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Cerdà Revisited: Food Retail in Barcelona's Eixample District. A Spatial Point Pattern Analysis.

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Abstract

The commemoration of the 150th anniversary of Ildefons Cerdà's death during the Cerdà Year 2026, together with Barcelona's designation as World Capital of Architecture 2026, provides a timely context in which to reassess the contemporary relevance of Cerdà's urban principles. This study examines whether the spatial organisation of food retail in the Eixample district continues to reflect the proximity-based and territorially balanced provision envisaged in his plan. Using georeferenced data for seven food retail categories, we combine kernel intensity estimation, Clark–Evans statistics, inhomogeneous Ripley's K-functions, entropy measures across Voronoi-based market catchments, and inhomogeneous Poisson point process models. The findings reveal two distinct spatial logics: most traditional food retailers exhibit significant clustering, whereas supermarkets follow a more spatially extensive distribution and do not differ significantly from complete spatial randomness. Population density is positively and significantly associated with the intensity of every retail category, confirming the importance of residential demand. Conversely, distance to municipal markets shows a weak and category-specific relationship, suggesting that the market network no longer constitutes the principal organising structure of food retail anticipated by Cerdà. Distance to Passeig de Gràcia has a consistently negative effect, although the density surfaces reveal a spatial displacement process. Market catchments remain functionally diverse, particularly around Sagrada Família and Ninot. Overall, the results show how Cerdà's historical framework of proximity is being reconfigured by residential density, commercial centrality, and touristification, with implications for food accessibility, retail diversity, and spatially equitable planning in dense urban environments.

Keywords: Cerda's plan; food retail; spatial point processes; municipal markets; touristification

1 Introduction

Ensuring equitable access to fresh food is an important issue in urban planning and public health (Wrigley, Guy, & Lowe, 2002). The spatial distribution of food retail outlets, such as greengrocers, supermarkets and municipal markets, shapes the ability of residents to obtain healthy foods within convenient distances (Barata-Salgueiro & Cachinho, 2021). Food deserts, areas under-served by fresh food retailers, exemplify the risks of uneven distribution: low-income neighbourhoods lacking proximate grocery stores often face poorer diet outcomes and a higher prevalence of processed food consumption (Apparicio, Cloutier, & Shearmur, 2007; Hamidi, 2020; Reynolds, 2025; Walker, Keane, & Burke, 2010). However, this body of literature is heavily dominated by North American case studies (Beaulac, Kristjansson, & Cummins, 2009), where the concept of food deserts was originally formulated, thereby limiting the extent to which its assumptions and conclusions can be generalised to different urban and governance contexts. Contemporary research emphasises that the geography of urban food supply is rarely random; instead, it reflects broader socio-spatial dynamics, including income disparities and infrastructure networks (Davies & Evans, 2019). These patterns underscore the importance of deliberate planning interventions to promote spatial justice in food access, aligning with a wider movement in urban policy towards sustainable and inclusive neighbourhood retail systems (Fernandes & Chamusca, 2014).

Equity-driven spatial planning is not a new idea. In the mid-19th century, the Catalan engineer *Ildefons Cerdà* pioneered modern urbanism with an ambitious expansion plan for Barcelona's Eixample district (Cerdá, 1867), explicitly addressing hygiene, traffic flow, and equality of access to services (Urbano Lorente et al., 2016). Cerdà viewed the city as an organism that needs a balanced provision of amenities for all citizens. His Eixample design, a regular grid of octagonal blocks, included the systematic placement of marketplaces, schools, parks, and hospitals as central elements of each new neighbourhood (Pallares-Barbera, Badia, & Duch, 2024). The plan proposed

a distribution of the facilities to ensure that no resident was too far from basic services, a revolutionary approach in treating urban layout as a tool for social well-being and access to fresh food as a matter of urban right. This egalitarian logic, grounded in early location theory, makes the Eixample an historic case study in spatial equity. Cerdà's expansion plan is internationally revered as an icon of modern city planning precisely because it merged engineering foresight with social progressivism (Aibar & Bijker, 1997).

Our study proposes a spatial point process framework, going beyond the area-based aggregate analysis, to use the locations of fresh food stores and markets as stochastic point patterns in urban space. This approach allows us to jointly evaluate first-order effects (variation in intensity of stores across the city) and second-order effects (interaction or clustering between stores), providing a richer picture of spatial logics. With point pattern analysis, we gain fine-grained insight into whether, for instance, supermarkets tend to agglomerate in certain parts of the Eixample beyond what underlying population patterns would predict and how the presence of traditional markets might influence nearby store clustering or dispersion. Addressing this gap is important for both historical understanding and contemporary policy: if the spatial logic of fresh food provision is shifting, it could affect urban equity and vitality.

Our work uses Cerdà's Eixample as a living laboratory to examine contemporary patterns of food retail distribution. The study addresses a clear literature gap by moving beyond areal summaries to point-level modelling of the spatial logic of fresh food retail. The findings aim to illuminate whether the ideals of Cerdà's plan, regarding equitable and convenient access to markets, still manifest in the spatial structure of the city or whether new clustered geographies of food retail have emerged due to market forces. This research is not purely historical; it has practical implications for planning and policy. More specifically, the analysis is guided by the following research questions.

- (i) To what extent do different types of food retail exhibit distinct spatial patterns of clustering or dispersion?
- (ii) To what extent do municipal markets structure the spatial distribution of different types of food retail, shaping patterns of clustering, dispersion, and interaction?
- (iii) Do supermarkets exhibit spatial patterns that differ from those of fresh food retailers?

Methodologically, the study contributes to the urban literature by applying a spatial point process framework to analyse the distribution of retail activities on a fine spatial scale. Moving beyond conventional areal approaches, the analysis combines exploratory point pattern techniques with second-order statistics and inhomogeneous modelling to jointly capture spatial intensity, interaction effects, and the influence of contextual factors. This approach allows for the distinction between covariate-driven location processes and endogenous spatial dependence, while reducing the aggregation biases associated with the Modifiable Areal Unit Problem (MAUP) (Openshaw, 1984). By integrating these components, the proposed framework provides a flexible and transferable methodology for examining how urban dynamics shape the spatial organisation of everyday services.

The subsequent sections will examine the Eixample district and municipal food markets, detail the methodology and data, present the results of the analysis, and discuss their implications considering urban geographic theory and planning practice.

