

Airbnb and Urban Renewal in Lisbon (2015–2019): Spatial Interactions Revealed by Network-Enhanced Kernel Density Modelling

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Abstract

Understanding how spatial representation affects the interpretation of Airbnb activity and urban-renewal processes in Lisbon is relevant for more informed and territorially sensitive urban planning. This study compares their distributions for 2015–2019 using georeferenced datasets of Airbnb listings and municipally licensed urban-renewal events. Methodologically, it combines planar Kernel Density Estimation (KDE) with Network Kernel Density Estimation (NKDE), thereby capturing both general concentration fields and their organisation along the city's street structure. The integrated approach makes it possible to identify hotspots, areas of co-location, and linear concentrations structured by the street network. The results show that the two phenomena occupy many of the same central areas, while the network analysis also reveals street-level differences that are obscured by planar smoothing. From a methodological standpoint, the study shows that combining KDE and NKDE improves the diagnostic capacity for emerging urban phenomena by articulating a strategic citywide reading with an operational reading at street and junction level. The findings contribute to evidence-based planning strategies that can support more territorially precise forms of urban regulation and monitoring.

Keywords: Airbnb; urban renewal; kernel density estimation; network kernel density estimation; spatial analysis; Lisbon

1. Introduction and Background

Short-term rental (STR) platforms like Airbnb have profoundly reshaped the urban geography of tourist accommodation by expanding a digitally mediated market that operates at a fine spatial resolution. In Lisbon, the rapid expansion of Airbnb during the second half of the 2010s coincided with an intense cycle of licensed building rehabilitation, particularly in central historic neighbourhoods. This co-occurrence has been widely noted in public and academic debate, but its spatial expression can still often be described in impressionistic or fragmentary terms. From an urban planning perspective, the critical question is not simply whether both phenomena increased but how their apparent relationship can change when the same events are represented as planar density fields, as street-network intensities or as local-scale configurations.

Research on Airbnb has examined the disruptive role of the platform in tourist accommodation as well as its implications for market structure, urban regulation and neighbourhood transformation (Guttentag 2015). Much of this STR research relies on scraped platform data or derivative databases, which enable fine-grained spatial analysis but require careful interpretation of what listings actually measure (Cox 2020; Slee 2021). For cities under strong tourist pressure and real-estate investment, it becomes particularly important to understand how the presence of the platform can coincide with other urban processes, especially building rehabilitation.

In Lisbon, previous research has shown that licensed urban renewal activity can be represented through continuous density surfaces, making it possible to read concentration, gradients, and spatial persistence over time (Brandão et al. 2018). Density surfaces have also long been used to delineate central areas, communicate patterns that cross administrative boundaries and support comparative readings between distinct urban phenomena (Thurstain-Goodwin and Unwin 2000; Porta et al. 2009; Wang 2015). In the case of urban renewal, this type of representation is especially useful because it transforms heterogeneous permit locations into comparable fields of spatial intensity without imposing arbitrary territorial divisions.

It is important, however, to distinguish between different ways of constructing these density surfaces. In a planar approach, estimation is produced in Euclidean space and covers the whole study area. In a network approach, intensity is estimated directly on the street network with distances being calculated along its links and nodes. This second option is particularly appropriate when events are distributed predominantly along streets because it can avoid treating as equivalent a planar space that is too broad for phenomena occurring mainly on the linear support of the network. A substantial part of the methodological literature has shown that planar distance and planar search space can misrepresent the proximity and interaction of phenomena whose spatial organisation is governed by the street network (Okabe and Kitamura 1996; Miller 1999; Spooner et al. 2004; Yamada and Thill 2004; Lu and Chen 2007; Xie and Yan 2008, 2013; Okabe et al. 2009; Okabe and Sugihara 2012; Okabe et al. 2015). NKDE formalizes this principle by estimating intensity directly on the links and nodes of the street network, making linear concentrations, urban corridors and nodal points more legible where planar representations may smooth or dilute them (Okabe and Kitamura 1996; Xie and Yan 2008, 2013; Okabe et al. 2009; Okabe and Sugihara 2012; Okabe

et al. 2015). The interpretation also recognises that streets can differ in their configurational position and in their relationship to the surrounding land uses (Cutini 2001; Sevtsuk and Mekonnen 2012).

Following this methodological framework, the article combines planar KDE and NKDE to examine Airbnb and urban renewal in Lisbon between 2015 and 2019 through two complementary spatial approaches (Thurstain-Goodwin and Unwin 2000; Porta et al. 2009; Wang 2015). NKDE extends the analysis to the street network, identifying linear concentrations, connected corridors, high-intensity nodes and local spatial configurations that may not be fully captured by planar KDE (Okabe and Kitamura 1996; Xie and Yan 2008, 2013; Okabe et al. 2009; Okabe and Sugihara 2012; Okabe et al. 2015). Combining both methods also allows the consistency of spatial patterns to be evaluated across municipal, parish, and street scales. Related Lisbon applications have used network-based density analysis for urban renewal and Airbnb, while later work examined high-density Airbnb areas in the city (Correia et al. 2021a, b; Correia et al. 2024).

The analysis uses the common period from March 2015 to March 2019 because both principal datasets are available within the same continuous temporal frame. This period corresponds to a phase of rapid expansion and consolidation of Airbnb activity in Lisbon, during which the number of listings increased substantially and became increasingly concentrated in the historic centre and other central areas in the central-southern part of the city. It also coincided with an intensive cycle of licensed urban rehabilitation, making it particularly suitable for examining the spatial relationship between the two phenomena. The article uses the pooled four-year period to prioritise the comparison between planar and network-based spatial analysis and between municipal, parish and street scales, rather than focusing on annual variations.

The article aims to be explicitly diagnostic rather than causal in nature. The objective is therefore to map co-locations, interpret their spatial form and examine how their interpretation changes across two-dimensional, networked, municipal, parish and street-level representations, without inferring cause-and-effect relationships or even introducing additional external covariates. Within these limits, the text offers three main contributions. Firstly, it compares the KDE and the NKDE as complementary, but not equivalent, spatial frameworks. Secondly, it tests whether the conclusions for the city remain consistent at the finer scales of the parish and the street. Thirdly, it demonstrates how the choice of representation affects the level at which evidence of urban planning can be interpreted.

2. Data and Methods

2.1. Study Area and Analytical Scope

The study area is the Municipality of Lisbon, framed in the national context through a locator map of Portugal in Fig. 1. Two main event datasets were analysed for the period 2015–2019: (i) georeferenced Airbnb listings and (ii) licensed urban-renewal events understood here as building rehabilitation. For each phenomenon, planar KDE and NKDE surfaces were calculated and interpreted at three nested scales: municipal, parish, and street. The choice of the 2015–2019 period is treated as a coherent pre-pandemic baseline and as a methodologically consistent basis for the joint treatment of both datasets.

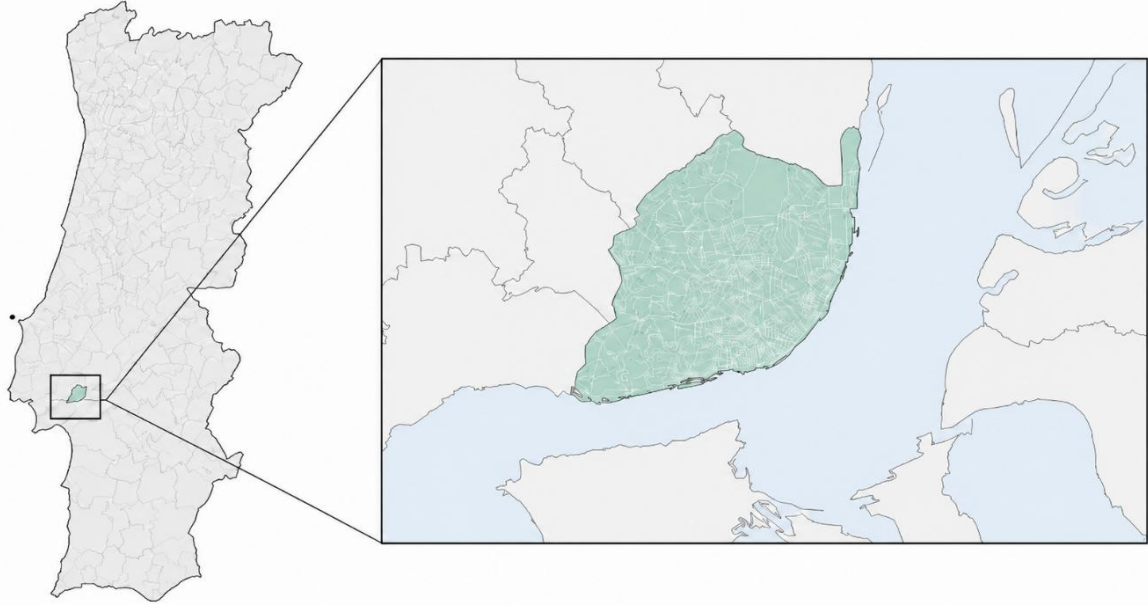


Fig. 1 Locator map of the Municipality of Lisbon in national context, with district and municipal boundaries and an enlargement of the Lisbon street network

2.2. Datasets

Airbnb Listings (2015–2019)

The Airbnb dataset was built from georeferenced records collected at different moments and derived from independent digital sources, including Inside Airbnb and tomslee.net, which were subsequently harmonised into a single database for spatial analysis. Each listing was identified, georeferenced and temporally associated with its collection date. The resulting database was clipped to the municipal boundary of Lisbon and cleaned to exclude inconsistent records or observations located outside the municipality's polygon. The final dataset also supported annual analyses while enabling an overall assessment of the 2015–2019 period.

