed-use retention is 40.44% and visibility retention is 51.61%. Vertical composition in Central approaches the pure live receiver pathway because pure live rises by 36.74 percentage points while pure work, pure visit, and mixed use drop. Tsim Sha Tsui displays greater vertical persistence because its mixed-use retention is 63.80% and visibility retention is 89.44%. Vertical transition of Tsim Sha Tsui is work-receiver oriented since pure work increases by 20.30 percentage points while mixed use falls by 22.10 percentage points. The visit enrichment in lower floors of 14.4 percentage points equals 44.25% of the mixed use incidence loss in Central and 60.01% in Tsim Sha Tsui. These findings prove that volumetric mixed use cannot be assessed by the measure of mixed use incidence. Central and Tsim Sha Tsui differ in persistence, compositional discontinuity, receiver orientation, and lower interface reliance and, therefore, require different planning approaches.

Keywords: volumetric urbanism; transit-oriented development; vertical sorting; functional mix; Jensen–Shannon divergence; pedestrian interface; Hong Kong

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1. Introduction

Transit stations in high-rise urban centres are organised as a vertical territory of rail platforms, ticket halls, passages, elevated walkways, malls, lifts, hotels, offices, residential towers, and service corridors, not a mosaic of horizontal land use. Multi-level footbridges, underground passages, malls, podiums, and station integrated developments are characteristic of the vertical transit district in Hong Kong [1]. Walkability studies have confirmed that multi-level pedestrian connections significantly impact access assessment [2]. Hybrid walkable network analysis also confirms that Hong Kong public space is an interplay between public, quasi-public, commercial, and privately managed zones [3]. Studies in vertical spatial cognition have demonstrated that the vertical environment is interpreted as a 3D city system [4]. That is why, when the whole building is considered a single entity, a station area may appear mixed, although the visible record may reveal that the live, work, visit, and mixed functions are not evenly distributed within layers.

The point is that the transit-oriented development is related to compactness, accessibility, density, pedestrian movements, and land use mix. Recently published research in TOD has shown that the mix of urban functions affects the ridership and performance of station area in a scale and composition-dependent manner [5]. At the same time, the sensitivity to the scale increases in the context of vertical urban environments. Ground or parcel-based approach identifies the proximity to transit and the mix of urban functions but is unable to define whether the activity is vertically distributed or aggregated around the lower interface. Three-dimensional urban morphology studies emphasise the same point stating that the building height, volume, and massing provide the information that goes beyond the footprint [6]. Functional vertical 15-minute city studies have developed the floor-based measures of density and service composition [7]. All these confirm the premise of the present paper: a mixed-use transit district has to be examined not only in terms of functional diversity, but also in terms of its vertical dynamics.

A mix of functions is a challenging issue to be interpreted in multi-level urban districts, as the same count can result from different configurations. A building with a retail sector at podium and housing above the podium can be defined as a mixed building in terms of the whole-building categorization, but in terms of the above-ground visible composition it will be live-oriented. The office-hotel-retail complex can preserve the work-oriented or visitor-oriented upper profile. A station-linked podium can cluster visit functions in the lower parts, leaving the upper layers to become less visible. The assemblage-based studies of the functional mix highlight the importance of the relations between the use categories [8]. The studies on walkability also underline the importance of the spatial relations between the destinations, movement networks, and urban interfaces [9]. Similarly, the analysis of the functional mix in dispersed urban settings demonstrates the significance of the relations between the use categories in addition to their count [10]. In the vertical district, the question of the interface between the public pedestrian movement and specialized upper functions becomes an important part of the relational problem. The simple count of the mixed use cannot indicate which receiver pathway the upper profile belongs to: live, work, visit, or a loss of functional evidence.

The increasing application of the point-of-interest data and multi-source urban data sets allows the identification of functional urban areas and functional mix. The advantage is a fine spatial granularity of the analysis, but the weakness is a non-uniform observability across buildings, floors, and interior zones. The analysis of the functional mix based on the point-of-interest data allows defining urban functional areas with the help of the detailed categorisation and the measures of functional mixture [11]. The spatial partitioning of the POI data provides another approach to delineate the functional urban areas [12]. The vertical functional analysis has recently moved beyond the planar count of the POIs by assigning or inferring the floor-level activities, applying 3D spatial containers, and comparing the vertical and planar categorizations [13]. In the present analysis, the compact level of analysis is selected: the analysis is based on the recorded district-layer count record of Central and Tsim Sha Tsui. In the analysis, we do not imply any trajectory of individual buildings because it is not supported by the aggregate records, but it allows to determine the vertical pathway of each district.

That is why, the research question of the present analysis is rather precise: when the whole-building functional mixture is transformed into the above-ground visible composition in Central and Tsim Sha Tsui, which receiver pathway appears, and what implications does it have for the volumetric TOD evaluation? The dataset is narrow and transparent: it includes four observations: Central overall, Central vertical, Tsim Sha Tsui overall, and Tsim Sha Tsui vertical. Central includes 2,566 buildings; Tsim Sha Tsui includes 771 buildings. Each district-layer record divides buildings into the categories of pure live, pure work, pure visit, mixed function, and buildings without assigned POIs. The analysis is based only on the recorded district-layer categories and reads them in the light of visibility, persistence, closure, closed composition, divergence, transition work, receiver direction, and lower-interface burden. The contribution lies in interpretation: Central and Tsim Sha Tsui are not considered as examples of one type of mixed use, but as different vertical sorting pathways with the help of the numerical evidence.

Central and Tsim Sha Tsui districts provide a good example for comparison because they are intense transit districts with different urban roles. Central is a high-density business and institutional centre represented by office towers, commercial podiums, elevated pedestrian system, and station-linked interiors. Tsim Sha Tsui is a commercial, visitor, hotel, retail, and service district with active pedestrian movement and multi-level access to transit. Central and Tsim Sha Tsui contain mixed functions, but mixedness has a different vertical meaning in each case. The central question is not whether one of the districts is mixed, but what happens to mixed use when the visible above-ground layer is separated from the whole-building categorization.