2 Eixample district and the role of food municipal markets

The Eixample district is typically characterised by high levels of walkability, the effective assimilation of rail transit into the urban fabric, and a dense yet legible spatial structure. Within this framework, previous research identifies a set of transferable

design principles (Baş, Andrianne, & Reiter, 2024; Shakibamanesh & Ebrahimi, 2020), including compact block dimensions, calibrated height-width ratios that reinforce spatial enclosure, a balance between visual complexity and formal order in streetscapes, a functional land-use mix, and the embedding of transit nodes within everyday urban life. At the same time, these approaches are not without tension: affordability issues, privatisation processes, and displacement complicate the relationship between liveability and accessibility, highlighting broader concerns about equity and social justice (Haarstad, Kjærås, Røe, & Tveiten, 2023). However, despite this extensive focus on urban form and transport integration, relatively little attention has been paid to how such spatial configurations shape access to daily provisioning systems, particularly fresh food retail. In the case of Barcelona, municipal markets constitute a historically embedded and spatially distributed network that can play a central role in mediating food accessibility within a dense urban fabric. However, their contribution remains under-explored within the literature on liveability and accessibility, which has largely prioritised North American retail structures and conceptualisations of food access. Addressing this gap requires situating municipal markets within their original conceptual and planning framework, as articulated in the work of Ildefons Cerdà.

Municipal food markets occupy an important place in Cerdà's urban thought as key elements of the city's functional and social organisation. He defines them as urban spaces where people gather to buy and sell everyday goods (Cerdá, 1867, Vol. I, p. 570) and includes them within the administrative organisation of domestic provisioning services (Cerdá, 1867, Vol. I, p. 671). Markets are also classified as public buildings alongside hospitals and churches (Cerdá, 1867, Vol. I, p. 686) and incorporated into the planning guidelines for the Eixample (Cerdá, 1867, Vol. III, pp. 390 and 399). These references show that Cerdà viewed markets not only as economic spaces but as essential urban infrastructure linked to accessibility, proximity, and the equitable provision of basic goods.

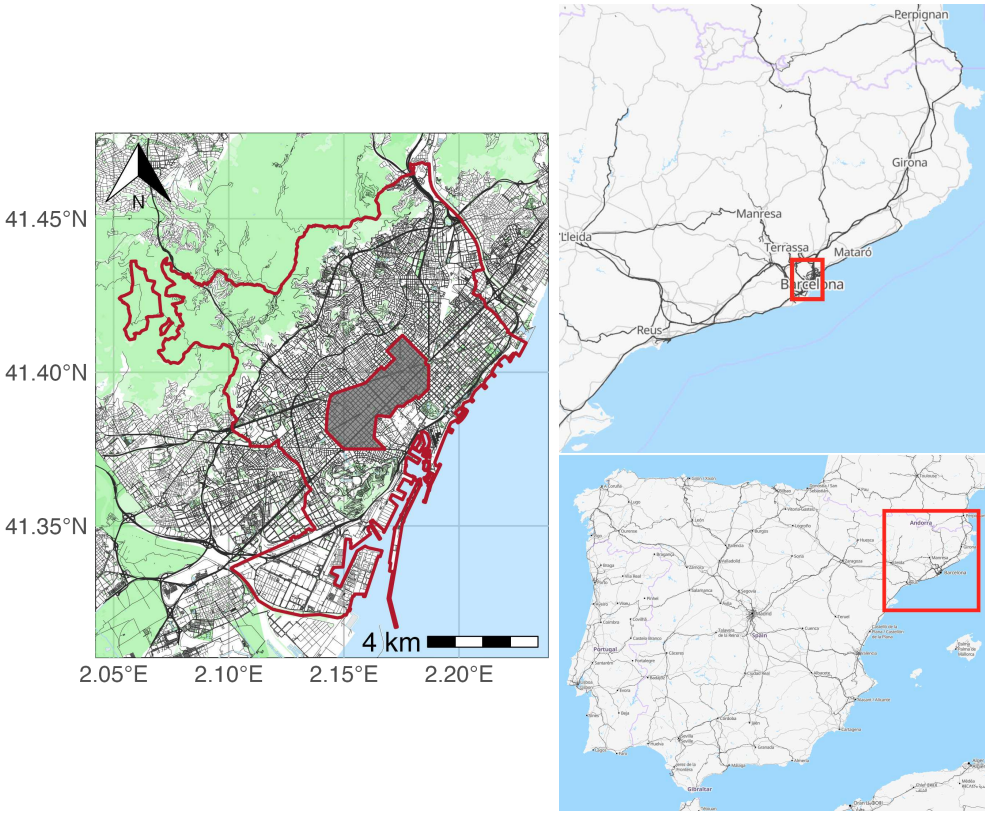


Fig. 1 Eixample district within the city limits of Barcelona (left); within the Catalonia region (right top); within Spain (right bottom)

Barcelona's Eixample currently contains five municipal food markets (Figure 1), reflecting different stages in the evolution of urban provisioning. Three date from the late nineteenth century: *Sant Antoni* (1882; 3,664 m^2), *La Concepció* (1888; 2,910 m^2), and *El Ninot* (1894; 5,584 m^2). Their transformation from open-air markets into permanent facilities reflects the institutionalisation of food distribution during the development of Cerdà's urban model. *Sagrada Família* (1944; 4,341 m^2) and *Fort Pienc* (2003; 1,532 m^2) represent later phases of urban consolidation. Figure 1 shows their spatial distribution. Together, these markets form a layered spatial and temporal system that may produce differentiated patterns of accessibility, service provision, and urban centrality across the district. Table 1 summarises the number of each type of grocery store.

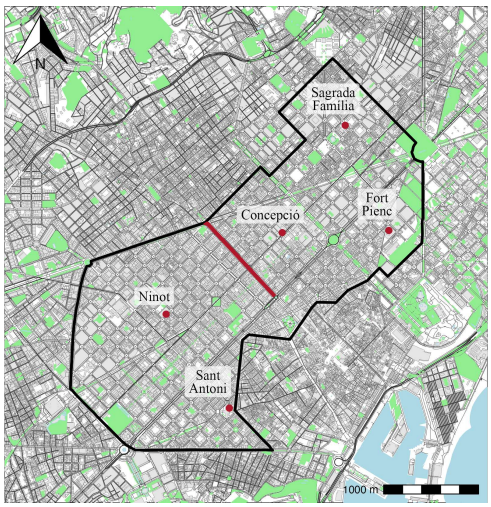


Fig. 2 Configuration of municipal food markets in the Barcelona's Eixample district. The *Passeig de Gràcia* Avenue is also highlighted.