Urban-Renewal Permits (2015–2019)

Urban rehabilitation events correspond to buildings with georeferenced records of permits for rehabilitation or refurbishment works. The dataset was prepared to remove duplicate records, standardise dates and ensure full compatibility with the municipal area and the time period used for the Airbnb data.

Street Network

NKDE requires a topologically valid and metrically embedded network. It was therefore necessary to model Lisbon's street network as a planar graph with link geometries and node topology suitable for network computation.

2.3. Pre-Processing and Quality Control

All datasets used in this study were transformed into a projected metric coordinate reference system appropriate for the Lisbon study area. This system thus ensured that the bandwidth and sampling parameters could be specified in metres. A polygon with the municipal area was also applied to restrict the events to the municipality's actual territorial area, thereby ensuring spatial consistency in this analysis. Temporal allocation was carried out consistently across all years, with four annual time slices defined for each phenomenon, supplemented by an integrated analysis covering the four-year period 2015–2019. This approach made it possible to link the temporal evolution of the patterns with an overall understanding of their spatial configuration.

2.4. Planar KDE

Planar KDE was estimated for Airbnb listings and for urban rehabilitation permits as a non-parametric smoothing method for point data distributed discontinuously in space. Instead of representing isolated locations alone, KDE can produce continuous intensity surfaces that are better suited to reading concentrations, gradients and persistent patterns at city scale, while also contributing to more legible and analytically consistent representations than those based on arbitrary aggregation units (Thurstain-Goodwin and Unwin 2000; Porta et al. 2009; Wang 2015). Implementing the method required defining the kernel function, the bandwidth and the resolution of the analysis

grid. These parameters were kept constant across years for each phenomenon to ensure that the resulting density estimations were directly comparable.

2.5. NKDE

NKDE was used as a method for estimating event density on the road network, based on the assumption that, when phenomena are predominantly distributed along streets, the planar space may become too extensive to represent them accurately (Okabe and Kitamura 1996; Miller 1999; Xie and Yan 2008, 2013; Okabe et al. 2009; Okabe and Sugihara 2012; Okabe et al. 2015). Unlike planar KDE, which estimates intensity across the entire study area, NKDE restricts the estimation to the links and nodes of the street network and calculates distances along the shortest paths (Okabe et al. 2009; Okabe and Sugihara 2012). The implementation adopted was based on the formulation of Okabe et al. (2009) and Okabe and Sugihara (2012) operationalised through SANET 4.1 (Okabe et al. 2015). Network intensity is estimated by propagating the kernel contribution along the shortest paths and redistributing it across the nodes according to explicit rules, thereby obtaining values for both links and nodes. To ensure comparability, the main parameters were kept constant, namely: kernel type, joining rule and sampling interval.

2.6. Comparison Between Phenomena

The comparison was carried out in three stages. Firstly, the densities of Airbnb listings and building refurbishments were analysed separately on a map to identify their main high-density areas – hotspots – across the city, as well as gradients and areas of spatial continuity. Secondly, the same aggregated time period was analysed within the road network to identify linear concentrations, sequences of connected links and peaks in the number of junctions that were not so easily distinguishable in Euclidean space. Thirdly, specific parishes and streets were examined to determine whether the relationship observed at the municipal scale persisted at more refined analytical scales.

Harmonised panels were used for direct visual comparison within each methodological approach. The parish of Santa Maria Maior was selected to represent the historic districts of Baixa and Alfama. Avenida da Liberdade was selected to examine a major central avenue and its surrounding parallel streets. The parish of Misericórdia and Avenida Almirante Reis serve as further examples of areas where the relationship between Airbnb and building rehabilitation varies according to spatial scale and the method used.

Co-location was identified when the areas or network links with the highest density were situated within the same urban structure or directly adjacent structures. Displacement was identified when the concentration of a phenomenon occurred on parallel streets, along sequences of shorter links or at different junctions. The comparison is descriptive and diagnostic. No Pearson or Spearman correlation coefficients or other formal coefficients were calculated, as this analysis does not seek to establish a causal relationship between Airbnb and urban regeneration.

2.7. Complementary Analytical Developments Within the Dataset

Without requiring additional data sources, future research using the same datasets could extend this methodological framework in three complementary directions. First, annual density surfaces could be compared to explore possible lead-lag relationships between Airbnb intensification and the concentration of urban renewal. Second, robustness analyses could be incorporated by systematically varying KDE bandwidth and grid resolution, as well as NKDE junction rules and sampling intervals, together with alternative Airbnb weighting schemes and host-structure segmentation. Third, three-dimensional density visualisations could enhance the comparison of hotspot hierarchies and the spatial organisation of the main urban corridors.

3. Results

This section presents the spatial patterns for Airbnb listings and licensed building rehabilitation in Lisbon (2015–2019) using the KDE and NKDE methods described in the previous section. The results are read at three scales—municipal, parish, and street—and combine planar density areas (KDE) and network-organised densities (NKDE) to examine how co-location appears both as a persistent central-area concentration in planar space and as a network of corridors and nodes along the street network.

3.1. Municipal-Scale KDE: A Persistent Central Belt of Co-Location (2015–2019)

The aggregated 2015–2019 KDE of Airbnb reveals a compact central area that encompasses Baixa, Chiado/Bairro Alto, and Alfama, extending towards Lisbon’s consolidated nineteenth- and twentieth-century urban expansions. The aggregated KDE of building rehabilitation produces a field that is strongly aligned with Airbnb’s central core.

This configuration is clearly visible in Fig. 2, while Fig. 3 shows that the KDE surface of building rehabilitation reproduces a strongly aligned central zone. The overlap is immediately visible: both phenomena concentrate in the historic centre and its immediate extensions, with gradients losing intensity as they move away from this central-southern core.

