

Article

House Sparrow Nesting Site Selection in Urban Environments: A Multivariate Approach in Mediterranean Spain

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Abstract: The House Sparrow (*Passer domesticus*) is a common but declining bird species in its native urban areas, partly due to reduced nesting site availability caused by modern urbanisation and loss of old architectural styles. In this study, we analysed, through a multivariate approach, the environmental factors influencing House Sparrow nest site selection in three diverse inland urban areas within the Valencian Community, Spain. We located 584 House Sparrow nests during spring 2017 and also selected 300 random points (habitat availability) in the study localities. We used Factorial Analyses of Mixed Data to assess urban feature gradients of nests and urban variables. We carried out Generalized Linear Mixed Models to compare nest locations to random points and explore variations in nesting typologies between urban zones. Specific nest site preferences vary between urban sectors, indicating that House Sparrow nests are not randomly located in urban areas. Nests are typically found near parks, schools, vacant plots, city limits, and surrounding crops, where greater vegetation cover provides abundant food sources. Low-rise terraced houses with traditional roofs and open clay tiles are consistently preferred for nesting, whereas modern architectural trends reduce nesting opportunities. Preserving green areas and old architecture with open clay tiles is essential for maintaining nesting sites and promoting House Sparrow conservation in Mediterranean urban areas. Adherence to these conservation measures may also benefit other hole-nesting species and urban wildlife reliant on green spaces.

Keywords: cities; conservation; habitat selection; nest; *Passer domesticus*; urban areas; urbanisation



Citation: Bernat-Ponce, E.; Gil-Delgado, J.A.; López-Iborra, G.M. House Sparrow Nesting Site Selection in Urban Environments: A Multivariate Approach in Mediterranean Spain. *Urban Sci.* **2024**, *8*, 108. <https://doi.org/10.3390/urbansci8030108>

Academic Editors: Siu-Kit Lau, Vesna Kosorić, Abel Tablada, Miljana Horvat, Milena Vukmirović, Silvia Domingo-Irigoyen, Marija Todorović, Jérôme H. Kaempf, Kosa Golić, Ana Peric and Tatjana Kosić

Received: 3 June 2024

Revised: 2 August 2024

Accepted: 3 August 2024

Published: 9 August 2024



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1. Introduction

Urbanisation is constantly expanding, with projections indicating continued growth throughout the 21st century [1]. Although cities have existed for millennia, their dominance over terrestrial surfaces has intensified only in recent centuries [1,2]. Consequently, numerous animal species, including those considered urban adapters, dwellers or exploiters, are facing challenges in these modern environments [3–6]. Over the last few decades, various studies conducted in towns and cities have significantly advanced urban ecology, particularly in relation to birds [1,2,5,7]. Birds are among the few forms of wildlife with which city inhabitants regularly interact, making them a valuable model group for studying urban biodiversity [1,2,8]. These studies are essential for understanding the effects of urbanisation on wildlife and for proposing effective conservation measures and proper management strategies in urban areas [9,10].

Although urbanisation has been identified as a major threat to biodiversity, urban areas are a unique ecosystem used by a wide range of bird species [11]. These environments provide them with a constant and predictable food supply, protection from predators, and a buffer against extreme weather events, but they are also important providers of

nesting sites [1,2,8,11,12]. Nests and nesting sites play a crucial role in bird survival and reproduction in every ecosystem [13,14]. These structures not only provide protection from predators but also shield them from the elements by creating a suitable microclimate with insulating materials [15–18]. Additionally, nest site availability can limit bird populations, even in the presence of enough food and other resources [14,19–21]. Therefore, nest site availability is crucial for bird conservation, especially considering the declining numbers of many bird species due to habitat loss, fragmentation, and urbanisation [3,19,22,23]. Urbanisation has further impacted nesting patterns by reducing natural cavity nesters but increasing the number of birds utilizing cavities in buildings [14].

The House Sparrow *Passer domesticus* is widely regarded as one of the most iconic and common urban birds [24–26]. However, currently common species can also be susceptible to decline [27]. Despite its preference for urban environments and extensive use of anthropogenic substrates for nesting [26,28], the species has experienced negative population trends in Europe over the last few decades, coinciding with increased urbanisation [25,29–31]. Several hypotheses have been proposed to explain these negative trends, including urbanisation and loss of green areas [10,25,32], urban pollution [33,34], avian malaria [35,36], urban diet [37,38], competition [39], and predation [40,41]. However, the prevailing hypothesis to explain the decline of House Sparrows in urban areas is likely due to a combination of factors rather than a single cause [26]. The conservation of common species, such as the House Sparrow, and not only endangered species is important for many reasons, such as maintaining the ecological balance of the urban ecosystem or its utility as an urban bioindicator [26,37,38].

One of the most highlighted factors contributing to the decline of the House Sparrow is the reduction in nesting site availability in urban areas [25,42]. While the House Sparrow is a secondary cavity nester and adaptable in its choice of nesting sites, it typically prefers structures such as building tiles, rafters, vines on walls, ventilated roofs, wall cracks, gutter clips in wall recesses, crevices, and holes in urban structures [24,26,28,43–45]. Studies have consistently reported higher House Sparrow abundances in low socioeconomic status areas with abundant old buildings, as these areas often have buildings that are less frequently repaired or renovated compared to wealthier neighbourhoods [32,42,46]. However, recent regulations and strategies in European Union countries since 2014 aim to promote investments in renovating residential and commercial buildings for energy efficiency to combat climate change [47]. Therefore, modern building technologies or refurbishment of old ones using insulating materials may offer fewer hollows, holes, recesses, and cracks, which are essential for urban cavity nesters like House Sparrows [32,48,49]. Consequently, modern building trends may have altered the availability of nesting sites due to changes in architectural styles.