Table 1 Number of stalls per category in each market

	Concepció	Fort Pienc	Ninot	Sagrada Família	Sant Antoni
Beverage stores	0	0	0	0	0
Bread and bakery stores	1	1	0	1	0
Fish and seafood stores	9	5	15	8	16
Fruits and vegetables stores	11	2	9	10	14
Meat and meat products stores	21	9	30	18	32
Other specialised stores	17	4	4	3	5
Supermarkets	1	1	1	0	1

The actual development diverged due to the higher density of population and the speculative building, but the layout of the grid still influences the distribution of services and retains a rich network of municipal markets that are greatly due to Cerdà's influence. These covered markets, in addition to smaller fresh food shops, form the backbone of Mediterranean food culture and provide accessible healthy produce to local communities. At the same time, the late twentieth and early twenty-first centuries have seen a proliferation of supermarkets in the Eixample district, partly driven by its status as one of the most central areas of Barcelona, where the high concentration of

tourist apartments has intensified demand for convenient and standardised food retail options, raising questions about how contemporary retail geographies compare to the intentional pattern Cerdà envisaged.

In contrast, fresh food retailers and municipal markets play a central role in supporting urban liveability, social cohesion, and resilience. In Barcelona, planners increasingly recognise these markets as key nodes of community life and as anchors of the "15-minute city" model (Ferrer-Ortiz, Marquet, Mojica, & Vich, 2022; Zhang, Zhen, Kong, Lobsang, & Zou, 2023), in which daily needs can be met within a short walk or cycle ride from home. Ensuring an even spatial distribution of such resources aligns with the principles of spatial justice and resonates with Ildefons Cerdà's conception of the city as an equitably shared collective resource. Barcelona is frequently cited as a model of "urban proximity" retail, where a substantial share of fresh food purchases occurs in markets and local stores accessible on foot. However, this model is increasingly subject to competitive pressures from supermarkets and changing retail dynamics. This raises critical questions regarding the extent to which different types of food retail outlets exhibit distinct spatial patterns and whether the distribution of supermarkets diverges from that of fresh food retailers. In addition, it prompts a further examination of the extent to which municipal markets continue to structure the spatial organisation of food retail, shaping patterns of clustering, dispersion, and interaction within the Eixample. Against this backdrop, analysing the spatial configuration of fresh food retail provides a means to assess whether the historical logic of balanced accessibility persists or whether new spatial inequalities are emerging.

Another important aspect to be considered in the spatial analysis of retail services in the Eixample district is the *Passeig de Gràcia* axis, which runs through the central portion of the district (see Figure 2) and constitutes a structurally singular retail environment, generating spatial dynamics that diverge from the surrounding retail fabric (Frago, 2026; Frago, Morcuende, & Lloberas, 2024). Originally consolidated

as a bourgeois residential avenue in the late nineteenth century, when Barcelona's elites relocated from the historic centre to the newly urbanised Eixample, *Passeig de Gràcia* combined residential prestige with emerging commercial functions. During the twentieth century ground-floor premises became increasingly occupied by financial institutions, giving the corridor the characteristics of a central business district. However, in the late 1980s, this financial specialisation was gradually replaced by transnational retail firms, marking a decisive shift towards a consumption-orientated urban landscape. This transition has resulted in a strong contemporary specialisation in fashion and personal accessories, particularly in the luxury and fast-fashion segments, while everyday retail functions, especially food-related services, have been progressively displaced. The process of retail desertification in basic services introduces a structural bias in the spatial distribution of retail supply, where consumption orientated to visitors and higher-income users dominates over neighbourhood orientated provision (Cheung & Yiu, 2024). In terms of spatial modelling, *Passeig de Gràcia* therefore represents a singular retail environment, where demand is driven more by tourism and symbolic centrality than by residential needs (Frago, 2026; Gómez-Varo, Delclòs-Alió, Miralles-Guasch, & Marquet, 2024).

3 Data and methodology

The empirical analysis focuses on the Eixample district in the city of Barcelona, Spain (see Figure 1). Conceived in the mid-nineteenth century as the urban expansion of the historic city, the Eixample was designed by the engineer and urban theorist Ildefons Cerdà as a regular grid of octagonal blocks with chamfered corners and wide streets (Cerdá, 1867). The district is presently located in the city centre and constitutes one of the most densely built and functionally diverse areas of the city. Today, the Eixample is both a highly consolidated residential area and a key economic and cultural core, internally structured into seven neighbourhoods with marked social and functional

diversity. With a surface area of 7.48 km^2, the Eixample is one of the most densely populated districts, hosting 262,951 residents in 2024 —approximately one sixth of the total population of Barcelona of 1,627,559 inhabitants within a municipal area of 101.4 km^2. Beyond its residential function, the district concentrates a significant share of economic activity and urban centralities, while also hosting emblematic works of Catalan Modernism which act as important tourist hubs.

3.1 Data sources

Multiple spatial datasets were used to characterise the distribution of economic activities and key public facilities in the Eixample. Retail data were obtained from the *Cens de locals en planta baixa destinats a activitat econòmica de la ciutat de Barcelona*[1], published by Barcelona City Council (Ajuntament de Barcelona, 2025). The dataset provides georeferenced information on street-level premises, including economic sector and activity type. Food retail activities were classified according to Division 47 of Eurostat NACE Rev.2[2]. The analysis uses the most recent available data, corresponding to 2024.

Municipal market locations were obtained from the *Mercats municipals de la ciutat de Barcelona*[3] dataset. OpenStreetMap data were used exclusively for cartographic context and base mapping (OpenStreetMap, 2025). All datasets were processed in R (R Core Team, 2024). Tabular data were converted into spatial objects using their georeferenced attributes and projected to UTM zone 31N (EPSG:25831) using the PROJ.4 library (Bivand, 2021). Records were filtered to the administrative boundaries of the Eixample district, and data cleaning included standardising variables and classifications and checking coordinate validity against the source metadata.

[1] Census of premises on the ground floor intended for economic activity in the city of Barcelona. https://opendata-ajuntament.barcelona.cat/data/en/dataset/cens-locals-planta-baixa-act-economica

[2] Statistical classification of economic activities in the European Community. https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-ra-07-015

[3] Municipal markets in the city of Barcelona. https://opendata-ajuntament.barcelona.cat/data/en/dataset/mercats-municipals

3.2 Methods

The increasing availability of georeferenced point data has expanded the use of spatial methods based on individual locations. Compared with polygon-based approaches, point-based methods avoid much of the spatial generalisation, boundary uncertainty, and scale dependence associated with areal data, thereby reducing biases related to the Modifiable Areal Unit Problem (MAUP) (Openshaw, 1984). In urban planning, these methods allow infrastructure, accessibility, and activity patterns to be examined at finer spatial scales (Páez & Scott, 2004).