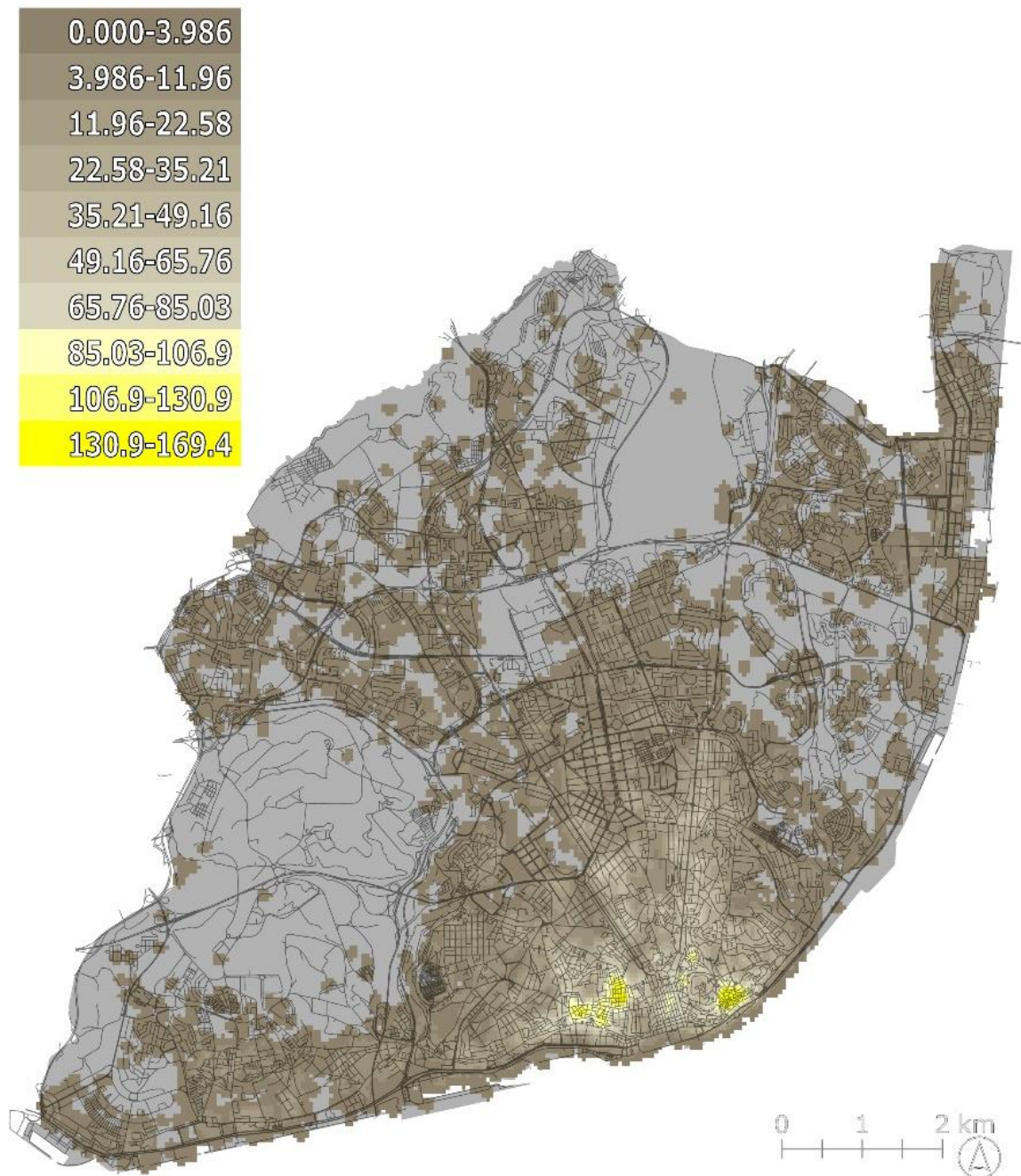


Fig. 2 Airbnb KDE, aggregated for 2015–2019. Legend classes indicate relative KDE intensity across the municipal grid; higher classes correspond to stronger concentration of Airbnb listings

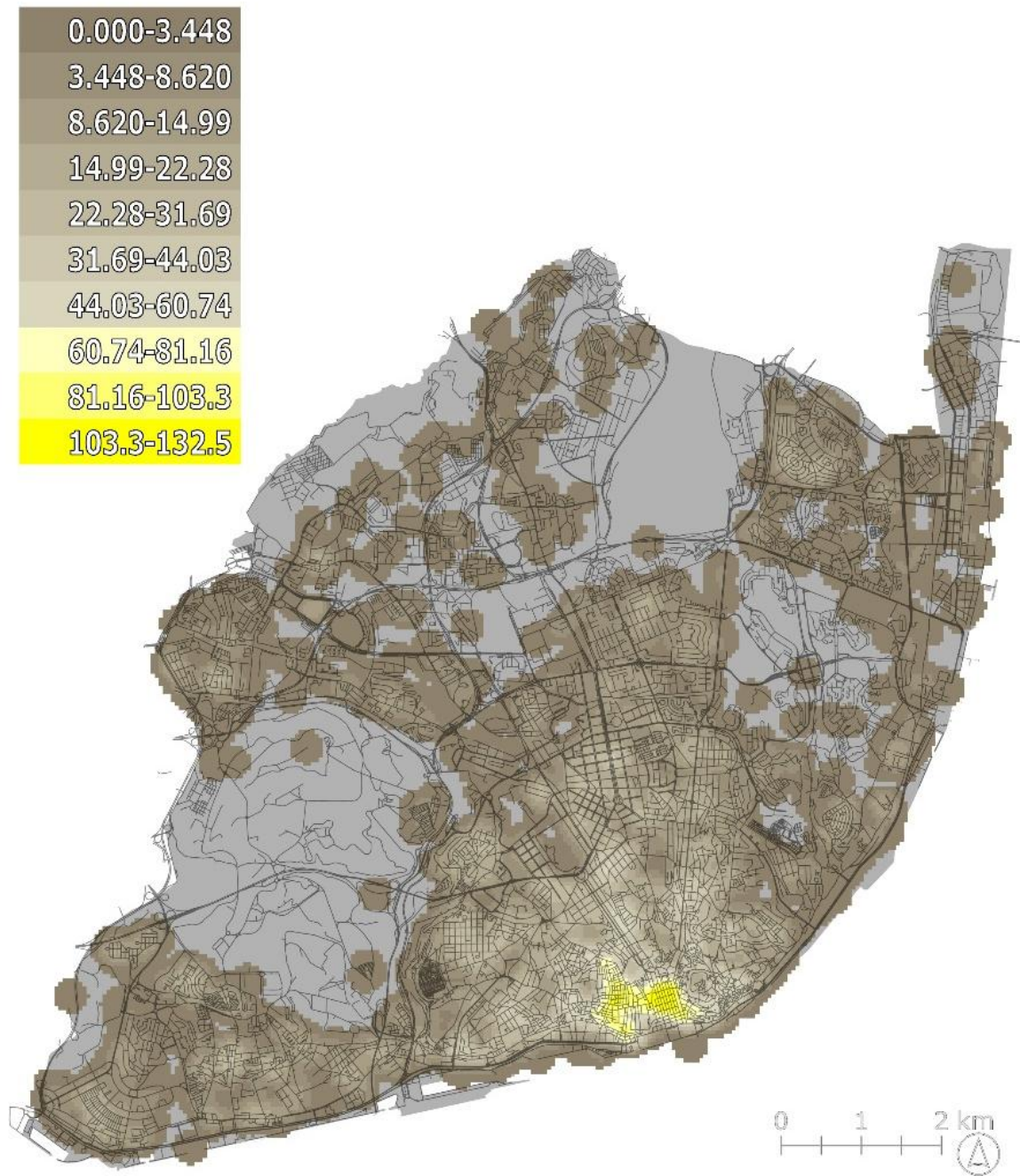


Fig. 3 Urban-renewal KDE, aggregated for 2015–2019. Legend classes indicate relative KDE intensity across the municipal grid; higher classes correspond to stronger concentration of licensed urban-renewal events

The annual surfaces confirm the persistence of this configuration. In every year, the main peaks remain in the centre, and the aggregated 2015–2019 surface consolidates them into a stable and legible field. This corresponds closely to the analytical potential of KDE: to communicate functional centres, hotspot fields, and spatial gradients that cross administrative boundaries (Thurstain-Goodwin and Unwin 2000; Porta et al. 2009; Wang 2015).

From a planning perspective, two aspects deserve emphasis. First, the density gradient around the central core is very steep, meaning that small spatial shifts in the centre correspond to major changes in intensity. Second, the central belt is not isotropic: it stretches preferentially along directions that anticipate the corridors later made explicit by NKDE. KDE therefore identifies not only where phenomena concentrate, but also how that concentration may be organised by the structure of the city.

3.2. Municipal-Scale NKDE: Linear Hotspots and Nodal Maxima (2015–2019)

When the same period is analysed on the street network, the central belt decomposes into linear concentrations and maxima located at highly connected nodes. As shown in Fig. 4, the Airbnb NKDE is organised around a set of recognisable urban systems, while Fig. 5 reveals that urban-renewal NKDE follows many of the same axes. The NKDE of Airbnb is organised around five main systems: Bairro Alto–Chiado–Cais do Sodré, Baixa (Santa Maria Maior), Avenida da Liberdade / Rua de Santa Marta, Avenida Almirante Reis, and Rua Carlos Mardel / Areeiro.

The NKDE of urban renewal reveals partially coincident concentrations along many of the same axes. These linear concentrations vary in thickness, reflecting the density of parallel and transversal links that sustain the observed intensity, and in several cases they cross parish boundaries. This shows that administrative limits do not always coincide with the functional corridors that structure both phenomena (Okabe and Kitamura 1996; Miller 1999; Xie and Yan 2008, 2013; Okabe et al. 2009; Okabe and Sugihara 2012; Okabe et al. 2015).