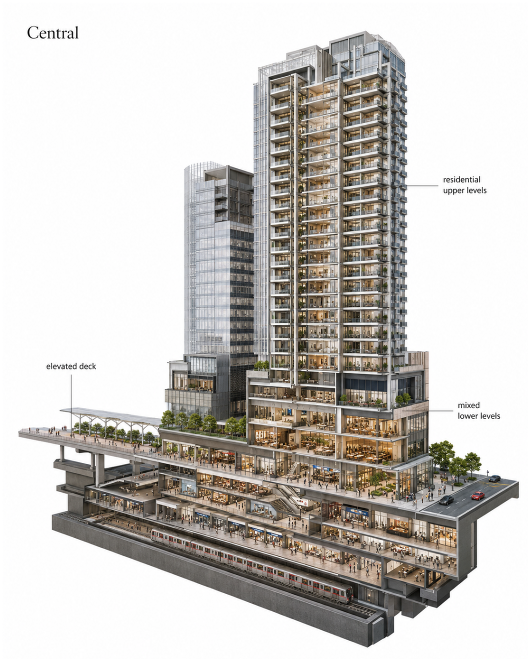
The initial image in Figure 1 defines the spatial setting for the question. Figure 1a presents Central as a vertically layered station district, where the mixed interface at the lower level is followed by the live-oriented upper level. Figure 1b presents Tsim Sha Tsui as a visitor-commercial district, where the visitor-oriented lower interfaces are connected with the work-oriented upper levels. The image is not used as evidence for calculations, but it helps to interpret the district-layer count record.

The visual contrast supports the sequence of analysis in the manuscript. Central is expected to respond to the divide between commercial lower layers and upper residential visibility, whereas Tsim Sha Tsui is expected to maintain a greater relationship between visitors and work above the lower interface. The following sections test these hypotheses using the district-layer count record rather than the visual illustration.

2. Materials and Methods

2.1 Study areas and numerical record

Here are analyzed two Hong Kong transit districts: Central and Tsim Sha Tsui. Central is a tightly condensed central business district where rail access, office towers, commercial podiums, elevated walkways and station-linked property development make up a highly layered urban environment. Tsim Sha Tsui is a compact commercial and visitor-oriented district where metro access, hotels, retail and service businesses, waterfront movement and substantial pedestrian economy exist. The two districts



(a) Central.

(b) Tsim Sha Tsui.

Figure 1. Volumetric district context.

are suitable subjects for a layer-based analysis of functional relationships because they both have multi-layered access systems and mixed-use buildings, but are different in terms of economic specialization and vertical organization.

The numerical record includes aggregate building counts by whole-building and above-ground vertical conditions in [14]. Each district-layer row has six categories: pure live, pure work, pure visit, mixed function, buildings without assigned POI functions and total buildings. In Central there are 2,566 buildings in total. In Tsim Sha Tsui there are 771 buildings in total. Central's overall counts are 166 pure-live buildings, 425 pure-work buildings, 115 pure-visit buildings, 1,402 mixed-function buildings and 458 buildings without POIs. Central's vertical counts are 481 pure-live buildings, 3 pure-work buildings, 27 pure-visit buildings, 567 mixed-function buildings and 1,478 buildings without POIs. Tsim Sha Tsui's overall counts are 3 pure-live buildings, 117 pure-work buildings, 32 pure-visit buildings, 511 mixed-function buildings and 108 buildings without POIs. Tsim Sha Tsui's vertical counts are 15 pure-live buildings, 225 pure-work buildings, 27 pure-visit buildings, 326 mixed-function buildings and 178 buildings without POIs. The comparison of interfaces uses a mean visit-related share of 0.544 below the third floor and 0.400 at or above the third floor.

In the following analysis, these numbers are treated as an aggregate layer-transition record rather than individual building observation. The claims are not being made about floor space, pedestrian flow or tenant intensity in the building stock. The unit of measure is building count per category. The analysis evaluates compositional information in the listed building stock and not floor-space intensity or actual person-trips. This is in line with the nature of compositional analysis, in which the principal question revolves around the proportions of observed categories [15]. It also keeps the empirical claim contained: the paper studies a district-layer count record, not lease areas, cadastral floor areas or pedestrian flows.

2.2 Notation and visible stock

Let s be the district where $s \in \{C, T\}$ stands for Central and Tsim Sha Tsui. Let l be the layer condition where $l = O$ is the overall whole-building condition and $l = V$ is the above-ground vertical condition. Then for each district and layer N_s is the total number of buildings, B_{sl} is the count of buildings without assigned POI functions, M_{sl} is the count of mixed-function buildings and P^L_{sl}, P^W_{sl} and P^R_{sl} are the counts of pure-live, pure-work and pure-visit buildings. The visible stock is

$$A_{sl} = N_s - B_{sl}. \tag{1}$$

The listed functional sum is

$$S_{sl} = P^L_{sl} + P^W_{sl} + P^R_{sl} + M_{sl}. \tag{2}$$

Differentiating A_{sl} from S_{sl} is critical from the methodological point of view. A_{sl} stands for the total number of buildings that have POI function(s) after the buildings which lack POI are deducted. S_{sl} stands for the four category count which was specifically designated as living, working, visiting, or mixed. When $S_{sl} = A_{sl}$, all the functional categories presented are accounted for the visible stock. When $S_{sl} < A_{sl}$, a residual arises, which cannot be automatically assigned elsewhere.

2.3 Layered functional persistence index

Functional visibility is calculated as

$$\Phi_{sl} = \frac{A_{sl}}{N_s}. \tag{3}$$

District-wide mixed-use incidence is calculated as

$$\mu_{sl} = \frac{M_{sl}}{N_s}. \tag{4}$$

The mixed-use retention ratio is

$$\rho_s = \frac{M_{sV}}{M_{sO}}, \tag{5}$$

and the visibility retention ratio is

$$\nu_s = \frac{\Phi_{sV}}{\Phi_{sO}}. \tag{6}$$

The Layered Functional Persistence Index is

$$\mathrm{LFPI}_s = 100 \times \rho_s \times \nu_s. \tag{7}$$

The LFPI is the combination of the mixed-use count preservation and functional visibility preservation. A high score means that mixed use functionality is still visible at the vertical layer level, and the vertical layer has not lost too many functional stocks compared to the whole building level. A low score means that mixed use occurrence and/or functional visibility have been largely diminished at the vertical layer level.