A spatial point pattern dataset consists of the locations of events or objects observed within a defined study area.

$$X = \{u_1, u_2, \ldots, u_n\}, \qquad u_i \in W, \tag{1}$$

denote the observed spatial point pattern of retail establishments, where each point $u_i = (x_i, y_i)$ represents a retail establishment within the observation window (W). In this study, explanatory covariates include distance to the nearest municipal market, distance to *Passeig de Gràcia*, and population density. Euclidean distance is used as a proxy for network distance. Although both measures can differ (Gutiérrez & García-Palomares, 2008; Hsiao, Lu, Sterling, & Weatherford, 1997; Knaap & Rey, 2024; O'Neill, Ramsey, & Chou, 1992), this approximation is reasonable in the Eixample because its dense, regular street grid limits divergence between straight-line and network distances.

The observation window (W) corresponds to the administrative boundary of the Eixample district. Its explicit definition is important because window geometry affects the estimation of spatial statistics through edge effects, particularly for second-order and kernel-based measures (A. Baddeley, Rubak, & Turner, 2015; Goreaud & Pélissier, 1999).

The analysis begins with an exploratory examination of the observed point patterns in order to characterise the spatial structure of retail services in the district. Following standard point process theory (A. Baddeley et al., 2015; Diggle, 2013), the exploratory stage distinguishes between first-order and second-order properties. First-order properties describe spatial variation in the intensity function $\lambda(u)$, representing the expected infinitesimal rate at which points occur around the location $u \in W$, conditional on the spatial configuration observed elsewhere in the study region. In the context of this study, $\lambda(u)$ can be interpreted as the local propensity for a retail establishment to occur at a given location within the Eixample, given the surrounding urban context. On the other hand, second-order properties characterise spatial interactions between points, allowing the identification of clustering, dispersion, or regularity beyond complete spatial randomness. These interactions are analysed using summary statistics, such as the Ripley's K-function and the pair correlation function (Ripley, 1976), assessing spatial dependence at varying distances. Because the observed point pattern exhibits clear spatial heterogeneity, second-order structure was assessed by comparing the empirical K-function with the theoretical expectation under an inhomogeneous Poisson process. The Poisson model provides the relevant null benchmark because it assumes no interaction between points such that any discrepancy from the theoretical function can be interpreted as evidence of clustering or inhibition. Therefore, we employ the inhomogeneous Ripley's K-function (A.J. Baddeley, Møller, & Waagepetersen, 2000; Waagepetersen, 2007), using border correction (reduced-sample) to account for edge effects. For a inhomogeneous point process, Ripley's K-function is defined as

$$K_{\text{inhom}}(r) = \mathbb{E}\left[\sum_{x_j \in X} \frac{1}{\lambda(x_j)} \mathbf{1}\{0 < \|u - x_j\| \leq r\} \,\middle|\, u \in X\right], \tag{2}$$

where $\lambda(x_j)$ denotes the intensity of the process at location x_j, $\|\cdot\|$ is the Euclidean distance and $\mathbf{1}\{\cdot\}$ is the indicator function. To assess the deviation of the observed pattern from an inhomogeneous theoretical Poisson process, we computed the inhomogeneous K-function with edge correction and compared it with Monte Carlo simulations.

Applied to the retail dataset, these statistics make it possible to assess whether food-related establishments exhibit spatial concentration or relative underrepresentation and whether their distribution departs from the proximity-based logic historically associated with Cerdà's urban framework. Together, these exploratory analyses provide a robust empirical basis for the subsequent modelling of retail service accessibility and spatial inequalities.

To further examine the functional structure of food retail around municipal markets, an entropy analysis was performed within the catchment areas defined by a Voronoi tessellation of the market locations. Let V_j denote the polygon associated with market j, and let p_{jk} be the proportion of retail establishments belonging to category k within V_j. Retail diversity within each catchment area was measured by Shannon entropy (Shannon, 1948),

$$H_j = -\sum_{k=1}^{K} p_{jk} \log(p_{jk}), \tag{3}$$

where higher values indicate a more heterogeneous mix of retail categories and lower values indicate a more specialised retail structure. For comparability across catchment areas, entropy can also be expressed in a normalised form as

$$H_j^* = \frac{H_j}{\log(K)}, \tag{4}$$

so that $0 \leq H_j^* \leq 1$, with values close to 1 indicating maximum diversity.

When the differences between the empirical Ripley's K-function and the theoretical expectation are relatively small, the observed point patterns might be interpreted as being driven primarily by first-order spatial inhomogeneity rather than by strong

second-order interaction effects. On this basis, the analysis can be modelled using an inhomogeneous Poisson point process, which allows the intensity function to vary as a function of observed spatial covariates while assuming independence between points conditional on that intensity surface. The model therefore estimates how the expected location intensity of establishments changes according to three contextual predictors considered. The inhomogeneous Poisson model is specified through a log-linear form,

$$\log \lambda(u) = \beta_0 + \beta_1 d_M(u) + \beta_2 d_{PG}(u) + \beta_3 \log\big(PopDen(u)\big), \tag{5}$$

where $d_M(u)$ denotes the distance from location u to the nearest municipal market, $d_{PG}(u)$ the distance to *Passeig de Gràcia* and $PopDen(u)$ the population density at u. Under this specification, the coefficients β_k measure the contribution of each contextual factor to the expected intensity of retail establishments. Negative distance coefficients imply a higher intensity near the corresponding urban characteristic, whereas positive coefficients indicate an increase in the intensity of establishments as the covariate increases. The resulting specification provides a parsimonious and interpretable framework for evaluating the extent to which the contemporary geography of food retail in the Eixample can be explained by location context.

All statistical and modelling testing procedures were carried out in R software (R Core Team, 2024) using several packages, among which the most relevant were spatstat(A. Baddeley & Turner, 2005), spatstat.model, and spatstat.geom (A. Baddeley et al., 2015; A. Baddeley, Turner, Mateu, & Bevan, 2013), raster (Hijmans, 2018) and terra (Hijmans, 2020).

4 Results

Building on the methodological approach presented in the previous section, the results focus on the exploratory examination of the spatial distribution of food retail and on

the results of the spatial point process modelling. This analytical framework makes it possible to identify the main spatial structures underlying the location of food-related establishments and to assess the role of relevant covariates in shaping their distribution.