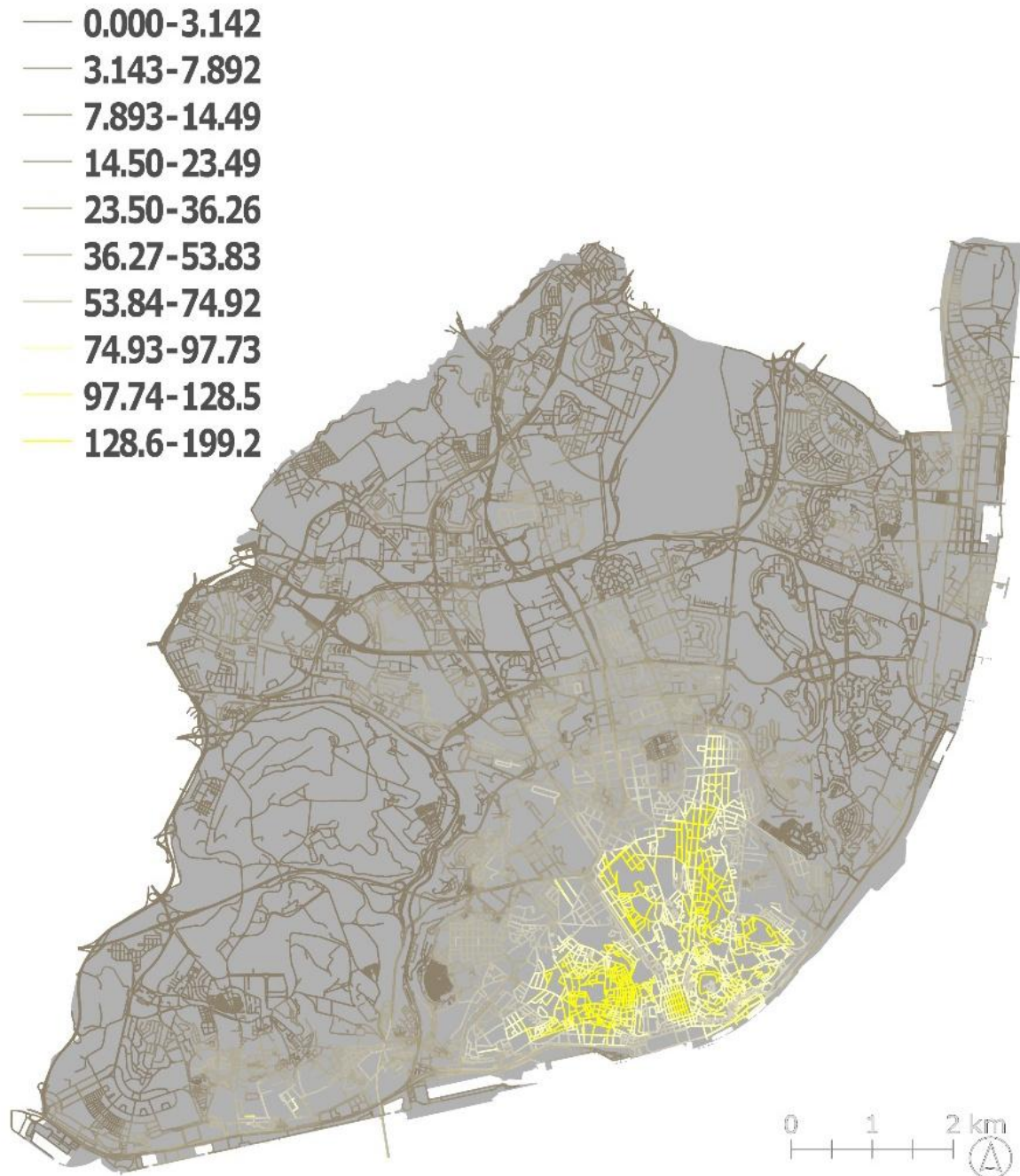


Fig. 4 Airbnb NKDE, aggregated for 2015–2019. Legend classes indicate relative NKDE intensity along network links; higher classes correspond to stronger concentration along the street network

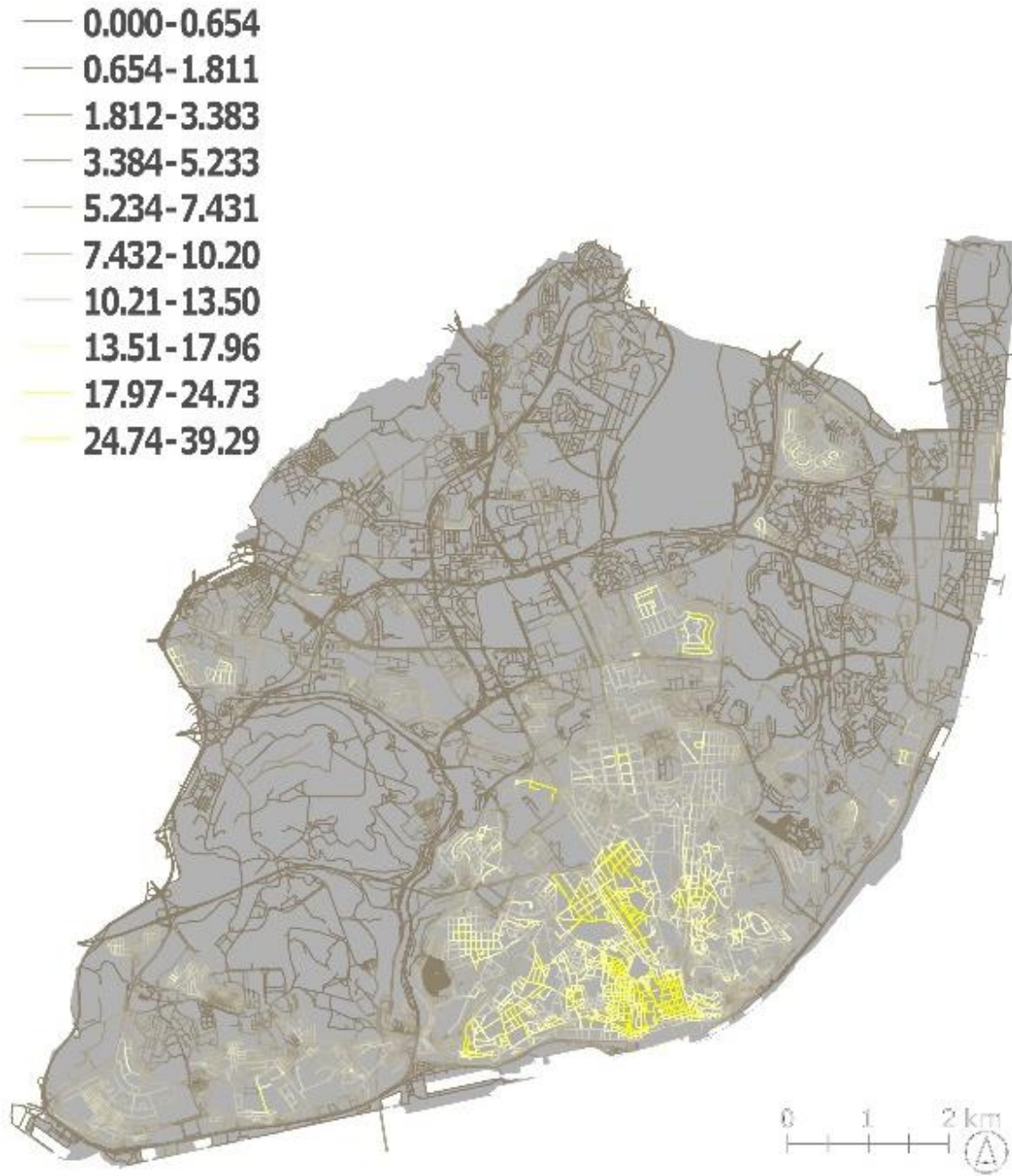


Fig. 5 Urban-renewal NKDE, aggregated for 2015–2019. Legend classes indicate relative NKDE intensity along network links; higher classes correspond to stronger concentration of licensed urban-renewal events on the street network

NKDE therefore provides the operational anatomy behind the field revealed by KDE: it names streets, link sequences, and high-intensity nodes, making the linear organisation of co-location explicit.

3.3. Planar and Network Co-Location: Alignment of Patches and Street-by-Street Coupling

The side-by-side comparison makes the translation between the two readings visible. In the planar domain, the KDE panels for Airbnb and urban renewal show co-location at the level of patches and intensity fields, namely a shared central core. In the network domain, the same relationship appears as street-by-street coupling: sequences of links and nodes where both NKDE surfaces reach high values. The paired comparison panels are retained not as repetitions of the individual KDE and NKDE figures, but as harmonised side-by-side displays that make cross-phenomenon co-location directly readable under identical visual classification.