Although the House Sparrow is a well-studied urban bioindicator species, its nesting site selection has never been explored from a multivariate approach. There is an increasing need to assess the effects of modern urbanisation and refurbishment trends as potential factors contributing to the species' decline given the loss of old architectural styles in urban areas. This study aims to identify the gradients of the environmental variables representing habitat availability (random points) and the characteristics of habitats actually used for nesting (nest points) that determine nesting site selection by the House Sparrow. It is hypothesized that House Sparrows locate nests in specific sectors of gradients of urban variables rather than randomly along them. It is expected that nests will preferably be located in sectors associated with old and low-rise buildings, with traditional roofs and near food sources (e.g., parks). Additionally, this study aims to determine if House Sparrow nest placement differs between urban sectors. Achieving both objectives will help identify gradients that may be disappearing in modern cities and propose urban planning measures that mitigate potential negative impacts on the species.

2. Materials and Methods

2.1. Study Area

The present study was carried out in three inland localities of different characteristics (Alcoy, Benilloba, Cocentaina) within a 6 km radius in the northern part of Alicante province (Southeastern Spain). The selection of these three localities increased the generalizability of our results by considering a gradient of small to medium-sized localities while maintaining their geographic proximity. Their geographical, demographical, and climatic characteristics can be found in Table 1 and Figure 1. The region has a Mediterranean climate, characterized by a Mesomediterranean thermotype, with cold winters featuring freeze days typically occurring between November and April, and hot summers with temperatures reaching up to 40 °C [50,51].

Table 1. Geographical, demographic, and climatic characteristics of the three localities where the nesting behaviour of the House Sparrow was studied were obtained from AVAMET [52] and Instituto Nacional de Estadística [53].

Locality	Coordinates	Number of Inhabitants 2017	Density (Inhabitants/km ²)	Temperature 2017 (°C)			Rainfall 2017 (mm)	Altitude (m.a.s.l.)	Old Town	Sectors of Study		
				Max.	Mean	Min.				Suburban/ Outskirts	Residential/ Commercial	Industrial
Benilloba	38°41′57″ N 0°23′28″ O	755	80.95	40.1	15.4	−5.2	594.7	520	1	0	0	0
Cocentaina	38°46′47″ N 0°26′10″ O	11,461	297.91	40.0	16.6	−3.6	421.4	410	1	1	1	1
Alcoy	38°41′54″ N 0°28′25″ O	59,106	468.48	40.4	16.1	−4.4	548.4	562	1	1	2	1

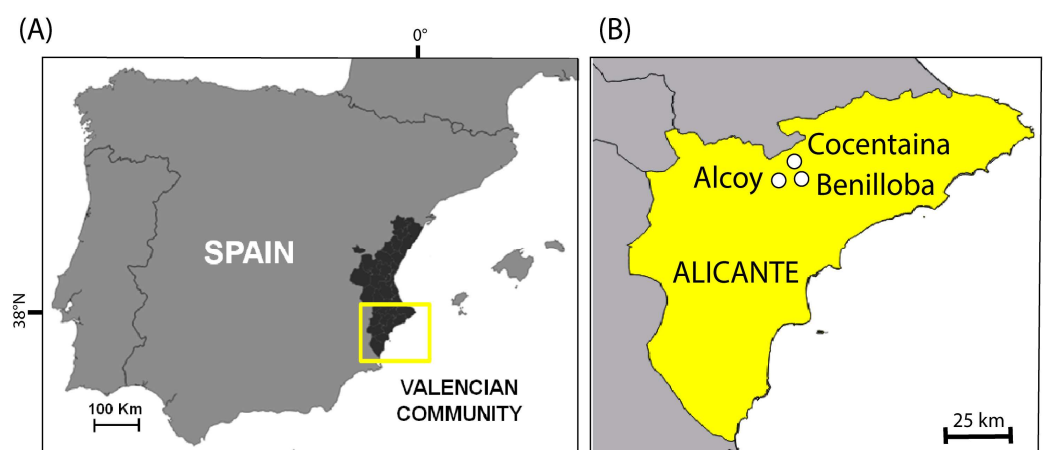


Figure 1. (A) The study area is located in the northern region of the province of Alicante (highlighted by the yellow square) in the Valencian Community, eastern Spain. (B) Study localities (Alcoy, Cocentaina, and Benilloba) were chosen as representative of a gradient of small to mid-size localities in the region.

2.2. House Sparrow Nest Surveys

Nest surveys in the three localities were carried out during the peak of the breeding season of the House Sparrow in the study area, from late April to late June of 2017 [45,54]. The survey methodology for nest detection was based on De Laet et al. [55]. In each of the three localities, representative sectors of homogeneous and accessible types of urban habitats were randomly selected, avoiding non-sampling habitat, inaccessible gardens/closed private properties (range 10–15 ha; Table 1; 10 parcels in total). Selection of these sectors was performed using QGIS 2.18 Las Palmas software [56]. The main urban sectors available in these anthropized areas included [57]: (1) old town, characterized by old buildings with some commercial areas, scarce private gardens, and small public gardens or parks; (2) suburban/outskirts residential areas, consisting of low-rise houses with private gardens, with few commercial establishments; (3) urban residential/commercial areas, featuring tall buildings with a high density of businesses and may be associated with urban parks,

but generally with a low density of private gardens; and (4) industrial areas located on the outskirts, characterized by non-residential buildings and industrial warehouses without green areas.

One sector per day was sampled, starting from official sunrise and not exceeding 2–3 h, aligning with the peak activity period of House Sparrows [26]. This method reduces the influence of human activity and noise, which could affect the detectability of active nests. Additionally, sampling was not conducted on rainy days or when wind speeds exceeded 15 km/h [55]. Each of the 10 sectors was sampled three times during the study period (from 20 April to 30 June, breeding season peak), with a minimum separation of 15 days between visits. One observer (EB-P) systematically walked along each street and accessible areas, searching for active House Sparrow nests (hereafter nests). Initially, nests were easily detectable due to the regular calls of the males in proximity of the nest and were confirmed by observing any pair member entering the nest with or without building material or food for the chicks [55]. During each visit, detected nests were precisely mapped on a 1:2500 map, and the substrate/location used for nest placement (hole, tube, open clay tile, beam) was noted (Table 2).