Several exploratory analyses are first presented, including descriptive statistics, point pattern maps, kernel density estimates, and Ripley's K-functions. Together, these techniques provide an initial overview of spatial intensity, concentration, dispersion, and clustering among the different types of establishment considered. Table 2 summarises the main point pattern statistics for each category. Establishments located within municipal markets are not included in the computations; however, they only represent 14.93% of the total food retail supply in the district. Significant differences in both the density and spatial organisation of retail activities can be observed throughout the district. Supermarkets are by far the dominant retail category, with 618 establishments and an intensity of 82.66 establishments/km^2, followed by Bread and bakery stores (423 establishments; 56.58 establishments / km^2). In contrast, Fish and seafood stores represent a residual activity with only 20 establishments and the lowest spatial intensity (2.68 establishments/km^2). These differences suggest a highly uneven commercial structure, where convenience-orientated and daily-consumption activities dominate the urban retail landscape.

The Clark–Evans statistics in Table 2 further indicate that most traditional food retail categories exhibit significant spatial clustering. Meat and meat products stores show the strongest clustering pattern ($p < 0.001$), followed by Beverage stores and Other specialised food stores. Bread and bakery stores and Fruits and vegetables stores also display significant aggregation tendencies, although with slightly weaker clustering levels. These results suggest that fresh-food activities tend to co-locate spatially, likely benefiting from agglomeration economies. By contrast, Supermarkets do not differ significantly from complete spatial randomness ($p = 0.86$), consistent with

Table 2 Number, intensity and Clark-Evans clustering test retail activity

	Count	Intensity	R	p-value
Beverage stores	78	10.43	0.8106	< 0.001
Bread and bakery stores	423	56.58	0.8647	< 0.001
Fish and seafood stores	20	2.68	0.9081	0.2158
Fruits and vegetables stores	101	13.51	0.8735	0.0075
Meat and meat products stores	86	11.50	0.7668	< 0.001
Other specialised food stores	92	12.31	0.8139	< 0.001
Supermarkets	618	82.66	1.0227	0.8596

Intensity expressed as establishments/km^2. Establishments located inside municipal markets are not included. Alternative hypothesis: clustered ($R < 1$)

competitive strategies based on territorial coverage rather than local clustering. Similarly, Fish and seafood stores do not exhibit statistically significant difference from spatial randomness, possibly reflecting the small number of establishments and the greater dependence of this activity on localised demand conditions. Overall, the results point to the coexistence of two distinct retail spatial logics within the Eixample: clustered traditional commerce associated with proximity-based shopping environments, and more spatially regular modern retail formats characterised by broader territorial distribution strategies.

Figure 3 and Figures S1-S6 in the Supplementary Material present the spatial point patterns, kernel density estimation of intensity function and Ripley's K-functions for each retail activity. These visualisations collectively illustrate the spatial distribution, intensity, and clustering behaviour of each type of establishment within the study area.

Kernel-density maps were estimated using an isotropic Gaussian kernel with category specific bandwidths selected using Diggle's cross-validation criterion. Edge correction was applied to compensate for the loss of kernel mass near the boundaries of the study area. The kernel density estimates indicate that the spatial intensity of food retail in the Eixample is uneven and differentially articulated around the network of municipal markets. For fresh and specialised food categories, most notably

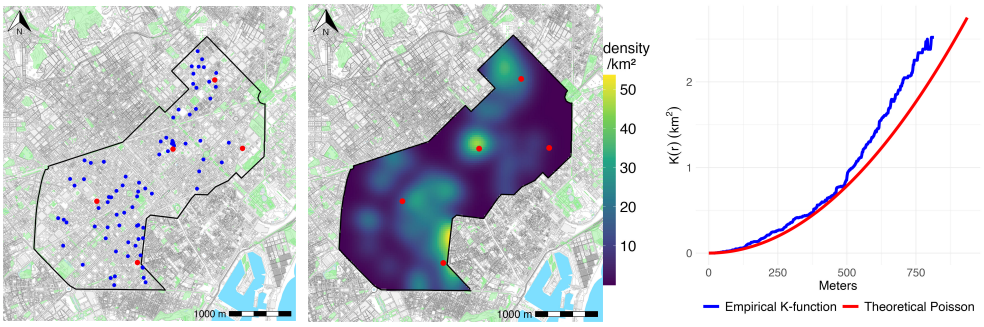


Fig. 3 Point pattern (left), kernel density estimation of intensity function (centre), and Ripley's K-functions (right) for Beverage stores.

Meat and meat products, Fruits and Vegetables, and Other specialised food stores, the main intensity peaks tend to occur around or near several market locations, suggesting that municipal markets continue to structure local concentrations of food-related commerce. In contrast, Bread and bakery stores and Supermarkets exhibit more diffuse and territorially extensive density surfaces, pointing to a wider neighbourhood-based logic of provision that is less tightly tied to market nodes. Fish and seafood stores, in turn, show the most discontinuous pattern, with isolated hotspots that only partially overlap with the market network, while Beverage stores present a mixed structure, combining market-related and more autonomous concentrations. These results suggest that municipal markets remain relevant as spatial anchors of food retail, although their organising role is uneven across establishment types and appears strongest for fresh-food activities.

Concerning the Ripley's K-functions from Figure 3 and Figures S1-S6 in the Supplemenetary Material, taken together they suggest that most food retail categories tend to cluster rather than disperse, although the strength of aggregation varies between establishment types. The clearest evidence of clustering is observed for Beverage stores, followed by Fruits and vegetables stores. Supermarkets, Bread and bakery stores and Meat and Meat product stores appear much closer to a random spatial distribution, showing only limited positive deviations from the Poisson expectation. In contrast, Fish and seafood stores stand out as the only category that exhibits a clear

dispersed or regular pattern, with the empirical curve remaining below the theoretical benchmark across almost all distances.

Table 3 Integrated deviation measure between empirical and theoretical Ripley's K-functions.

	D_{abs}
Beverage stores	129.7003
Bread and bakery stores	20.9101
Fish and seafood stores	113.5184
Fruits and vegetables stores	98.8145
Meat and meat products stores	28.6900
Other specialised food stores	41.3473
Supermarkets	27.4139

Table 3 reports the The integrated absolute deviation (D_{abs}) between the empirical Ripley's (K)-function and its theoretical counterpart is defined as:

$$\int_{r_{\min}}^{r_{\max}} \left| \widehat{K}(r) - K_{\text{theo}}(r) \right| \, dr \tag{6}$$

Under complete spatial randomness, $K_{\text{theo}}(r) = \pi r^2$, so the measure becomes:

$$\int_{r_{\min}}^{r_{\max}} \left| \widehat{K}(r) - \pi r^2 \right| \, dr \tag{7}$$

Larger values of D_{abs} indicate a greater overall departure of the empirical point pattern from the theoretical reference model across the selected distance interval. Beverage stores exhibit the largest deviation, followed by Fish and seafood stores and Fruits and vegetables stores, indicating the strongest overall deviations from the theoretical spatial pattern over the analysed distance range. Conversely, Bread and bakery stores display the smallest deviation, followed by Supermarkets and Meat stores, suggesting that their empirical K-functions are comparatively closer to the theoretical reference.