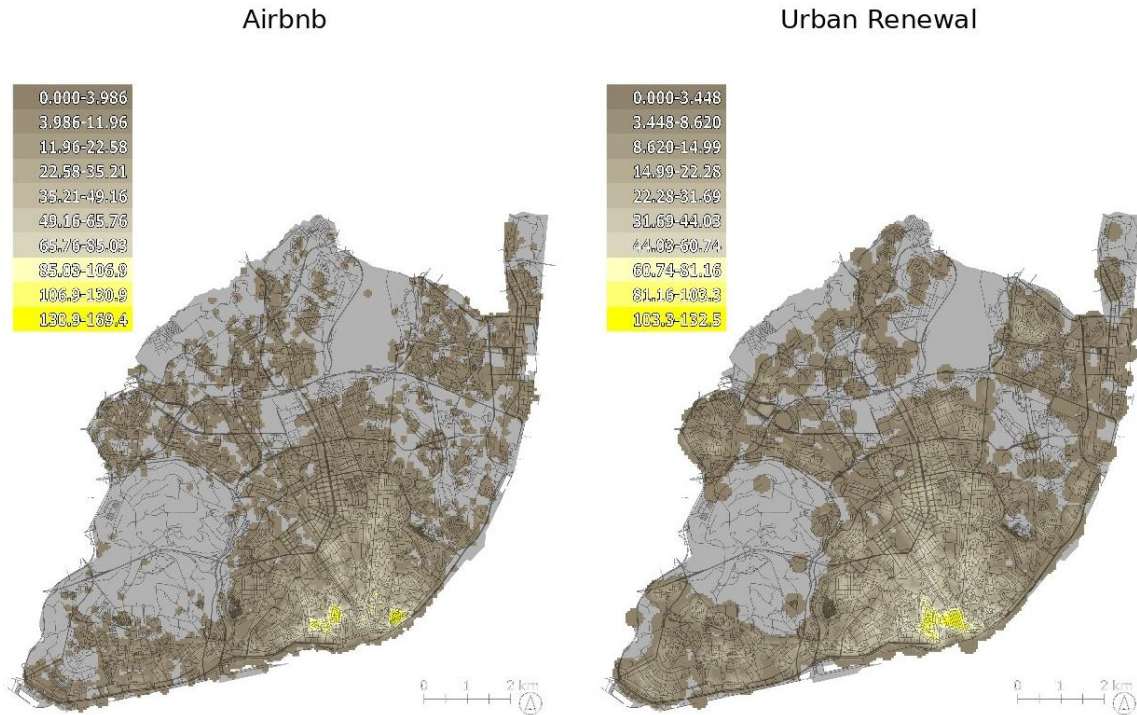


Fig. 6 Airbnb vs. urban renewal—KDE comparison. Harmonised side-by-side KDE panels retained to make patch-based co-location directly readable under the same visual classification

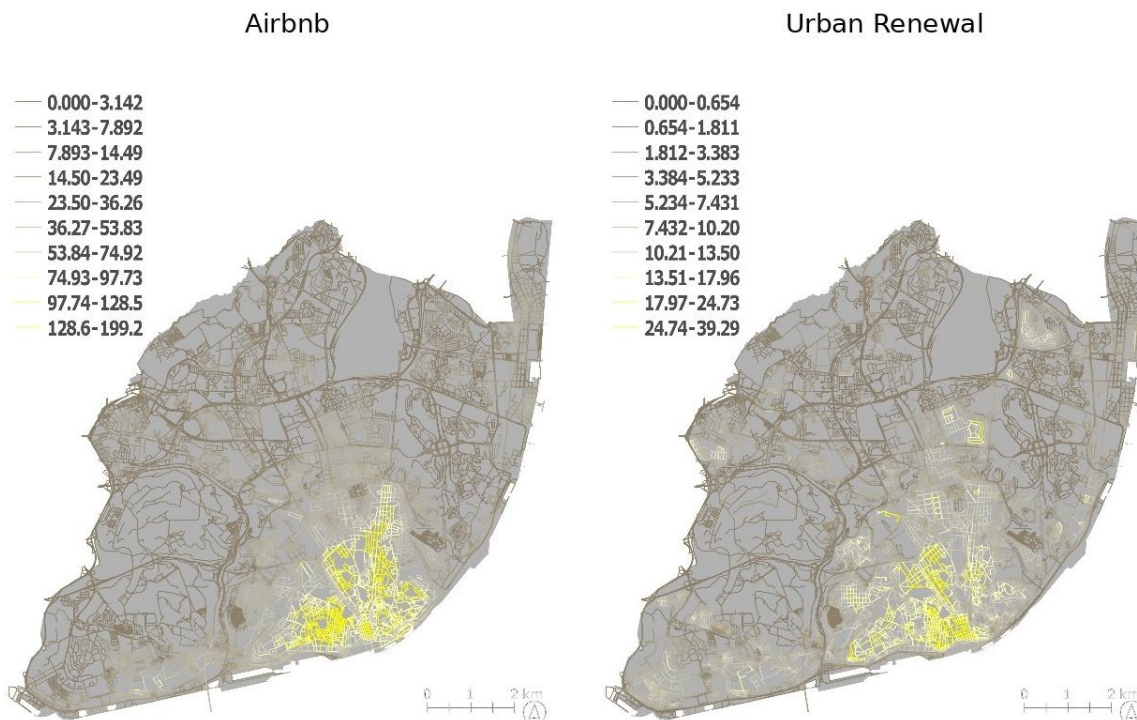


Fig. 7 Airbnb vs. urban renewal—NKDE comparison. Harmonised side-by-side NKDE panels retained to make corridor- and node-based co-location directly readable under the same visual classification

This shift is decisive in practice. Whereas KDE supports a strategic reading—where the centre concentrates—NKDE supports an operational reading—which streets and which nodes sustain that intensity. The comparison also reduces the risk of misleading inferences resulting from planar smoothing in areas where blocks, topography, or discontinuities of the urban grid do not correspond to functional proximity.

3.4. Scale-Dependent Interpretation of Network Concentrations

The aggregated network maps show that a concentration identified at municipal scale can contain several different local structures. Some broad citywide concentrations resolve into continuous street sequences, whereas others consist of neighbouring but non-identical links. The change in scale therefore affects whether Airbnb and urban renewal are interpreted as coincident, adjacent, or locally displaced.

This distinction is visible in the central areas examined below. Santa Maria Maior contains a dense lattice of short links in which both phenomena may occupy the same broader area while reaching different local maxima. Avenida da Liberdade and Rua de Santa Marta, by contrast, show how parallel or connected axes can separate concentrations that appear merged in the planar surface.

3.5. Parish Example I: Santa Maria Maior (Baixa/Alfama)

At parish scale, Santa Maria Maior shows how a central patch decomposes into a recognisable street lattice. Airbnb NKDE highlights a primary axis along Rua Augusta, with transversal branches reflecting the short and regular grid of Baixa. Urban-renewal NKDE partially overlaps this same structure, showing coincident intensities along several of the same segments. In Fig. 8, Airbnb NKDE highlights a primary axis along Rua Augusta and its transversal branches, while Fig. 9 shows that urban-renewal NKDE partially overlaps that same lattice.

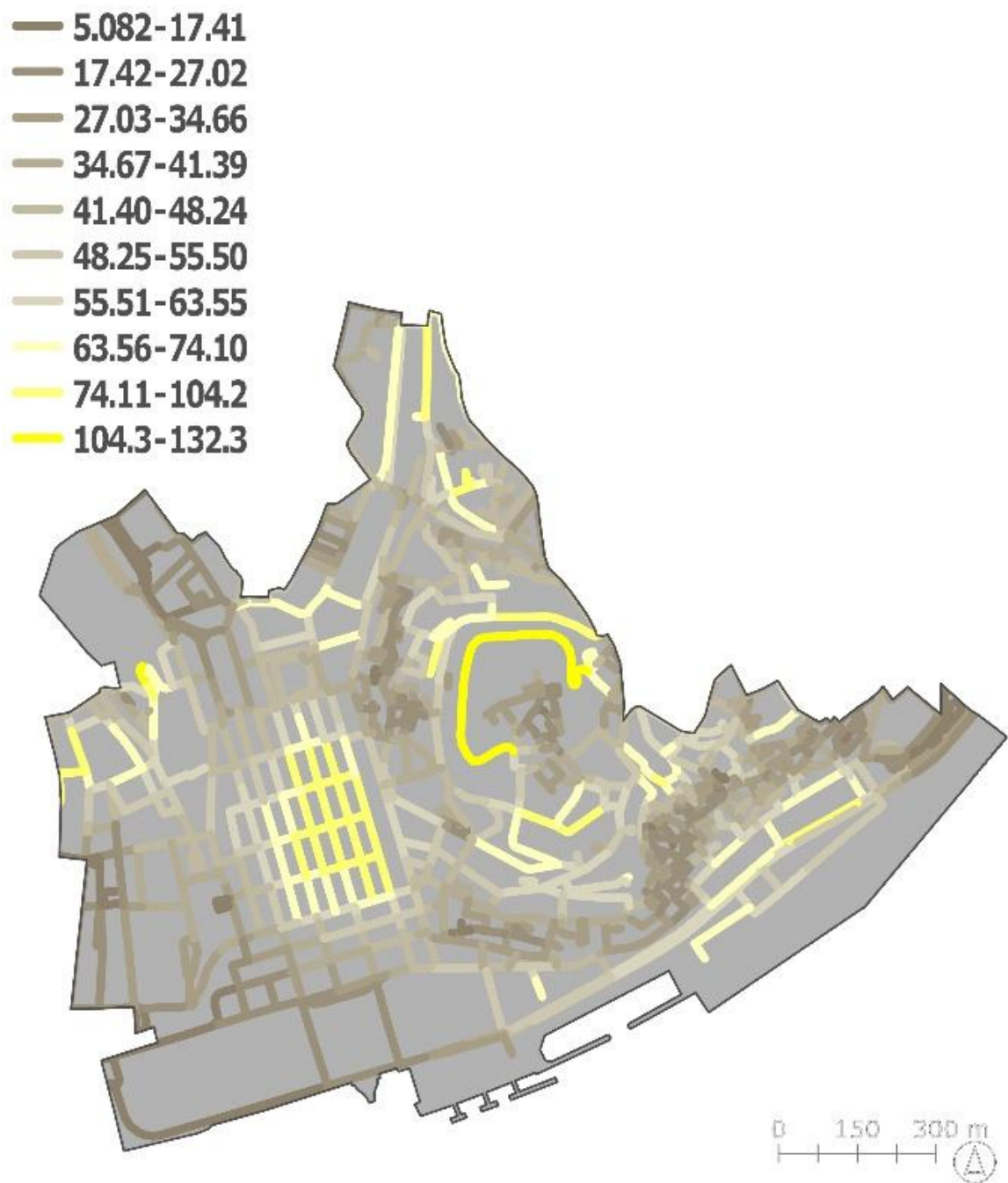


Fig. 8 Santa Maria Maior: Airbnb NKDE (2015–2019)