2.3. Nest and Habitat Characterization

For each nest, 20 environmental variables were recorded in situ or measured using SIGPAC [58] or SEC [59], as indicated in Table 2. These variables encompassed both the general features of the building selected for nesting and its location within the urbanized matrix. This location included distance to potential food sources surrounding the nest (Table 2). To assess habitat availability for nest placement, the same variables (Table 2) were measured at 30 random points per sector (300 random points in total), identified using QGIS 2.18 Las Palmas software. Random points not situated on buildings were allocated to the closest one, as House Sparrows in urban areas tend to prefer human structures for nesting [26].

2.4. Statistical Analyses

2.4.1. Nest Site Selection

A factorial analysis of mixed data (FAMD) was employed to explore the gradients of the environmental variables representing habitat availability (random points) and the characteristics of the habitats actually used for nesting (nest points). FAMD facilitates the integration of both continuous and categorical variables into the same analysis [60], allowing the examination of associations between the categorical and continuous variables describing nests and random point locations. The nest placement variable (Table 2) was excluded from this analysis. The R package FactoMineR [61] was used to perform the FAMD. The “dimdesc” function was employed to identify the variables with a stronger association with each dimension. Correlation was used for continuous variables. The significance and R^2 values obtained from an ANOVA were used to evaluate the importance of each categorical variable, testing for variations in axis coordinates among different levels of the variable [60,61].

To assess whether particular values of the FAMD gradients of environmental variables were selected for placing nests, we used Binomial Generalized Linear Mixed Models (GLMMs) fitted using the glmmTMB package [62], with the type of sample point (random point coded 0 or nest point coded 1) as the dependent variable. A separate GLMM was fitted for each selected dimension (D1, D2, D3) in each urban sector (old town, outskirts, residential, industrial), totalling 12 models. In these models, the coordinates in each FAMD dimension served as the predictor variable, while Locality (Alcoy, Benilloba, Cocentaina) was included as a random effect [63].

Table 2. Environmental variables recorded at House Sparrow nests and random points. Note that nest placement variable was only available for nest points. The number of categories for each categorical variable is indicated in brackets and can be found in the description. Data were obtained in situ, from SEC [59], or through the SIGPAC 2017 software [58]. See Table S1 for more information.

Group	Variable	Category	Sampled	Description
Building features	Year	Numerical	SEC	Year of building construction
	Reform	Categorical (2)	SEC	Presence/absence of reform/improvement in the building
	Building	Categorical (4)	In situ	Flat, House, Detached House, Industrial warehouse
	Floors	Numerical	In situ	Number of floors of the building
	Roof	Categorical (5)	In situ	Open Arabic roof tiles, Closed Arabic roof tiles, No tiles, Plain roof tiles, Asbestos/metal sheet roof (Figure S1)
	Facade	Categorical (4)	In situ	Plain, Metal sheet, Exposed (bricks/stones), Mixed
	Holes	Categorical (2)	In situ	Presence/absence of holes in the building
	Gutter	Categorical (2)	In situ	Presence/absence of gutter under the tiles of the building
	Eaves	Categorical (2)	In situ	Presence/absence of eaves in the building
	Tree	Categorical (2)	In situ	Presence/absence of trees (>3 m) in the street
	Garden	Categorical (2)	In situ	Presence/absence of private gardens in the building
	Terrace	Categorical (2)	In situ	Presence/absence of terraces in the building
Location features	Nests_Du	Categorical (2)	In situ	Presence/absence of <i>Delichon urbicum</i> nests in the building [45]
	D_limit	Numerical	SIGPAC	Distance in metres to the closest urbanized area limit
	D_school	Numerical	SIGPAC	Distance in metres to the closest school
	D_crop	Numerical	SIGPAC	Distance in metres to the closest crop
	D_park	Numerical	SIGPAC	Distance in metres to the closest urban park
	D_plot	Numerical	SIGPAC	Distance in metres to the closest vacant plot
Nest (only for nest points)	D_container	Numerical	SIGPAC	Distance in metres to the closest rubbish container
	Nest placement	Categorical (10)	In situ	Arabic clay tile, flat tile, open clay tile, asbestos, beam, hole, ornament, slot, tube, <i>Delichon urbicum</i> nest

2.4.2. Differences in Nest Placement between Urban Sectors

A Chi-squared test was conducted to examine if the frequency of substrates used for nesting differed between urban sector types using the “chisq.test” function of the ‘stats’ R Package [64].

A second FAMD was used to investigate if the habitats and substrates used for nest placement in buildings differed between urban sectors. For this analysis, only building feature variables for nest points were utilized, including the nest location variable (Table 2). When nests were located in the same building and had the same nest substrate, only one nest was included in the analysis, as all variable values were equal.

We checked if the coordinates in the selected dimensions resulting from this FAMD (dependent variables) varied between urban sectors (residential, outskirts, industrial, old town; Table 2), using linear mixed models (glmmTMB package; [62]) with locality as a random effect [63]. The significance of the fixed effects was tested by the “Anova” function of the “car” package [65]. The “pairs” function of the “emmeans” package [66] was used to compare differences in gradients between urban sectors.

3. Results

A total of 584 nests were found (252 in Alcoy, 237 in Cocentaina, and 95 in Benilloba) across the 4 urban sectors studied (246 in the old town, 200 in residential/commercial areas, 90 in suburban/outskirts areas, and 48 in industrial areas; see Table 3). Nests were mainly located (73.28%) under tiles (55.82% under Arabic clay tiles and 17.47% under open clay tiles), while a smaller proportion were found on tubes, asbestos, and holes, each representing approximately 5% of the nests. The Chi-squared test showed that the frequency of substrates used for nesting differed between urban sector types (Table 3; $\chi^2 = 500.49$; $df = 27$; $p < 0.001$).