To further characterise the functional composition of retail around each municipal market, we assess the entropy of retail activities within the corresponding Voronoi-based catchment areas, where entropy measures the degree of diversity or mixture of retail categories, with higher values indicating a more heterogeneous retail structure. The results presented in Table 4 reveal a substantial variation in the functional composition of retail activities across market catchment areas, as defined by the Voronoi tessellation. In absolute terms, Shannon entropy values range from 1.30 (Concepció) to 1.60 (Sagrada Família), indicating that all markets support a relatively diversified retail structure, although with significant differences in the degree of functional mix.

Table 4 Entropy and retail diversity by market catchment area

Market	**Number of retails**	**Retails/km2**	**Shannon H**	**Normalised entropy**	**H / km²**
Concepció	283	159.7390	1.2991	0.6676	0.7332
Fort Pienc	125	234.6479	1.3372	0.6872	1.1796
Ninot	460	246.8203	1.5363	0.7895	1.3352
Sagrada Família	266	129.3504	1.5916	0.8179	1.6470
Sant Antoni	284	187.4249	1.4189	0.7292	0.5781

After normalisation, these values confirm that none of the catchment areas is strongly specialised, but rather that they operate along a gradient of diversification. The highest levels of diversity are observed in Sagrada Família and Ninot, suggesting that these areas function as multifunctional retail hubs, where a wide range of activities co-locate. In contrast, Concepció and Sant Antoni exhibit comparatively lower entropy values, pointing to a more selective or specialised commercial structure, potentially reflecting historical retail configurations or local demand patterns.

When entropy is adjusted by area (H/km^2), sharper spatial contrasts emerge. Sagrada Família (1.65) and Ninot (1.34) show the highest diversity intensity, indicating not only a broad mix of activities but also a high concentration of that diversity

in space. In contrast, Sant Antoni (0.59) shows the lowest entropy density, suggesting that its commercial structure, while not strictly specialised, is less functionally dense relative to its spatial extent. Taken together, these results highlight a dual dimension of retail centrality: not only the number of establishments (density), but also the degree of functional diversity within market areas. Catchments combining high density and high entropy can be interpreted as complete retail centres, while those with lower entropy may reflect specialised or niche-orientated commercial environments.

As a baseline specification, homogeneous Poisson point process models were first estimated for each retail category and are reported in the Supplementary Material Tables S1-S7 . These models include only an intercept term and assume a constant intensity over the Eixample district, without incorporating spatial covariates or allowing for first-order spatial inhomogeneity. They therefore provide a simple reference model against which the explanatory value of the subsequent inhomogeneous Poisson specifications can be assessed. Given the relatively small differences between the empirical Ripley's K-functions and the theoretical Poisson expectation for several retail categories, the observed point patterns were interpreted as being driven primarily by first-order spatial inhomogeneity rather than by strong second-order interaction effects. The inhomogeneous Poisson estimates indicate the extent to which the spatial distribution of each retail category is associated with the selected contextual covariates. By allowing intensity to vary as a function of distance to the nearest municipal market, distance to *Passeig de Gràcia*, and population density, the models identify the main first-order spatial gradients shaping the location of food retail establishments across the Eixample. In this way, the results provide a direct assessment of whether retail presence is more strongly related to market proximity, central commercial attractiveness, or the surrounding residential structure.

The inhomogeneous Poisson estimates reveal a broadly consistent structure in the seven retail categories. The comparison of AIC values indicates that, for all retail

Table 5 Inhomogeneous Poisson model for Beverage stores

Variable	Estimate (ψ)	SE	Z.value	signif.
(Intercept)	-79.4381	19.9538	-3.9811	***
Dist. to nearest Market (km)	-1.5877	0.5881	-2.6998	**
Dist. to *Passeig de Gràcia* (km)	-3.2555	0.8922	-3.649	***
Population density (log)	6.8132	1.9625	3.4717	***
AIC	1921.4800			

Note: Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$

Table 6 Inhomogeneous Poisson model for Bread and bakery stores

Variable	Estimate (ψ)	SE	Z.value	signif.
(Intercept)	-38.4957	7.6899	-5.006	***
Dist. to nearest Market (km)	-0.2033	0.2374	-0.8566	
Dist. to *Passeig de Gràcia* (km)	-1.2598	0.3238	-3.8909	***
Population density (log)	2.8511	0.7526	3.7881	***
AIC	9102.0000			

Note: Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$

Table 7 Inhomogeneous Poisson model for Fish and seafood stores

Variable	Estimate (ψ)	SE	Z.value	signif.
(Intercept)	-106.3641	35.3688	-3.0073	**
Dist. to nearest Market (km)	0.4148	1.0762	0.3854	
Dist. to *Passeig de Gràcia* (km)	-2.4126	1.3505	-1.7864	.
Population density (log)	9.0249	3.4316	2.6299	**
AIC	549.5800			

Note: Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$

Table 8 Inhomogeneous Poisson model for Fruits and vegetables stores

Variable	Estimate (ψ)	SE	Z.value	signif.
(Intercept)	-95.3431	16.1174	-5.9155	***
Dist. to nearest Market (km)	-0.1733	0.4782	-0.3624	
Dist. to *Passeig de Gràcia* (km)	-2.1312	0.6194	-3.4409	***
Population density (log)	8.1401	1.5664	5.1968	***
AIC	2420.4200			

Note: Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$

Table 9 Inhomogeneous Poisson model for Meat and meat products stores

Variable	Estimate (ψ)	SE	Z.value	signif.
(Intercept)	-59.9782	17.5662	-3.4144	***
Dist. to nearest Market (km)	-0.4197	0.5168	-0.8121	
Dist. to *Passeig de Gràcia* (km)	-1.2175	0.6934	-1.756	.
Population density (log)	4.7224	1.7123	2.7579	**
AIC	2114.7300			

Note: Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$

Table 10 Inhomogeneous Poisson model for Other specialised food stores

Variable	Estimate (ψ)	SE	Z.value	signif.
(Intercept)	-53.6327	16.8320	-3.1864	**
Dist. to nearest Market (km)	-0.1655	0.5016	-0.3299	
Dist. to *Passeig de Gràcia* (km)	-1.2409	0.6768	-1.8335	.
Population density (log)	4.1263	1.6425	2.5123	*
AIC	2258.9500			

Note: Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$

Table 11 Inhomogeneous Poisson model for Supermarkets

Variable	Estimate (ψ)	SE	Z.value	signif.
(Intercept)	-29.5314	6.3346	-4.6619	***
Dist. to nearest Market (km)	-0.0998	0.1939	-0.5149	
Dist. to *Passeig de Gràcia* (km)	-0.7552	0.2626	-2.8755	**
Population density (log)	1.9836	0.6194	3.2024	**
AIC	12844.7700			

Note: Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$

categories, the inhomogeneous Poisson models improve model fit relative to the homogeneous baseline specifications (Table 5 to Table 11). The lower AIC values suggest that assuming a constant intensity throughout the district is insufficient and that incorporating contextual covariates provides a more appropriate representation of the spatial distribution of food retail establishments.