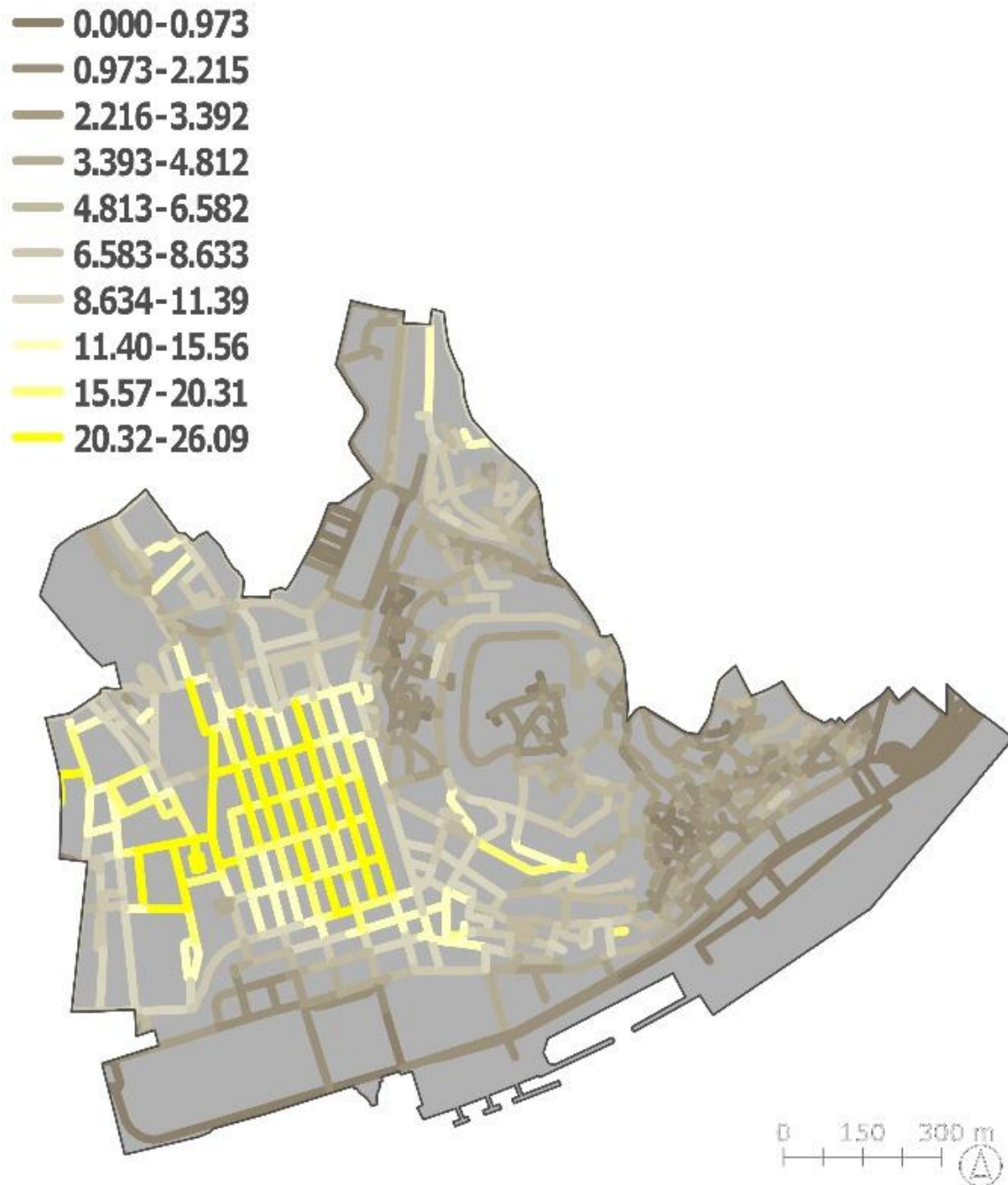


Fig. 9 Santa Maria Maior: urban-renewal NKDE (2015–2019)

Nodal maxima occur precisely where multiple short links intersect, that is, in points of high visibility, strong frontage continuity, and intense pedestrian circulation. The case shows that the central belt is not a diffuse patch but a structured lattice in which co-location depends on position within the network.

3.6. Parish Example II: Misericórdia (Bairro Alto / Chiado) and Arroios (Avenida Almirante Reis)

Although not displayed in separate figures in this version, the readings for Misericórdia and Arroios reinforce the same pattern. In Misericórdia, Airbnb NKDE reveals a crossed north–south and east–west lattice extending towards Cais do Sodré, accompanied by urban-renewal NKDE. This is one of the clearest overlap areas in the city, where historic fabric, micro-connectivity, and tourist pressure converge.

In Arroios, Avenida Almirante Reis functions as a dominant arterial corridor. Both Airbnb and urban renewal concentrate along this axis, with particular reinforcement at nodes such as Praça do Chile and with lateral

intensification in adjacent streets. The example shows that a single highly connected axis can organise a broad area of co-location.

3.7. Street-Scale Example: Avenida da Liberdade / Rua de Santa Marta

At street scale, Avenida da Liberdade provides a clear example of how certain prestigious urban axes concentrate both phenomena. Airbnb NKDE reveals a continuous linear concentration along and around the avenue, while urban-renewal NKDE follows the same structure, including the lateral bundle of Rua de Santa Marta. As seen in Fig. 10, Airbnb NKDE forms a continuous concentration along and around the avenue, while Fig. 11 shows that urban-renewal NKDE follows the same structure, including the Rua de Santa Marta bundle. The co-evolution suggested by this pair—enhancement of building stock through renewal and monetisation of centrality and frontage through Airbnb—becomes especially clear at this scale.

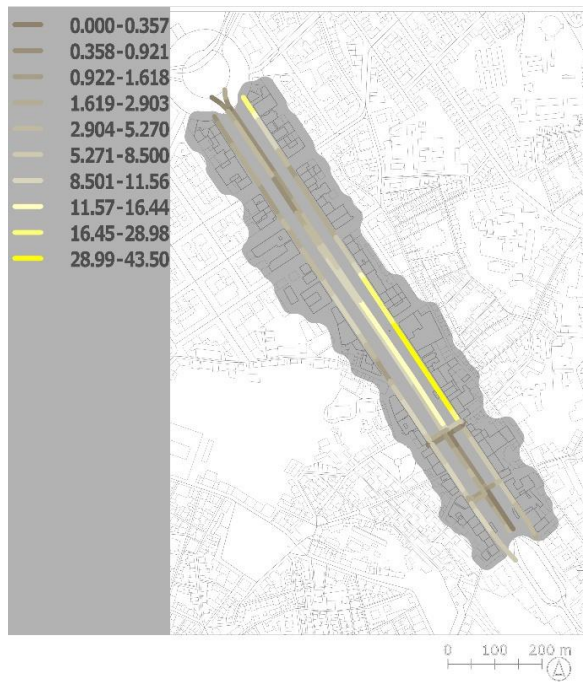


Fig. 10 Avenida da Liberdade: Airbnb NKDE (2015–2019)

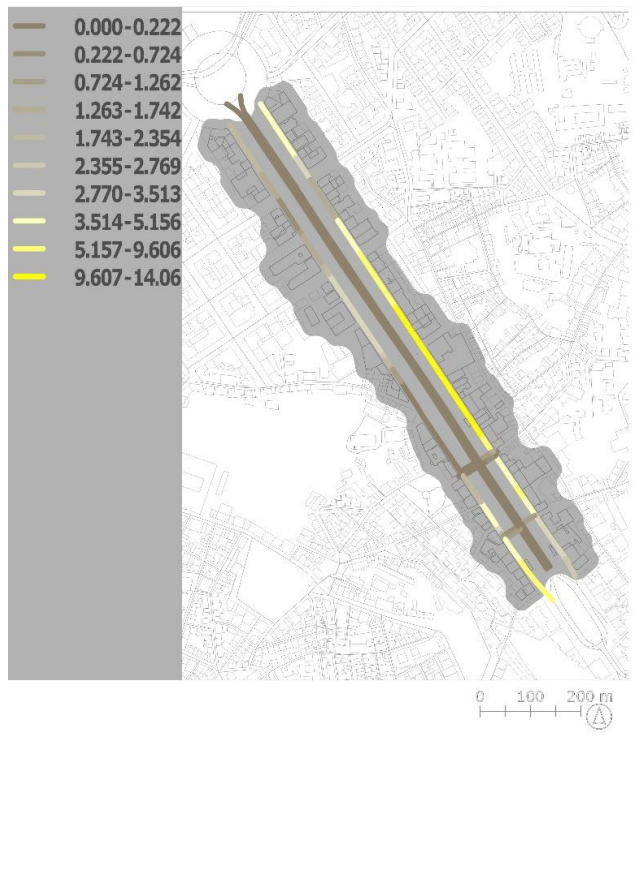


Fig. 11 Avenida da Liberdade: urban-renewal NKDE (2015–2019)