2.4 Layer-closure reliability

The layer-closure reliability value is

$$\mathrm{LCR}_{sl} = \frac{S_{sl}}{A_{sl}}. \tag{8}$$

This figure is represented as a percentage. This is used to carry out validation before composition analysis. If complete closure is achieved, then the four functional categories listed above make up all the visible stock. If near complete closure is achieved, then the four functional categories listed above are sufficiently representative although the remainder must not be ignored. The closure test does not indicate the quality of the city.

For the compositional analysis, the four functional categories listed above are normalized as

$$c_{sl}^{k} = \frac{X_{sl}^{k}}{S_{sl}}, \qquad k \in \{L, W, R, M\}, \tag{9}$$

where X_{sl}^{k} is the count in category k. This produces a closed visible composition among pure live, pure work, pure visit, and mixed use. The raw counts remain unchanged.

2.5 Compositional layer divergence

For each district, the overall visible composition is

$$\mathbf{c}_{sO} = (c_{sO}^{L}, c_{sO}^{W}, c_{sO}^{R}, c_{sO}^{M}), \tag{10}$$

and the vertical visible composition is

$$\mathbf{c}_{sV} = (c_{sV}^{L}, c_{sV}^{W}, c_{sV}^{R}, c_{sV}^{M}). \tag{11}$$

The midpoint composition is

$$\mathbf{m}_s = \frac{1}{2}(\mathbf{c}_{sO} + \mathbf{c}_{sV}). \tag{12}$$

The Jensen–Shannon divergence is

$$\mathrm{JSD}_s = \frac{1}{2}\sum_k c^k_{sO}\log_2\left(\frac{c^k_{sO}}{m^k_s}\right) + \frac{1}{2}\sum_k c^k_{sV}\log_2\left(\frac{c^k_{sV}}{m^k_s}\right). \tag{13}$$

The Jensen-Shannon divergence is applicable in this case since it gives an entropy comparison of two probability-like compositions [16]. The bounded metric nature makes it easier to have comparison of the distribution [17]. This is given as

$$D_s = \sqrt{\mathrm{JSD}_s}. \tag{14}$$

The bigger the value, the stronger the discontinuity in the compositional relationship between the whole building and vertical conditions. This measure takes into account the total change in the distribution among living, working, visiting, and mixed use.

2.6 Layer-transition work and receiver classification

The layer transition work is the minimum amount of visible compositional share that must be changed from the whole building composition to obtain the vertical composition. This is given as

$$\mathrm{LTW}_s = \frac{1}{2}\sum_{k\in\{L,W,R,M\}}\left|c^k_{sV} - c^k_{sO}\right|. \tag{15}$$

This value is measured in percentage points. It is highly correlated with total variation distance and offers an easy interpretation of compositional reallocation. The value equaling zero means that there was no change. Higher values correspond to higher levels of layer sorting.

The signed transition of every functional category is

$$\Delta c^k_s = c^k_{sV} - c^k_{sO}. \tag{16}$$

The predominant receiver is the category which gained the highest value of Δc^k_s. In case when the biggest gain happened in pure live, the district is a live-receiver district; in case when the biggest gain happened in pure work, it is a work-receiver district; and in case when the biggest gain happened in pure visit, it is a visit-receiver district. In the case when the most significant change is not a gain in any functional category but the loss of visibility, the district is considered visibility-loss dominated district. It represents the translation of numerical transition into urban meaning.

2.7 Interface burden equivalence

The comparison of interfaces is based on the difference between the average proportion of visit-oriented functions under the third floor and the average proportion above the third floor. Let $\bar{v}_{<3}$ be the lower floor and $\bar{v}_{\geq 3}$ be the upper floor values. Interface enrichment is

$$E_v = \bar{v}_{<3} - \bar{v}_{\geq 3}. \tag{17}$$

The Interface-Burden Equivalence value is

$$\mathrm{IBE}_s = \frac{E_v}{\mu_{sO} - \mu_{sV}}. \tag{18}$$

The value is comparative, not causal. It is concerned with the relation between the scale of lower-floor visit enrichment and the district-wide reduction of mixed-use incidence across the overall and vertical layers. A larger value means that lower-interface visitor density is substantial compared with the vertical reduction of mixed-use incidence for the district. This value is particularly significant in transit districts due to the nature of accessibility depending on destination bundling and access through the pedestrian network [18]. Studies carried out in Hong Kong suggest that mobility between the underground and the surface is driven by planned pedestrian connectivity [19]. Furthermore, pedestrians in narrow, dense pavements show how activity becomes concentrated on certain circulation and interface levels [20].

3. Results and Discussion

The analysis proceeds from the observation-based counts into the pathway diagnosis. The sequence is crucial. Counts first determine the amount of functional evidence available in each record from district layers. Then, LFPI captures the persistence of mixed-use identification and visibility. Closed composition describes the distribution of categories within the available evidence. Then, divergence and transition analysis quantifies the redistribution of functional types. Receiver classification determines the direction of vertical shift. Finally, interface burden equivalence compares the scale of lower-floor visit enrichment against that of the reduction of mixed-use incidence. Discussion in each section follows immediately after each table or figure.

3.1 Structure of the raw count data and consistency of closure

The count table already reflects a clear disparity between the two areas prior to any index being generated. Central has 2,566 buildings for both the layers, but the without-POI count for Central increases from 458 for the entire building layer to 1,478 for the above-ground vertical layer. Tsim Sha Tsui is smaller with 771 buildings, and its without-POI count increase is less dramatic, increasing from 108 to 178. Hence, the vertical transition for Central is not merely one of functional composition; it is also an issue of visibility.

Table 1. Building counts and layer-closure reliability.