In all models, the coefficient for population density is positive and is statistically significant for every category. This indicates that denser residential environments are systematically associated with a higher estimated intensity of food retail establishments across the Eixample district. An inverse clear pattern emerges for distance to *Passeig de Gràcia*, whose coefficient is negative in all seven models. This effect is statistically significant for three retail categories. By contrast, the distance to the nearest market shows a much weaker and less systematic relationship with retail intensity. The coefficient is statistically significant only for Beverage stores, where it is negative, indicating a higher estimated intensity closer to municipal markets. For the remaining categories, the coefficients are mostly negative, except for the Fish and seafood stores, but not statistically significant for either of those categories. These results indicate that proximity to municipal markets is not a general explanatory factor for the spatial distribution of most food retail types in the current model specification.

At the category level, the strongest contextual structuring appears in Fruits and Vegetables, Beverage, and Fish and Seafood, which show the largest positive coefficients for population density and relatively strong negative coefficients for distance to *Passeig de Gràcia*, although the latter is not significant for Fish and Seafood. Bread and bakery stores and Supermarkets also display a clear association with both population density and proximity to *Passeig de Gràcia*, but with smaller coefficient magnitudes, suggesting a broader and less sharply differentiated locational pattern. Meat and meat products and Other specialised food stores occupy an intermediate position, with positive and significant density effects and weaker, though still significant, negative associations with the *Passeig de Gràcia* axis.

The reduction in AIC is observed for beverages, bread and bakery stores, fish and seafood stores, fruit and vegetables stores, meat and meat products stores, other specialised food stores, and supermarkets. This systematic improvement suggests that assuming a constant intensity across the district is insufficient, and that incorporating

contextual covariates—distance to municipal markets, distance to Passeig de Gràcia, and population density—provides a more appropriate representation of the spatial distribution of food retail establishments.

Taken together, Tables 5–11 indicate that the contemporary geography of food retail in the Eixample is consistent with shaped more consistently by residential density and proximity to the central axis of the *Passeig de Gràcia* than by distance to the nearest municipal market. In substantive terms, this suggests that current food retail intensity responds primarily to population concentration and central commercial attractiveness, whereas the market network exerts a much more limited and category-specific influence.

Additional inhomogeneous Poisson specifications were estimated by incorporating two socioeconomic covariates: personal income and the share of the population over 64 years old. The inclusion of these variables does not alter the direction or statistical significance of the main covariates, i.e. distance to municipal markets, distance to *Passeig de Gràcia*, and population density, indicating that the results are robust to the consideration of socioeconomic and demographic structure. Both personal income and population ageing exhibit negative coefficients, although their effects are statistically significant only for Supermarkets and Beverage stores. This suggests that while income levels and the presence of older residents can shape the location of some retail formats, they do not provide a systematic explanation for the distribution of most food retail categories in the Eixample. In general, these robustness checks reinforce the interpretation that food retail intensity is primarily associated with residential density and proximity to the central commercial environment of Passeig de Gràcia, whereas the additional socioeconomic variables play a more limited and category-specific role.

The inhomogeneous Poisson models were evaluated using global simulation envelopes based on the inhomogeneous Ripley's K-function and Pearson residual maps and (Supplementary Material, Figures S7 and S8). The observed $Kinhom(r)$ curves

remained within the global simulation envelopes for all retail categories, indicating that, after controlling for the selected covariates, there was no statistically significant residual clustering or inhibition over the range of distances considered. The agreement between the observed and theoretical curves was particularly close for supermarkets and bread and bakery stores. Moderate deviations were observed for beverage, meat, fruit and vegetable, and other specialised food stores, although these remained within the simulation envelopes. The envelope for fish and seafood stores was substantially wider, most likely because of the small number of establishments in this category, which reduces the statistical power of the validation procedure. Pearson residual maps showed generally small residual values. The absence of pronounced and spatially coherent residual concentrations suggests that the fitted covariates adequately captured the main spatial variation in retail intensity. The predominance of slightly negative residuals in some areas indicates a limited local overprediction of the number of establishments, but no strong systematic spatial misspecification was detected. Taken together, the residual and envelope diagnostics support the adequacy of the fitted Poisson models, although the results for fish and seafood stores should be interpreted cautiously because of the limited sample size.

5 Conclusions and Discussion

This work revisits the spatial logic of food retail in Barcelona's Eixample district through a point pattern approach, taking the historical framework of Ildefons Cerdà's plan as both an analytical reference and a normative benchmark. The starting point of the study was the idea that the Eixample district was conceived not only as a geometric urban expansion but also as a socially orientated spatial system in which the regular distribution of facilities such as municipal markets was intended to guarantee proximity, accessibility, and basic urban welfare. In this sense, the research addressed whether the current geography of food retail still reflects the proximity-based logic

embedded in the Cerdà's urban framework or whether contemporary dynamics of commercial specialisation, tourism pressure, and retail restructuring have produced a different spatial order. The results indicate that the contemporary distribution of food retail in the Eixample district only partially reflects the historical logic of market-centred provision.

An central finding is the weak and category-specific relationship between distance to the nearest municipal market and retail intensity, which is statistically significant only for Beverage stores. Contrary to the organising role envisaged in Cerdà's plan, the market network no longer appears to be the primary determinant of food retail distribution. Nevertheless, kernel density maps show concentrations of some fresh and specialised food retailers around particular markets, indicating that these facilities remain relevant as local anchors of traditional food retail and contribute to the formation of neighbourhood-scale commercial environments, although broader spatial patterns are increasingly shaped by other factors.