Table 3. Number of House Sparrow nests found in each substrate type in the urban sectors studied. Percentage of nests in each substrate within urban sectors is shown between brackets.

Nest Placement	Industrial	Old Town	Outskirts	Residential	Total
Arabic clay tile	16 (33.3)	208 (84.6)	12 (13.3)	90 (45.0)	326
Open clay tile	0 (0)	7 (2.9)	68 (75.6)	27 (13.5)	102
Tube	4 (8.3)	1 (0.41)	4 (4.44)	25 (12.5)	34
Asbestos	4 (8.3)	6 (2.4)	0 (0)	23 (11.5)	33
Hole	11 (22.9)	12 (4.9)	2 (2.2)	5 (2.5)	30
<i>Delichon urbicum</i> nest	1 (2.1)	3 (1.2)	0 (0)	14 (7.0)	18
Flat tile	0 (0)	1 (0.4)	0 (0)	13 (6.5)	14
Ornament	4 (8.3)	8 (3.3)	0 (0)	1 (0.5)	13
Beam	7 (14.6)	0 (0)	0 (0)	2 (1.0)	9
Slot	1 (2.1)	0 (0)	4 (4.4)	0 (0)	5
Total	48	246	90	200	584

3.1. Nest Site Selection

The FAMD performed with the 584 nests and 300 random points identified eight dimensions with eigenvalues > 1 (Table 4). We selected to interpret the first three dimensions based on relatively strong relationships with at least one continuous variable (defined as correlation > 0.5). We also confirmed that these correlations were not influenced by extreme values after inspection of the variables scatterplots (Figure S2). Density plots and selection indexes of the continuous variables and count and percentage of the categorical variables can be found in (Supplementary Material Figure S3, Table S2).

Table 4. Description of the first eight dimensions resulting from the factorial analysis of mixed data (FAMD) of House Sparrow nests and random points from the four study habitats (parcels) of anthropized areas of the Mediterranean Spain. For continuous variables, the correlations > 0.4 with scores in each selected dimension (Dim.1, Dim.2, Dim.3) are shown in bold and underlined in the table and displayed graphically in Figure S2. For categorical variables, the table presents the R^2 resulting from an ANOVA that compares the average scores of each variable's levels within each dimension (only results for significant ANOVAs are shown).

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8
eigenvalue	3.834	3.280	2.199	1.687	1.439	1.215	1.132	1.114
Cumulative % of variance	14.746	27.360	35.819	42.307	47.839	52.513	56.868	61.154
Continuous variables								
Year	0.266	0.243	<u>0.558</u>	−0.267	0.402	0.043	0.078	−0.100
Floors	<u>−0.483</u>	<u>0.551</u>	−0.030	−0.181	−0.031	0.228	0.115	0.043
D_limit	<u>−0.248</u>	<u>0.623</u>	−0.231	0.467	0.252	−0.009	0.049	−0.017
D_park	<u>0.820</u>	−0.134	−0.047	0.068	0.091	0.102	−0.057	0.100
D_school	<u>0.706</u>	−0.034	−0.280	0.115	−0.035	−0.184	−0.080	0.042
D_plot	−0.060	<u>0.433</u>	<u>−0.411</u>	0.373	0.118	0.179	0.051	0.204
D_crop	−0.273	<u>0.661</u>	−0.205	0.328	0.204	0.030	−0.172	0.077
D_container	0.289	−0.293	−0.037	0.174	−0.072	0.318	0.256	0.458
Categorical variables								
Building	0.786	0.453	0.220	0.344	0.033	0.171	0.033	0.027
Eaves	0.453	0.080		0.006	0.049	0.013	0.024	0.054
Facade	0.293	0.133	0.138	0.080	0.207	0.401		0.134
Gutter	0.195	0.288	0.062	0.021	0.146			0.019
Holes	0.011			0.157	0.126		0.044	0.033
Nests_Du	0.007		0.072	0.035	0.006	0.017	0.478	0.007
Garden		0.077	0.413	0.107	0.074		0.016	0.012
Reform	0.015	0.161	0.208	0.045	0.173	0.011	0.040	0.007
Roof	0.375	0.446	0.242	0.244	0.305	0.214	0.190	0.320
Terrace			0.172	0.023	0.017	0.096	0.035	0.219
Tree		0.161	0.009	0.008	0.005	0.055	0.138	

The first dimension is a gradient between industrial areas, which include buildings with particular characteristics located far from parks and schools, and the rest of urban sectors (Figure 2). The second dimension is a gradient that differentiates the rest of urban sectors, and particularly the residential/commercial sector, located farther from the urban limit and including tall buildings, from old town and outskirts sector, with low-rise buildings or detached houses located closer to the crops surrounding the towns. These sectors differ also in the types of roofs of their buildings. The third dimension is mainly a gradient of age of the buildings, so that newer buildings tend to be closer to vacant plots and to have private gardens.