District	Layer	Pure live	Pure work	Pure visit	Mixed	Without POIs	Total	Listed sum	LCR (%)
Central	Overall	166	425	115	1402	458	2566	2108	100.00
Central	Vertical	481	3	27	567	1478	2566	1078	99.08
Tsim Sha Tsui	Overall	3	117	32	511	108	771	663	100.00
Tsim Sha Tsui	Vertical	15	225	27	326	178	771	593	100.00

The closure values presented in Table 1 lend credibility to the closed-composition analysis. There are three out of four rows with closure value of 100% - Central overall, Tsim Sha Tsui overall, and Tsim Sha Tsui vertical. The only row that does not close completely is Central vertical with a sum of 1,078 versus a visible total of 1,088, resulting in the LCR of 99.08%. Such a residual is visible in the interpretation, but not hidden within any other category. It means that the Central outcome is not a result of category-balance error, but the real pattern where vertical visibility is much lower and the remaining visible functions are distributed towards pure live.

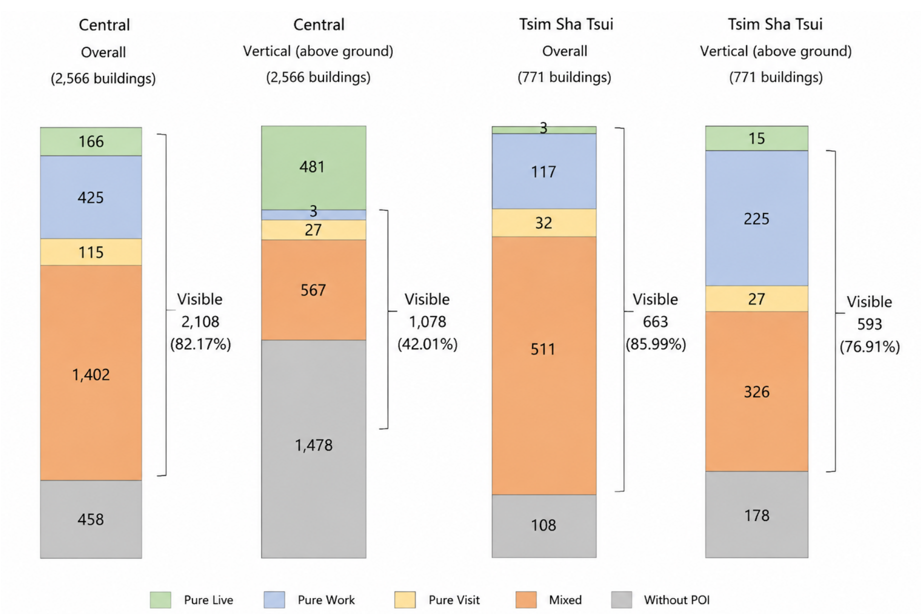


Figure 2. District-layer count exposure.

The visual count exposure on Figure 2 clarifies the contrast between Central and Tsim Sha Tsui. Central vertical column is dominated by the without-POI block, whereas the vertically oriented Tsim Sha Tsui district has more visible functional stock. It is the reason why later persistence results cannot be interpreted in terms of mixed-use loss alone. The LFPI of Central is low because of low visibility and function retention.

3.2 Vertical functional persistence

In LFPI, we separate vertical persistence into two parts: whether mixed-use buildings stay mixed vertically, and whether visible POI-function buildings stay visible vertically. The retention of mixed use in Central is 567 out of 1,402 mixed-use buildings, which means the retention of vertical mixed use rate is 40.44%. The visibility retention of Central drops from 82.15% to 42.40%, which gives a visibility retention rate of 51.61%. In Tsim Sha Tsui, 326 out of 511 mixed-use buildings retain their mixed use vertically, which results in a 63.80% retention rate of vertical mixed use.

Table 2. Layered Functional Persistence Index by district.

District	Φ_O (%)	Φ_V (%)	ρ_s (%)	v_s (%)	LFPI
Central	82.15	42.40	40.44	51.61	20.87
Tsim Sha Tsui	85.99	76.91	63.80	89.44	57.06

As seen in Table 2, the stronger vertical persistence district is Tsim Sha Tsui. It achieves an LFPI of 57.06, which is nearly three times the figure for Central, whose LFPI is 20.87. This disparity is not attributable to a single term. In Tsim Sha Tsui, mixed-use retention and visibility retention are both higher than in Central, where a large part of the vertical functions and a large part of mixed-use occurrence is lost. Here is the answer to the research question: these two districts are not comparable mixed-use districts when only the above-ground layer is considered.

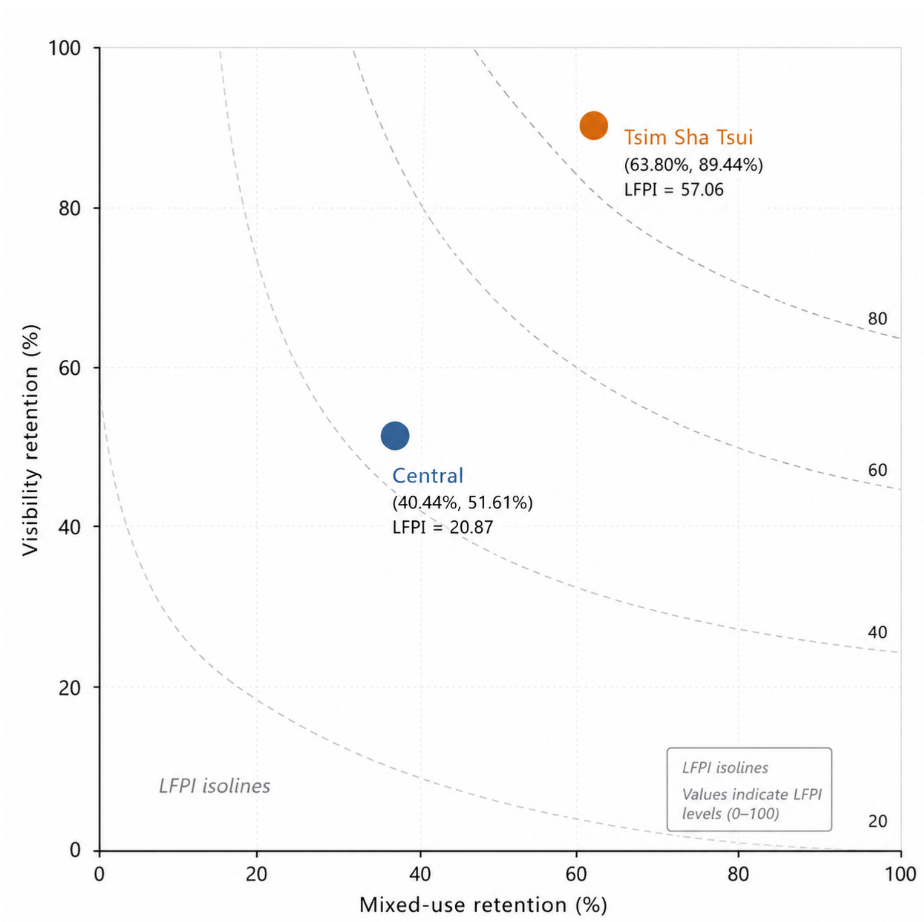


Figure 3. LFPI persistence surface.