3.8. Secondary Corridors and Peripheral Extensions

Although the central belt dominates the overall reading, secondary linear concentrations also emerge in areas such as Areeiro (Rua Carlos Mardel) and parts of Estrada de Benfica / Rua Maria Pia. Their absolute intensities are lower, but continuity in the network is real: these are coherent corridors connected to the central system. Recognising them broadens the governance focus beyond the most obvious historic core and suggests the need for distributed monitoring in areas where corridor-based growth is still incipient.

3.9. Robustness: Weighting and Host Structure Do Not Invert the Map

Weighted KDE variants were also tested, notably using nightly price and guest ratings as weights, together with splits by host structure (single listing versus multi-listing hosts). These variants are not reproduced here as separate figures, but the results show that the overall spatial signal remains consistent: the same central peaks and principal corridors continue to emerge. In other words, weighting and host-structure splits alter local rank ordering without shifting the dominant central belt or the principal corridors.

Weighting changes the local hierarchy of maxima, making some streets more prominent than others, but it does not shift the central belt or eliminate the main linear concentrations. Likewise, differentiation by host type modifies intensity distribution on certain segments without altering the underlying structure. This suggests that the observed pattern is associated with structural features—connectivity, visibility, and access to amenities—rather than with attributes of a specific host segment or price tier.

3.10. Triangulation with RNAL and RNET

Where relevant, platform-based short-term rental patterns can be qualitatively compared with administrative registries, namely RNAL (licensed Alojamento Local) and RNET (hotel registry). At city scale, a broadly shared central belt is observed across accommodation modalities. Even so, corridor-level divergences can emerge: certain street segments show stronger relative platform presence than licensing, while some axes with pronounced hotel expression are less visible in platform-based data. This comparison is used here as contextual triangulation rather than as a third analytical dataset.

These differences are useful for monitoring, compliance, and outreach actions, while also providing a complementary check on the corridor structure identified by NKDE, without introducing new external covariates.

3.11. Sensitivity Notes and Technical Considerations

Several technical considerations help to interpret the maps correctly. In the case of KDE, the bandwidth and grid resolution adopted for Lisbon aim to balance smoothing and detail retention: larger bandwidths would make the surface too diffuse, whereas smaller bandwidths would introduce excessive granularity. Across the figure set, KDE legend classes indicate relative intensity estimated on the raster grid, whereas NKDE legend classes indicate relative intensity estimated on network links; these values are intended for within-method comparison rather than direct comparison between KDE and NKDE magnitudes.

In the case of NKDE, the equal-split rule, the discontinuous kernel, the adopted bandwidth, and the sampling step along the network constitute a documented and operationally viable parameterisation for municipal-scale analysis. Nodal maxima should not be read as rendering artefacts, but as substantive effects of the network structure itself. Likewise, applying the municipal mask prevents artificial contamination of the surfaces.

3.12. From Diagnosis to Action: An Operational Reading of Overlap

Although this version does not report a formal cell-by-cell correlation coefficient between the Airbnb and urban-renewal KDE rasters, the fact that both share the same grid, extent, and mask means that such quantification could be implemented straightforwardly as an additional robustness check in future iterations.

Even by remaining strictly within the figure set already produced, it is possible to construct a tiered operational reading. In the planar domain, the intersection of higher-intensity KDE patches defines priority districts for joint governance of short-term accommodation and urban renewal. In the network domain, the intersection of the main linear concentrations in NKDE identifies priority corridors and junctions. Links that repeatedly appear in the upper classes across several years can be treated as persistent pressure corridors, whereas links with only punctual appearances can be read as emerging signals.

Because the same KDE/NKDE pipeline can be rerun annually with constant parameters, this tiered reading provides a monitoring basis for assessing whether corridor-oriented measures are reducing intensity, stabilising patterns, or displacing pressure elsewhere in the network.

In summary, the aggregated KDE maps establish a persistent central belt of co-location between Airbnb and urban renewal, while the NKDE maps reveal the corridor-and-node anatomy that organises that relationship. This reading is reinforced by the three-dimensional views in Figs. 12 and 13, which make the relative height of the main peaks and the hierarchy of central concentrations more immediately legible. Direct comparison panels convert patch co-location into street-by-street coupling. The parish and street-scale examples show how central areas resolve into recognisable lattices and specific urban axes. Weighted variants and complementary triangulations do not alter the underlying structure. Taken together, the results elevate links and nodes to the status of operative units for urban governance.

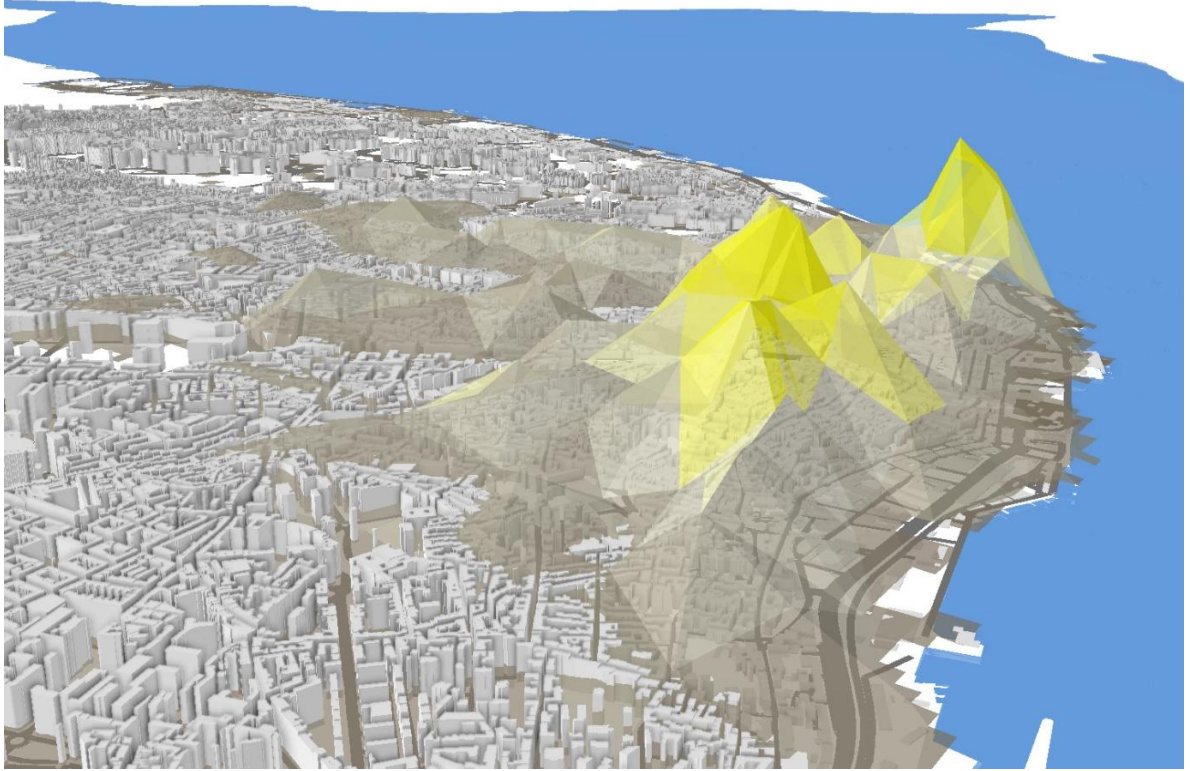


Fig. 12 3D view of Airbnb KDE (2015–2019)