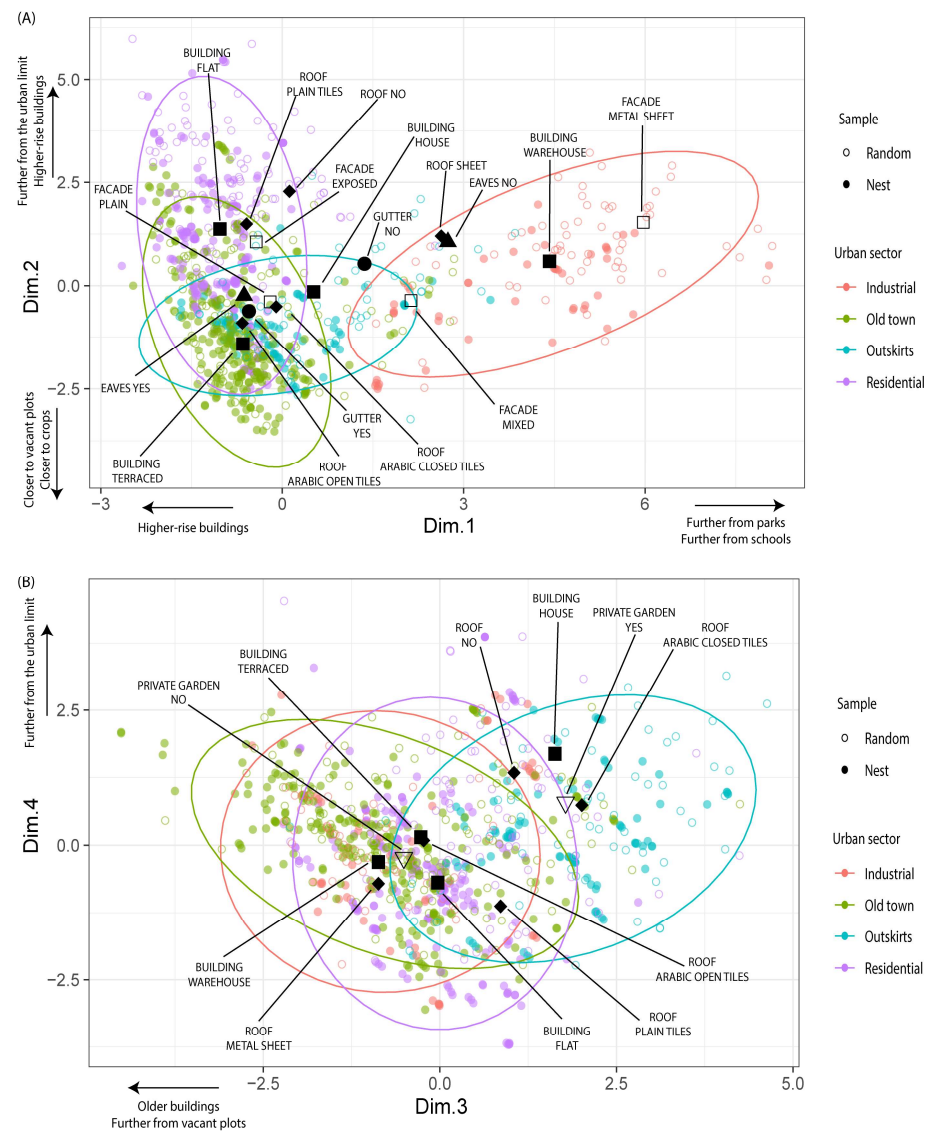


Figure 2. Available habitat (random sample) and selected nesting sites (nest) of the House Sparrow, ordered in the first four FAMD dimensions ((A): Dim.1 vs. Dim.2; (B): Dim. 3 vs. Dim.4), showing the most relevant categorical and numerical variables and the link between them in the four urban sectors. Nests are represented with filled circles and random locations are shown with empty circles, both coloured according to the urban sector. The black symbols identify the levels of the most relevant categorical variables: square (building type), triangle (eaves), diamond (roof), empty inverted triangle (garden), and circle (gutter). Levels within categorical variables are identified by text connected with a line to the symbol. The 95% confidence ellipses are shown with colours corresponding to the urban sector. The arrows identify continuous variables with stronger correlations with each selected dimension (refer to Table 4 and Supplementary Figure S2 for more information).

According to the Binomial GLMMs (Table 5), characteristics of habitats used for nesting differed from available habitats practically in all the urban sectors and FAMD dimensions considered. Only dimension 3 was marginally significant between random and nest points for the outskirts parcel. Within each urban sector, nests were preferably located in buildings close to parks and schools (Dimension 1), which is associated with higher buildings in the case of old town and residential-commercial sectors. Selection of gradient represented by FAMD dimension 2 was also consistent between urban sectors, as nests were more likely to be found closer to the urban limit, crops, and vacant plots. Contrarily to dimension 1, in that case nests were preferentially found in lower-rise buildings. Nest habitat selection along FAMD dimension 3 differed between urban sectors, since in the industrial sector nests were more likely found in the positive range of values, that is in newer buildings closer to vacant lots. On the contrary, in the other urban sectors, nests tend to be located preferentially in older buildings further from vacant lots.

Table 5. Results of the Binomial GLMMs fitted to explore the probability of a sampled point being a House Sparrow nest or random point with the scores in each of the first three FAM dimensions. Locality was included as random factor. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Urban Sector	Dim.1				Dim.2				Dim.3			
	Model Intercept		D1 Estimate		Model Intercept		D2 Estimate		Model Intercept		D3 Estimate	
Industrial	1.998	*	−0.524	***	−0.021		−0.999	***	−0.002		0.619	**
Old	0.677	*	−0.460	**	0.865	***	−0.175	*	0.866	***	−0.251	**
Outskirts	0.508	**	−0.601	***	−0.178		−0.723	***	0.939	*	−0.286	
Residential	0.317		−0.530	**	1.965	***	−0.703	***	0.921	***	−0.839	***