From the persistence surface in Figure 3, one can see that this ranking is quite reliable since Central is situated near the lower middle area due to the lack of either type of persistence, while Tsim Sha Tsui is placed close to the upper right corner due to comparatively good visibility of the vertical layer and the smaller decrease in the mixed-use counts. Of course, this is a valuable insight into the situation, but it still lacks some information, since LFPI does not tell us how the vertical layer changes. Therefore, the second result will examine the closed visible compositions.

3.3 Closed visible compositions

Closed visible composition excludes the without-POI category from the functional balance and normalises the remaining four functional categories to 100%. While the previous step does not ignore the problem of visibility loss, it poses a different question. Among buildings with pure live, pure work, pure visit or mixed status, which types of buildings are dominant?

Table 3. Closed visible functional composition by district and layer.

District	Layer	Pure live (%)	Pure work (%)	Pure visit (%)	Mixed (%)
Central	Overall	7.87	20.16	5.46	66.51
Central	Vertical	44.62	0.28	2.50	52.60
Tsim Sha Tsui	Overall	0.45	17.65	4.83	77.07
Tsim Sha Tsui	Vertical	2.53	37.94	4.55	54.97

The closed compositions presented in Table 3 provide the most obvious functional contrast in this study. While the whole-building visible composition in Central is mixed-dominated, the mixed function makes up 66.51%. In the vertical composition, the mixed function still remains dominant, constituting 52.60%, but the share of the pure live function goes up from 7.87% to 44.62%. At the same time, the share of pure work falls dramatically from 20.16% to 0.28%. As for Tsim Sha Tsui, the proportion of the mixed use drops from 77.07% to 54.97%, while the proportion of pure work increases from 17.65% to 37.94%. The proportion of pure visit is almost unchanged. Thus, the proportions indicate that Central changes its orientation toward live-receivers, while Tsim Sha Tsui – to work-receivers.

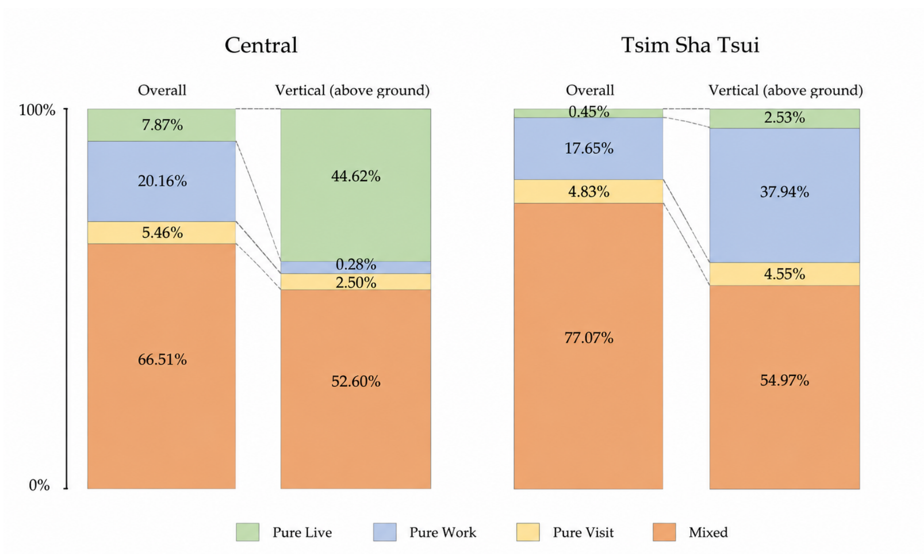


Figure 4. Closed visible composition.

The paired strips shown in Figure 4 provide a proportionally scaled presentation of the same information. In the vertical strip, Central gains a significant pure-live segment, while Tsim Sha Tsui acquires a considerable pure-work segment. It should be noted here that there are no flow ribbons in the figure, as the data represents an aggregation of district-layer counts, rather than any buildings' transitions. Hence, the figure reflects the compositional change in terms of proportions, not a transition of some particular building from one function to another.

3.4 Divergence of composition and layer transition work

Jensen-Shannon divergence and Layer Transition Work measure the magnitude of the vertical composition split by representing the same closed composition change using two different measures. JSD represents the difference between the building's total composition and the vertical composition using information units, whereas Layer Transition Work is the smallest reallocation needed for the transformation.

The diverging values presented in Table 4 support the assertion that Central experiences a greater compositional change. With a JSD of 0.204 bits and LTW of 36.74%, Central demonstrates an evident gap between the whole-building and vertical profiles. In the case of Tsim Sha Tsui, the JSD equals 0.047 bits, whereas the LTW stands at 22.37%. These diverging values demonstrate a clear but less prominent transition of the same type.

Table 4. Compositional layer divergence and layer-transition work.