A second major finding is the consistent negative association between the distance to *Passeig de Gràcia* and the intensity of food retail, indicating that establishments tend to be more abundant closer to this central commercial corridor. At first glance, this might appear to contradict the argument advanced in the literature on touristification and retail desertification (Cheung & Yiu, 2024). However, the kernel density maps show that the avenue itself constitutes a low-density area for food retail, while higher concentrations occur in the immediately adjacent streets. Rather than contradictory, these findings reveal a spatial displacement effect: the centrality and accessibility of *Passeig de Gràcia* support retail activity in its surroundings, while touristification, luxury specialisation and high commercial rents restrict the presence of less profitable everyday food retailers along the avenue itself (Frago et al., 2024). The model results therefore support the argument that touristification reorganises retail diversity by

shifting neighbourhood oriented activities from high-value commercial axes towards nearby streets (Cheung & Yiu, 2023; Frago, 2026; Gómez-Varo et al., 2024).

The most stable explanatory factor across all models is population density. The coefficient for population density is positive and statistically significant in every food retail category, indicating that denser residential environments are systematically associated with a higher estimated food retail intensity. This result highlights the continued importance of residential demand in shaping the geography of everyday food provision. Although centrality and tourism-related dynamics matter, food retail remains strongly tied to the presence of resident populations. In this sense, the Eixample district continues to operate as a proximity-based urban environment. This finding is consistent with the broader framing of the article, which emphasised that the Eixample district is not only a central economic and tourist area, but also a dense residential district hosting a substantial share of Barcelona's population.

Taken together, the modelling results indicate that contemporary food retail intensity in the Eixample district responds primarily to two forces: population concentration and proximity to the central commercial attractiveness. By contrast, the municipal market network exerts a much more limited and category-specific influence. This represents one of the main substantive contributions of the article. The historical structure of the district still matters and the markets remain embedded in the retail landscape, but the current spatial organisation of food retail is not primarily governed by distance to markets. Instead, it reflects a hybrid territorial logic in which residential density, commercial centrality, and the displacement effects of touristification interact. This hybrid logic complicates a simple reading of Cerdà's legacy.

The entropy analysis adds a complementary perspective by shifting attention from the intensity of establishments to the functional composition of retail around municipal markets. Even if the distance to markets is not a strong explanatory variable in point

process models, market catchments are not functionally irrelevant. They structure different types of retail environments, some more diversified and others more specialised, pointing to a more complex form of market centrality than the one implied by a simple distance-decay model. Rather than asking only whether establishments are closer to or farther from markets, future planning analysis should consider the kinds of retail diversity that emerge around each market, the density of that diversity, and the degree to which these catchments support everyday provisioning for surrounding residents.

The descriptive and second-order analyses also reveal important differences between retail categories. Clark–Evans tests show significant clustering for most traditional food retail categories except Supermarkets, which do not differ significantly from complete spatial randomness. This distinction is relevant to interpret the transformation of the Mediterranean food retail model. Traditional fresh-food retail appears to retain locally clustered patterns associated with agglomeration and neighbourhood commercial environments. By contrast, Supermarkets seem to follow a broader territorial coverage strategy, less dependent on short-distance clustering and more consistent with optimisation across the district. This coexistence is not merely descriptive; it has planning implications. If Supermarkets become the dominant form of everyday provision, the historical relationship between public markets, small specialised shops, and neighbourhood life may weaken. At the same time, the persistence of clustered fresh-food retail around some market areas indicates that local commercial ecosystems remain active and may still support the social and nutritional functions associated with Mediterranean market culture. The challenge for policy is therefore not simply to preserve markets as heritage infrastructures, but to maintain the surrounding retail diversity that gives them everyday territorial relevance.

From a planning perspective, these findings suggest that the contemporary relevance of Cerdà's model cannot be evaluated solely by the survival of municipal market buildings or the formal regularity of the grid. The key question is whether the district

still provides equitable, walkable, and functionally diverse access to everyday goods. The evidence presented here suggests that this objective is only partially fulfilled. The market network continues to contribute to the diversity of local retail and remains associated with some concentrations of fresh-food, but its influence is weaker than expected in statistical models. Population density remains a strong driver of food retail intensity, which is positive from the point of view of demand-responsive urban provision. However, the strong centrality effect points to the need to consider how tourism, symbolic centrality, and real-estate pressure shape access to basic services in central districts. Planning interventions should therefore address not only residential access to markets, but also the displacement of everyday retail from high-value commercial corridors and the possible weakening of basic services in highly touristified areas.

The methodological contribution of the study is also relevant. By using a point pattern framework, the article moves beyond areal summaries and directly models the location of individual retail establishments. This allows the analysis to distinguish between first-order spatial heterogeneity, second-order clustering, and covariate-driven intensity patterns. The use of kernel density estimation, inhomogeneous Ripley's K-functions, entropy measures, and inhomogeneous Poisson models provides an integrated framework for studying everyday service geographies at fine spatial resolution. This approach is transferable to other cities where public markets, commercial corridors, and residential density interact in shaping access to basic goods. It is especially useful in dense European and Mediterranean contexts, where food access cannot be understood through the North American food desert framework alone and where public markets remain embedded in historical urban fabrics.

The study also has limitations that should guide future research. First, the analysis is based on a 2024 cross-sectional snapshot and therefore cannot directly capture temporal changes in the food retail system. Second, although the main specification focuses on three contextual covariates, i.e. distance to municipal markets, distance to

Passeig de Gràcia, and population density, other potentially relevant factors are not incorporated in the current model, including commercial rents, tourist accommodation density, commercial turnover, and shop size. Additional specifications were estimated, including personal income and the share of the population over 64 years of age. These variables show negative coefficients, but their effects are statistically significant only for Supermarkets and Beverage stores. Importantly, their inclusion does not alter the sign or statistical significance of the core covariates, suggesting that the main findings are robust to consideration of income and demographic ageing. Third, the Fish and Seafood category contains a small number of observations (n = 20), so its spatial pattern should be interpreted with caution, as estimates of intensity and second-order structure are less stable than for categories with larger samples. Future research could extend the analysis longitudinally, incorporate network-based accessibility measures, and examine how tourism intensity, commercial rents, socioeconomic composition, and business-level characteristics contribute to the displacement or persistence of everyday food retail in central urban districts.

In conclusion, the study shows that the food retail geography of Barcelona's Eixample district is the result of a layered interaction between historical planning, residential density, market infrastructures, and contemporary commercial restructuring and tourist pressures. Municipal markets remain important elements of the district's food landscape, but they no longer operate as the dominant explanatory structure of food retail intensity. Population density and centrality attractiveness exert stronger and more systematic effects, although the latter must be interpreted through the lens of displacement rather than simple attraction. Therefore, the contemporary Eixample district does not represent a simple continuation of Cerdà's original model or a complete departure from it. Rather, it reveals how a historical framework of proximity and accessibility is being reworked by density, centrality, and touristification, producing a

complex geography of everyday provision that remains central to debates on urban equity, retail planning, and spatial justice.

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