3.2. Differences in Nest Placement between Urban Sectors

The FAMD conducted with placement characteristics of the House Sparrow nests identified ten dimensions with eigenvalues > 1 (Table 6). We selected to interpret only five dimensions (Dimensions 1, 2, 3, 5 and 8), which presented significant differences between urban sectors (See Methods; pairs “emmeans”). Dimension 1 relates the year of construction of the building to the type of building, its roof type, the presence of gutters, and the placement site of the nest. This dimension separates mainly nests in industrial sector buildings, that were mostly located in beams, slots, asbestos or holes, from nests in old buildings placed under Arabic clay tiles (Figures 3 and 4). Dimension 2 describes a relation between the number of floors of the building and the building type, the presence of private gardens, and nest placement type. This dimension identifies two groups of nests: those located in old town or residential sectors, where nests are on average located in taller buildings and those in outskirts and industrial sectors. Dimension 3 also describes a relationship between the year of construction, building roof type, and nest placement type, but only for nests located in sectors other than industrial areas (Figure S4). All urban sectors have different average coordinates along this dimension, indicating that nest placement has changed differently over time in each urban sector, likely in relation to the changes in roof construction methods. There have been few changes in nest placement over time in the industrial sector, while in older buildings in the old town, nests in Arabic clay tiles predominated until the 1970s, when sparrows began using holes as the main alternative to Arabic clay tiles. In the residential sector, buildings are more recent, and nest locations have been more diversified since the 1950s, with open clay tiles as an alternative site to Arabic clay tiles. Buildings in the outskirts are even more recent, and nests in open clay tiles predominate. Dimension 4 relates nest type to roof type and places nests in the industrial sector at one extreme and nests in the residential sector at the opposite extreme. Dimension 8 is related to the occupancy of house martin nests by sparrows to build their nests inside. Despite the percentage of buildings with house martin nests being similar across all urban sectors (ranging from 17% in industrial to 30% in old town), no nests of this type were found in the outskirts (22% of buildings with house martin nests) possibly because sparrows preferred to use open clay tiles (70% of nests).

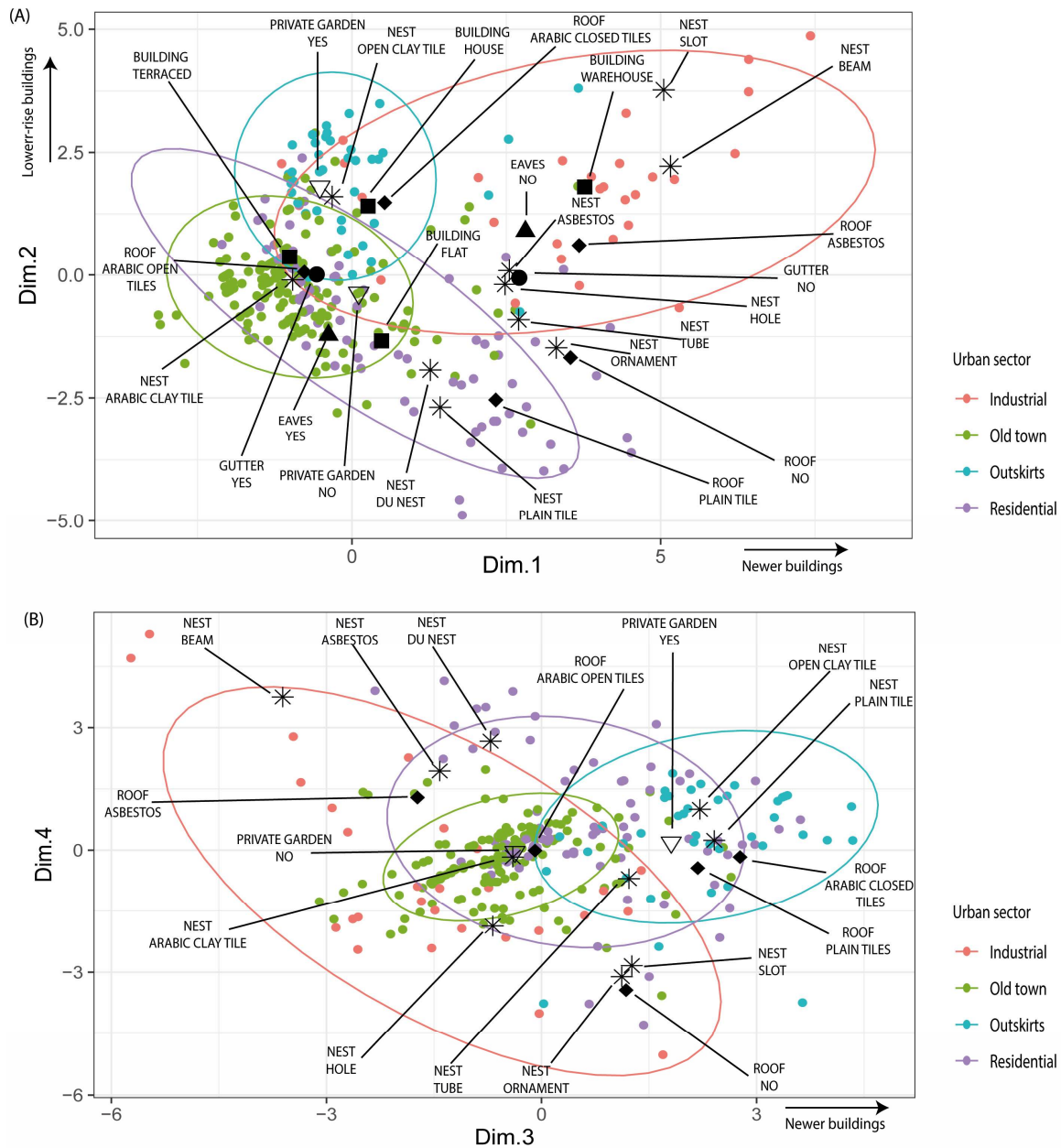


Figure 3. Nest placement of the House Sparrow in the different urban sectors, ordered in the first four FAMD dimensions ((A): Dim.1 vs. Dim.2; (B): Dim. 3 vs. Dim.4), showing the most relevant categorical and numerical variables and the link between them. Nests are coloured according to the urban sector. Symbols show the coordinates of each nest typology for the represented dimensions. The black symbols identify the levels of selected categorical variables (asterisks: nest support, squares: building type, diamonds: roof type, empty inverted triangle: private garden, full circle: gutter. The 95% confidence ellipses are shown with colours corresponding to the urban sector. Levels within categorical variables are identified by text connected with a line to the symbol. The arrows identify if included continuous variables (building year or building floors) had strong correlations with each selected dimension (refer to Table 6 and Supplementary Figure S4 for more information).