District	JSD (bits)	$\sqrt{\text{JSD}}$	LTW (%)	Main interpretation
Central	0.204	0.452	36.74	Strong layer discontinuity
Tsim Sha Tsui	0.047	0.216	22.37	Moderate layer transition

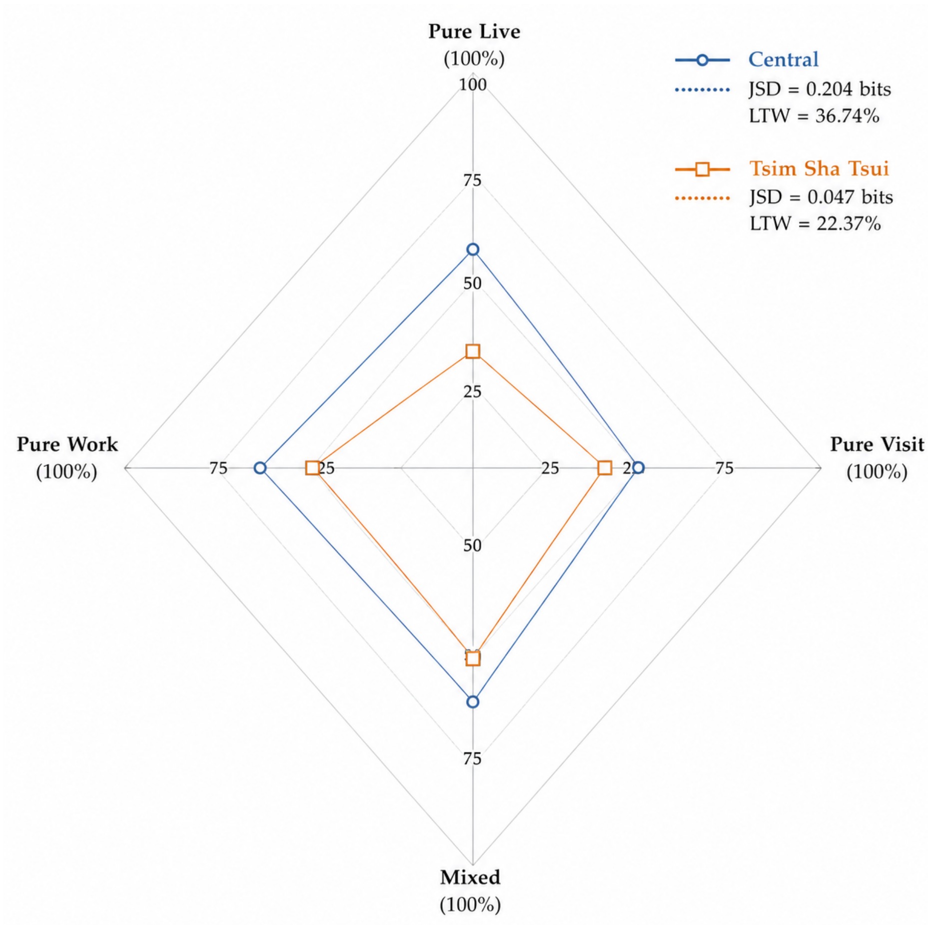


Figure 5. Compositional separation.

The separation diagram in Figure 5 provides further proof of the difference between the magnitudes and directions of the transitions. The longer displacement between the whole-building and vertical profiles is typical of Central and corresponds to higher JSD and LTW values. While Tsim Sha Tsui demonstrates a shorter displacement, it retains the direction towards the new functional balance. Compositional separation must thus be considered along with the receiver classification.

3.5 Dominant receiver pathways

The sign of the transition value reveals the receiving function category. This is the key step in formulating the answer to the research question, as it provides an urban pathway from persistence and divergence. A district can lose mixed-use dominance, but the planning meaning depends on whether the receiving category is live, work, or visit.

Table 5. Signed layer-transition values and dominant receiver classification.

District	Δ pure live (pp)	Δ pure work (pp)	Δ pure visit (pp)	Δ mixed (pp)	Dominant receiver
Central	+36.74	-19.88	-2.95	-13.91	Pure live receiver
Tsim Sha Tsui	+2.08	+20.30	-0.27	-22.10	Pure work receiver

The signed values in Table 5 provide direct answers to the question posed by the paper. Central represents a pure-live receiver example because pure live gains 36.74 percentage points and the other categories listed experience losses. The reduction in the pure work category is particularly steep (-19.88 percentage points), indicating that the vertical profile of Central cannot be regarded as merely a continuation of its overall building-district business identity. In the case of Tsim Sha Tsui, there is an increase of 20.30 percentage points for pure work and a decrease of 22.10 percentage points in the mixed use category. The two vertical layers thus show distinct vertical sorting processes rather than varying levels of persistence of mixed-use.

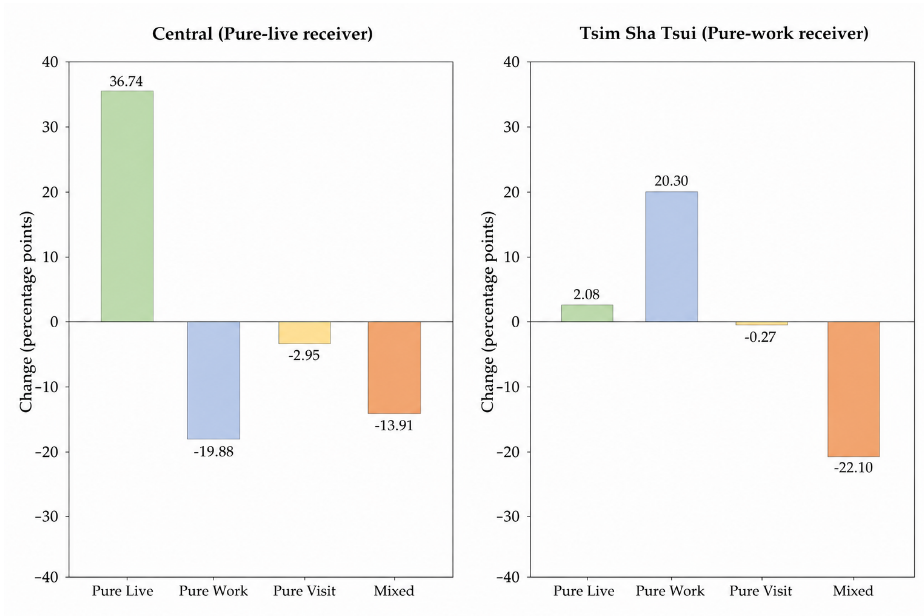


Figure 6. Receiver signature.

The gain-loss graph in Figure 6 helps to present the receiver finding visually. Central has one strong positive blade, namely pure live, and three negative blades. Tsim Sha Tsui has a dominant positive blade for pure work and a strong negative blade for mixed use. The visual pattern helps interpret the finding in an efficient way: Central is a residential-receiver layer whereas Tsim Sha Tsui is a work-receiver layer.