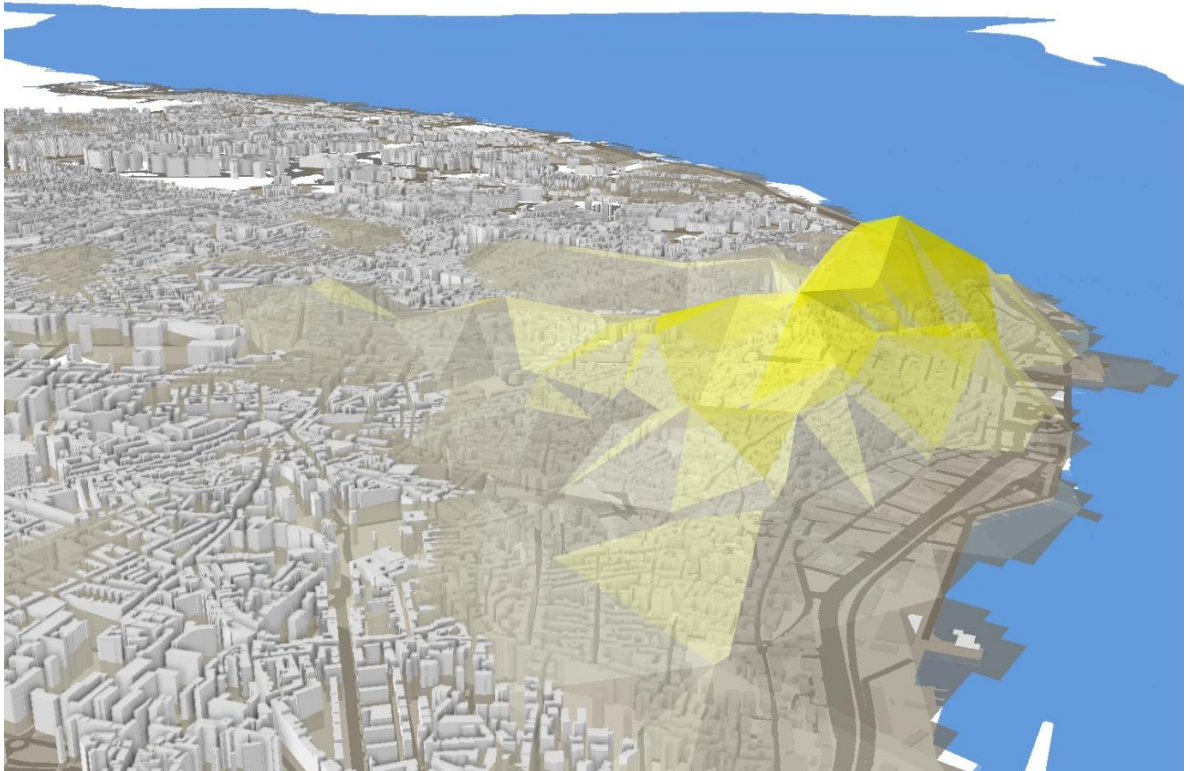


Fig. 13 3D view of urban-renewal KDE (2015–2019)

4. Discussion

4.1. Interpreting the Combined Evidence: Persistent Spatial Structure

Read together, the aggregated KDE fields and the linear concentrations revealed by NKDE indicate that co-location between Airbnb and urban renewal in Lisbon is persistent rather than episodic. KDE reveals a stable central belt

extending across Baixa, Chiado, Bairro Alto, and Alfama and into consolidated extensions of the city. NKDE decomposes that same belt into specific corridors and nodal maxima, showing that the geometry of co-location is organised along the street network rather than appearing only as simple isotropic diffusion.

The comparison between planar and network panels translates a diffuse central patch into recognisable sequences of streets and nodes. This capacity for translation is one of the main analytical gains of the study: it turns a general centre/periphery diagnosis into an operational diagnosis about which streets and which points in the network concentrate greater pressure.

4.2. Why the Network Lens Is Indispensable

KDE remains the best strategic instrument: it communicates the “where” through a legible centre and gradients that cross administrative boundaries, using a technique long established for delimiting central areas and comparing phenomena through time. However, because KDE assumes isotropy, it can create apparent continuities between areas that are in practice separated by urban form or by the network.

NKDE corrects this problem by measuring distances along the street graph and propagating kernel mass through nodes and links. The result is the operational skeleton behind the central patch. From a planning perspective, this means moving from “intervene in the centre” to “intervene in these streets and at these nodes.” In Lisbon, whose urban morphology combines marked topography, avenue hierarchy, and dense historic fabrics, that distinction becomes especially important.

4.3. Scale Dependence and Local Differentiation

The comparison across spatial scales shows that citywide co-location does not necessarily imply street-by-street equivalence. Planar KDE merges nearby events into continuous fields, while NKDE separates those fields into link-based structures whose local maxima may coincide, remain adjacent, or diverge.

The result is not that one representation is universally preferable. KDE is more effective for identifying broad areas of concentration, whereas NKDE is more informative when the planning question concerns specific streets, connected sequences, or junctions. The appropriate interpretation therefore depends on both the spatial support and the scale at which intervention is being considered.

4.4. Robustness and Triangulation Across Modalities

Weighted KDE variants and host-structure segmentations do not alter the central belt or the principal corridors; they merely reorder local maxima. This reinforces confidence in the interpretation that the observed overlap is associated with location, connectivity, visibility, and amenity access. Similarly, triangulation with RNAL and RNET supports the presence of a shared central core, even if differences emerge along some corridors.

The consistency of the pattern across these variants therefore does not depend on a single configuration of data or on a single typological cut. On the contrary, different ways of observing the phenomenon converge on the same underlying structure.

4.5. Translating the Findings into Urban Policy: From the Neighbourhood to the Street

Because NKDE classifies links and highlights high-intensity nodes, it becomes possible to think of intervention instruments oriented to corridors and nodes, articulated with municipal and parish scales. These may include thresholds or caps specific to higher-pressure corridors, monitoring points at nodes where multiple intense segments converge, articulation between renewal incentives and tenure-protection mechanisms in historic areas, and fiscal or regulatory tools adjusted to the effective geometry of urban pressure.

Each of these possibilities is supported by the figures in the study: KDE delimits the strategic space of intervention, NKDE identifies priority corridors and nodes, and the local examples show how intervention would materialise in concrete places.

4.6. Implementation and Annual Monitoring

One of the main advantages of this approach is its reproducibility. If inputs, parameters, and cartography are kept constant, the municipality—or research teams working in partnership—can rerun the pipeline on an annual basis. This means updating the data, repeating quality control, recalculating KDE and NKDE with the same parameterisation, and comparing the results against the 2015–2019 baseline.

In this way, the study ceases to be merely a picture of a past period and becomes the basis for a system of continued monitoring. The question then shifts from “where was pressure concentrated between 2015 and 2019?” to “how are those corridors now stabilising, intensifying, or shifting?”

4.7. Limits and Possible Extensions Within the Same Framework

The study is deliberately diagnostic. It maps co-locations and spatial forms, but it does not identify causal mechanisms or introduce additional external covariates. It remains within the temporal and documentary limits adopted here, including the decision to treat 2015–2019 as a coherent pre-pandemic baseline rather than to combine structurally different pre- and post-pandemic market regimes.

4.8. Communication: From Maps to Decision

KDE maps are immediately understandable to broad audiences, while NKDE maps are more directly operational for technical teams. The comparison panels function as a bridge between those two levels of reading. The parish and street-scale examples make the argument concrete, anchoring the discussion in recognisable streets, axes, and nodes. Because all visuals are based on the same data and parameters, the resulting narrative is coherent, auditable, and applicable.

5. Conclusions

This article consolidates KDE- and NKDE-based analyses into a unified and reproducible diagnosis of the relationship between Airbnb activity and urban renewal in Lisbon between 2015 and 2019. Four main conclusions emerge from the study.

First, central co-location is relevant for urban policy. The aggregated KDE fields reveal a central belt in the historic core and its contiguous extensions, but the local network analysis shows that this broad co-location includes both coincident and displaced street-level structures.

Second, that co-location is organised by corridors and nodes. The network lens shows that central concentration is not isotropic but articulated by recognisable street sequences and specific nodes. NKDE captures this organisation and translates the policy question from “which parishes?” to “which streets and which points in the network?”

Third, the interpretation changes with spatial support and scale. Concentrations that appear continuous in KDE can resolve into separate corridors, parallel links, or different local maxima in NKDE, especially when the analysis moves from municipal to parish and street scales.

Fourth, the spatial signal is consistent across the tested variants. Weighted variants, host-type splits, and triangulation with RNAL/RNET preserve the central belt and the main corridors, even if they change local maxima. This reinforces confidence in corridor- and node-oriented urban policy.

From a methodological point of view, the main contribution lies in pairing KDE and NKDE without treating them as interchangeable outputs. KDE offers a strategic and legible map, while NKDE provides a link-based reading anchored in specific streets and nodes. Used together and across multiple scales, they show which spatial conclusions remain stable and which depend on the representation selected.

In sum, the spatial pattern of Airbnb and urban renewal in Lisbon between 2015 and 2019 is characterised by a persistent central core organised through identifiable corridors. Managing those links, nodes, and the corridors they compose is the most direct way to align urban governance with the city’s actual anatomy. The combined KDE/NKDE pipeline makes that alignment measurable, repeatable, and operational, both in the present analysis and in future annual monitoring cycles.

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