Table 6. Description of the ten dimensions with eigenvalue > 1 resulting from a factorial analysis of mixed data (FAMD) of the placement of House Sparrow nests. For continuous variables, the correlation with scores in each dimension is shown (correlations > 0.40 are highlighted in bold and underlined in this table while displayed graphically in Figure S4). For categorical variables, the table presents the R^2 resulting from an ANOVA that compares the average scores of each variable's levels within each dimension (only results for significant ANOVAs are shown; $R^2 > 0.40$ are shown in bold and underlined).

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8	Dim.9	Dim.10
eigenvalue	3.437	2.388	2.259	1.752	1.616	1.546	1.368	1.313	1.188	1.142
Cumulative % of variance	11.852	20.085	27.875	33.917	39.490	44.820	49.536	54.062	58.158	62.095
Continuous variables										
Year	<u>0.447</u>	0.273	<u>0.468</u>	0.276	−0.116	−0.236	−0.071	−0.076	−0.061	−0.055
Floors	0.115	<u>−0.654</u>	0.231	0.224	0.187	−0.161	−0.132	−0.034	0.254	0.119
Categorical variables										
Nest	<u>0.737</u>	0.362	<u>0.589</u>	<u>0.651</u>	0.696	0.709	0.652	<u>0.418</u>	0.574	0.264
Building	<u>0.518</u>	<u>0.466</u>	0.223	0.155	0.079	0.069	0.023	0.082	0.051	0.217
Eaves	0.314	0.046	0.029	0.082	0.047		0.037	0.042		
Facade	0.167	0.199	0.166	0.123		0.171	0.226	0.090	0.386	0.126
Gutter	<u>0.451</u>		0.022	0.081		0.077		0.047		
Holes	0.132		0.018	0.136	0.173	0.223	0.019	0.015	0.027	
Nests_Du		0.017	0.018	0.064	0.058		0.081	0.251		0.050
Garden	0.016	0.281	0.297					0.014		0.013
Reform	0.143		0.144	0.039		0.020	0.021	0.154	0.013	
Roof	<u>0.713</u>	0.215	0.387	0.284	0.414	0.171	0.204	0.132	0.042	0.175
Terrace		0.100	0.090		0.032		0.066	0.047	0.014	0.070
Tree	0.032	0.181			0.046		0.013	0.014		0.204

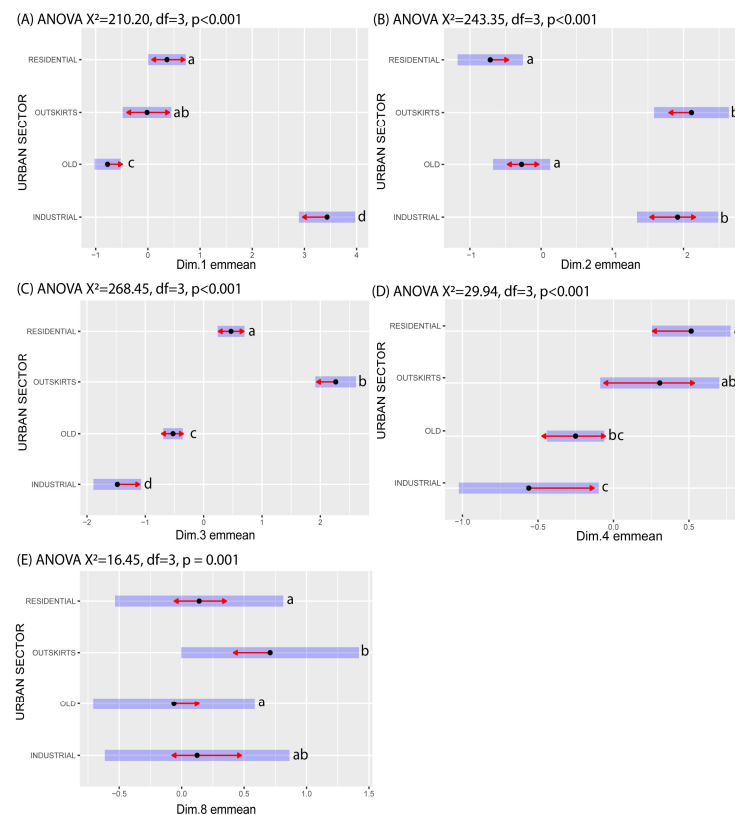


Figure 4. Mean values of each selected FAMD dimension ((A), Dim 1; (B), Dim 2; (C), Dim 3; (D), Dim 4; (E), Dim 8) of nests located in the four urban sectors identified in the study area. The blue bars are confidence intervals for the emmeans, and the red arrows indicate comparisons among them. If an arrow from one mean overlaps an arrow from another group, the difference is not considered “significant”, based on the “tukey” adjustment setting and the value of alpha (0.05).

4. Discussion

Our results show that a multivariate approach to study House Sparrow urban nesting ecology can help to disentangle the complex process of nest selection in a heterogeneous, complex, and changing breeding habitat like the urban matrix. We found that available nesting substrates differed between urban sectors and that sparrows change habitat selection according to the characteristics of man-made structures present in urban areas.

4.1. Nest Site Selection

The types of urban sectors considered in this study vary in terms of their location within the city and the characteristics of the predominant buildings, as evidenced by the point distribution on the first dimensions obtained by the FAMD. Despite these differences, it is highly significant that, when comparing random points to actual nest points across all sectors, there are consistent differences between the two types of points. This indicates that habitat selection for nesting is consistent within each urban sector, at least along the gradients identified by the first two FAMD dimensions. Therefore, in all four urban sectors, nests tend to be located closer to parks, schools, vacant lots, the city limits, and surrounding crops. All these areas share the common characteristic of having greater vegetation cover than other types of urban soil uses and, therefore, a higher availability of food in the form of arthropods, seeds, or fruits [67–69].