3.6 Interface-burden equivalence

The interface analysis concerns the distribution of visit-related functions below the third floor. The mean share of visit-related floors below the third floor is 0.544 while that at the third floor or above is 0.400. The difference is 0.144, or 14.4 percentage points. This interface burden is compared with the reduction in mixed-use incidence.

Table 6. Interface-burden equivalence.

District	Mixed incidence loss (pp)	Interface enrichment (pp)	IBE (%)	Reading
Central	32.54	14.40	44.25	Moderate relative burden
Tsim Sha Tsui	23.99	14.40	60.01	High relative burden

As we can see in Table 6, the same 14.4 percentage point lower interface enrichment has different relative importance in each of the districts. For Central, it is equal to 44.25% of the mixed-use incidence lost between the overall and vertical records. For Tsim Sha Tsui, it is 60.01%. It is not an inference of causality here. It means that the lower-floor visitor concentration in Tsim Sha Tsui is relatively greater compared to the mixed-use incidence lost between the overall and vertical records.

The floor threshold diagram in Figure 7 translates the number into a spatial perspective. We can see in this figure that the lower band is the recording of the 0.544 visit-related share below the third floor. On the other hand, the upper band is the recording of the 0.400 share at the third floor and above. As per the rulers of the figure, it can be seen that the same enrichment accounts for a relatively greater proportion of the incidence loss of Tsim Sha Tsui. Thus, a policy interpretation can be made that the vertical persistence of Tsim Sha Tsui is dependent on the performance of the lower visitor interface.

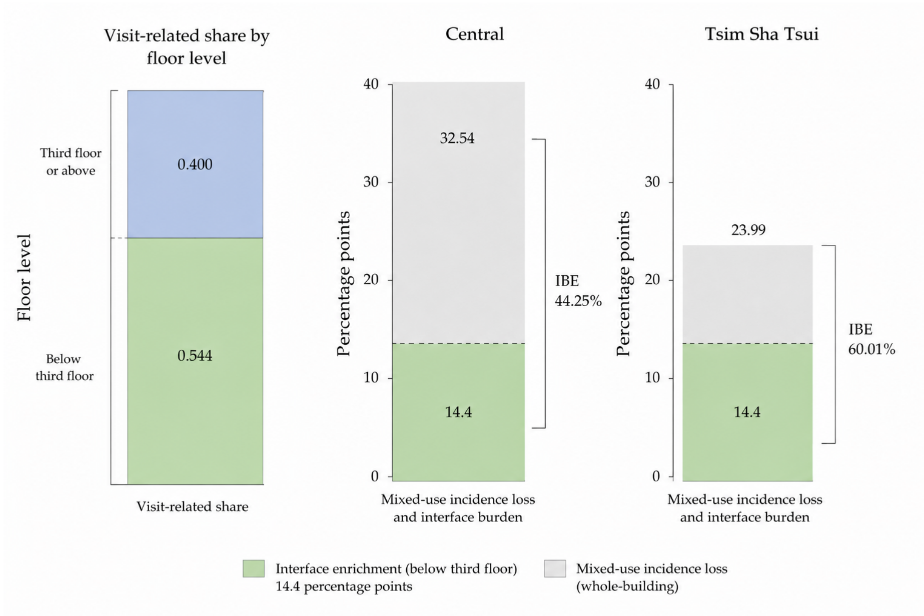


Figure 7. Interface burden equivalence.

3.7 Central as a live-receiver vertical sorting system

The results from Central should be understood as a live-receiver vertical sorting system rather than simply a low persistence mixed use district. From this figure, we can see that the whole building composition of Central has dominant mixed function, and also a considerable proportion of pure work. From the above-ground vertical record, we can see that the share of pure live goes up to 44.62%, the share of pure work goes down to 0.28%, and the without-POI buildings go up to 1,478. Thus, the conclusion can be drawn that Central's visible vertical layer is quite different from the whole building profile, in terms of reduced functional visibility, and live orientation.

In this case, the conclusion that we get is that in a district like Central, where there may be activity like office, retail, and pedestrian-interface activity at the lower or middle floors, the upper visible layer becomes more residentially sorted. However, it does not mean that there is no work activity in Central. It simply implies that in this case, the visible vertical composition captured by the counts does not have the same work-mixed balance as seen in the whole building profile. Therefore, planning evaluation should avoid making assumptions about the vertically distributed publicness based on lower interface activity.

3.8 Tsim Sha Tsui as a work-receiver persistence system

Tsim Sha Tsui makes a different vertical connection pattern. It has a higher LFPI, higher visibility persistence, and lower JSD and LTW than Central. This means that Tsim Sha Tsui retains better continuity between the whole building evidence and the vertical functional evidence. Nevertheless, this continuity does not imply the lack of sorting. Mixed use decreases from 77.07% to 54.97%, while pure work rises from 17.65% to 37.94%. The vertical layer becomes more work-focused while the district still maintains substantial mixing.

This work-receiver pathway reflects the nature of Tsim Sha Tsui as the commercial, visitor, hotel and service district in which the upper floors retain employment and service functions. The high interface-burden equivalence suggests the significance of visitor-facing lower layers. This way, the policy implication consists not only in mixed-use preservation, but in the coordination between lower visitor interfaces and upper work destinations. Station exits, hotel entrances, retail frontages, elevators and office/service lobbies should be interpreted as one vertical access environment.

3.9 Implications for volumetric mixed-use evaluation

The findings illustrate why a single mixed-use indicator is not enough for evaluating volumetric transit districts. Mixed-use incidence shows the existence of the combination of functions; LFPI shows whether the combination persists vertically; JSD and LTW show the gap in composition; receiver class shows the direction of the vertical change; and IBE compares lower visitor concentration with the overall district mixed-use losses. None of these measures is enough by itself. Collectively, they answer different pieces of the same urban puzzle.

In turn, the findings relate to the recent research in the field of 3D urban data analysis. The researches on 3D visual analytics highlight that urban data become harder to interpret when the form, use and movement operate in multiple dimensions [21].

Although the current analysis represents a compact count-based representation of 3D data rather than a complete model, the point is the same. Vertical urban evidence should not be flattened into planar indicators, especially in the case of Hong Kong when station-linked buildings, interior passages and elevated network divert public movement from the ground level.

3.10 Implications for comparative TOD policy

The pathway analysis divides three policy questions. The first concerns whether the district includes mixed functions in total; the second concerns whether these functions are preserved in the above-ground layer; the third concerns what type of receivers receives the vertical share of the decline in mixed-use. In this regard, the districts of Central and Tsim Sha Tsui have different answers. The same TOD label would mask the difference between live-receiver discontinuity and work-receiver persistence of Central and Tsim Sha Tsui.

For Central, the main task of urban planning is vertical legibility. Lower interface may be intense, but the vertical pattern indicates the significant separation between the mixed activity at the lower level and the live-oriented visibility of upper level. Thus, the design should address the boundaries, signs, lobby sequence, podium edge, pedestrian deck continuity and the boundary between public and private access. For Tsim Sha Tsui, the task is in the capacity of distribution. The district maintains the vertical functional visibility, but its higher relative interface burden implies the need of the effective lower floor pedestrian flow distribution towards upper work, hotel, retail and service destinations.

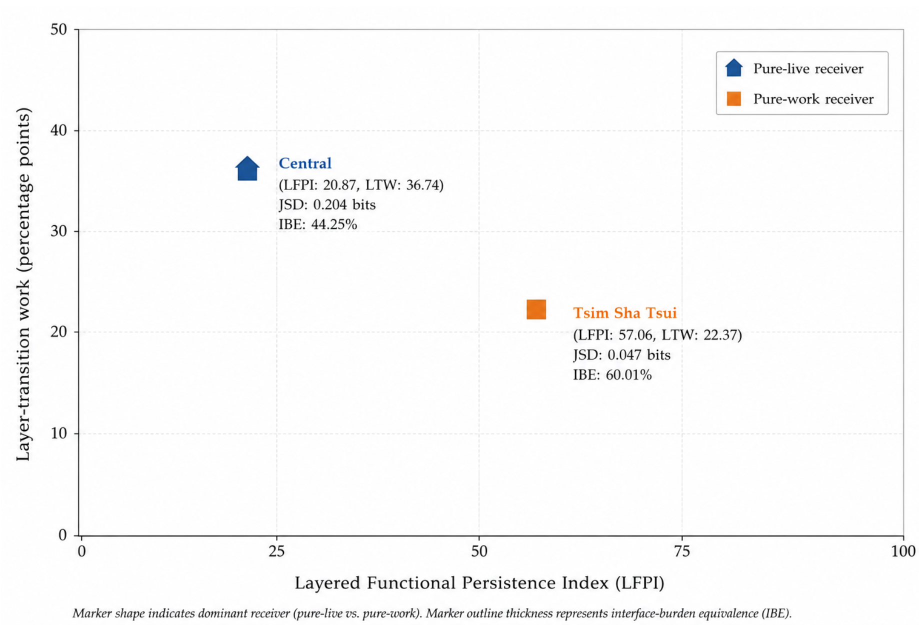


Figure 8. Integrated pathway diagnosis.

The diagnostic plane in Figure 8 provides a summary in one comparison view. Central is weak on LFPI and high on transition work, and therefore in a weak persistence and strong discontinuity position. Tsim Sha Tsui is high on LFPI and low on transition work, but also has the higher marker of higher relative interface burden. The figure demonstrates that the vertical mixed-use evaluation should not be reduced to ranking the two districts on a better/worse criterion. Their differences are categorical as well as numerical.

4. Conclusion

The research question inquired into which receiver pathway emerges with the re-expression of whole-building functional mixture as above-ground visible composition in Central and Tsim Sha Tsui, and how this pathway affects the evaluation of their volumes for TOD assessment. The answer to the question is district-specific. Central is not merely a mixed-use district performing poorly; it is the live-receiver vertical sorting case. Tsim Sha Tsui is not merely a mixed-use district performing well; it is the work-receiver persistence case with the higher relative dependence on lower interface visit activity.

Central's receiver pathway is characterised by low persistence and high compositional discontinuity. It is weak on LFPI, with its value equal to 20.87 since the mixed-use retention is only 40.44% and visibility retention is 51.61%. In the closed visible composition, the pure live increases from 7.87% to 44.62%, making up the gain of 36.74 percentage points. Meanwhile, pure work decreases from 20.16% to 0.28%, pure visit decreases from 5.46% to 2.50%, and mixed use decreases from 66.51%

to 52.60%. Central also has the higher value of JSD, equal to 0.204 bits, and of LTW, equal to 36.74%. These values reveal the vertical profile in which the whole-building mixed-use does not persist as a visible composition with an even distribution of the upper layer.

Tsim Sha Tsui's receiver pathway is characterised by higher persistence and work-receiver verticality. It is high on LFPI, with the value equal to 57.06 due to the 63.80% of mixed-use retention and 89.44% of visibility retention. In the closed visible composition, pure work increases from 17.65% to 37.94%, making up the gain of 20.30 percentage points, whereas mixed use decreases from 77.07% to 54.97%. The JSD and LTW are 0.047 bits and 22.37%, respectively, revealing a less pronounced shift of composition compared to Central. However, this district is characterised by the preservation of more vertical functional evidence, but with the upper visible composition moving away from mixed-use domination to the pure work.

The interface result provides the missing component in the answer to the question. The lower-floor visit enrichment is equal to 14.4 percentage points in view of the 0.544 ratio of visits below the third floor and 0.400 above the third floor. This enrichment constitutes 44.25% of the loss of mixed-use incidence in Central and 60.01% in Tsim Sha Tsui. Tsim Sha Tsui is characterised, thus, by higher vertical persistence and higher relative dependence on the lower visitor interface. Central is characterised by the low persistence and live-receiver shift.

The conclusion of the research is that the volumetric mixed-use assessment must take into account persistence, discontinuity, receiver direction, and interface burden. While the whole-building mixed-use counting makes it possible to estimate the aggregate diversity, it does not show whether the visible upper layer is live-receiver, work-receiver, visit-receiver, or visibility-loss dominated. The key planning issues for Central are the vertical segregation of the mixed lower interface and live-receiving upper visibility. For Tsim Sha Tsui, the key issue is the coordination of lower visitor interface and upper work/services.

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