Parks are regarded as providing the main feeding habitat for House Sparrows [10,39] as they offer resources that are otherwise scarce in the urban environment, such as invertebrate prey and gardening by-products [26,70–73], and/or sheltering sites for future fledglings. Urban vacant plots, crucial for nesting success of various bird species in cities, particularly generalists [74] and also significant for their abundance in urban areas [75], may strongly influence nesting preferences towards buildings nearby. Schools generally have courtyards with trees and gardens and are great suppliers of anthropogenic food, due to scraps from students' lunches and other food remains [76,77], which could explain that House Sparrows prefer to locate nests close to them. However, in the same study area, Bernat-Ponce et al. [49] did not find this variable as significantly related to the species abundance, although they did not study nests directly. Finally, as some agricultural products are an essential part of the House Sparrow's diet [26], it was expected to find nests preferably located closer to them. Crops are a source of fruits but also a valuable source of invertebrates [26,78].

Consistency in the selection of nesting sites across urban sectors is interrupted in the third dimension of the FAMD, as industrial areas exhibit a different directional preference compared to the other sectors. As this dimension represents a gradient of decreasing building age, in industrial areas, nests tend to be more frequent in newer buildings, while in the rest of the urban sectors, they tend to be proportionally more frequent in older buildings. Since this dimension also correlates with the distance to vacant plots, this result suggests that sparrows would preferably select the newer industrial parks for nesting, where there are more undeveloped plots. As these gaps fill up with new buildings, it is expected that industrial areas would lose their appeal to the species. In the rest of the sectors, older buildings would be used in greater proportion as found by previous studies [30,55,79,80].

These results are not independent of the characteristics of the buildings that predominate in each urban sector. Terraced houses are the predominant type of building in the old town and outskirts, and nests are located in this type of building more often than would be expected by the frequency of random points. In the residential sector, terraced houses are infrequent, accounting for just 4% of random points, but about 20% of nests are located in this type of building. Thus, there is a consistent positive selection of terraced houses in all urban areas where this type of building is found. Terraced houses were not found in the industrial sector, where the most selected building types were the scarce remnant houses, while the most abundant type, warehouses, were used under their availability. The type of building and type of roof are related, and the latter has a strong influence on nest site selection (see next section). Arabic open tiles are the most often used roof type, and they

predominate in terraced houses (64% of random points). This prevalence might explain the positive selection of this type of building in all urban sectors where it is present. Other building features such as the facade, roof, eaves, and gutter are relevant for the House Sparrow. New architecture trends with metallic facades, like those found in industrial sectors or recently urbanized sectors, reduce the nesting opportunities, while traditional ones like plain or exposed brick ones of old towns favour the species [81,82]. Furthermore, House Sparrows tend to preferably locate their nests in buildings with gutters and eaves. This might be due to the utility of these building elements as prominent locations for territorial defence or even as nesting support [28,45] even though we did not find any nests on them (see next section).

Regarding building height, higher-rise buildings were preferred in outskirts and industrial areas, while lower-rise ones were selected in old-town and residential/commercial areas. This preference is linked with the available buildings in each sector, as usually outskirts buildings and industrial warehouses are lower-rise while old town and commercial and residential flats are higher-rise. So, low-medium rise buildings were selected for locating the nests, as preferred buildings were those with 3–4 floors (9–12 m), in a similar way to nests found by Indykiewicz [28] in Polish urban areas. We propose that House Sparrows avoid both very low buildings, which are more susceptible to predation by cats or avian predators [83], and very high buildings. Nests located in buildings are less vulnerable to destruction by avian nest predators and mammalian predators capable of preying on nests in cavities (e.g., mustelids [84]), which are scarce in urban environments [83]. However, an alternative explanation could be that urban House Sparrows primarily forage at ground level, so an increase in building height might lead to a greater vertical distance between feeding areas and nests, potentially increasing the energetic cost of provisioning the nestlings [49].

4.2. Differences in Nest Placement between Urban Sectors

Nests differed between urban sectors in the substrate used. The specific nest site preferences in a particular location or urban sector depend on the types of structures available, as we found and as previously stated by Anderson [26]. Preferred nest sites are mostly located in buildings and other human structures [26,45,85]. However, House Sparrows also frequently usurp the nests of other species, as we found that they constructed some nests within *D. urbicum* cups [44,45,85]. In industrial areas, which differed from other sectors due to the absence of open Arabic tiles, nests were mainly found in warehouses, particularly in beams, holes, and asbestos. Nests in flats are predominant in residential sectors, while in outskirt and old town areas, nests are more commonly found in houses and terraced houses.

Buildings with gutters under the tiles are key for nest location, especially in residential and old town sectors; however, in our study, no nests were found in this location. In contrast, clips holding gutter spouts to houses were the preferred nesting location in urban areas of Poland [28]. Thus, the importance of gutters that we have detected might be due to their utility as prominent locations for territorial defence. Indykiewicz [28] also found that ventilation holes under flat roofs of houses and inside street lights were also preferred locations [85]. In our study area, no nests were found in street lights; however, in nearby areas (personal observation), they have been observed nesting there. On the other hand, ventilated roofs are not as common in Spain as in Poland, resulting in fewer nests being found in this location. In our study, we found other roof typologies that are indeed essential for the species, such as Arabic open tiles. In Spain, Cordero and Rodríguez-Teijeiro [44] found that more than 50% of nest sites were located under roof tiles which offer enough room for the nest. Conversely, other roof types, such as those made with plain tiles or Arabic tiles but with their edges closed with concrete, prevent nesting. Regarding the age of the buildings, nests tended to be located in older buildings in old towns while in industrial and outskirt sectors nests were located in newer ones, which is closely related to the intrinsic features of these urban sectors. Finally, flat tiles, slots, and ornaments were

the least utilized substrates for nest location in Spain, with flat roofs similarly found to be less frequently used by birds, including House Sparrows, Eurasian Jackdaws, Common Starlings, and Common Swifts, as observed in Poland [80].

4.3. Urban Management for Nesting Suitability

Our study underscores the importance of several building features in ensuring adequate habitat availability for the nesting of House Sparrows in Mediterranean urban areas. It also highlights the importance of some urban soil uses, as sparrows tend to locate their nests near these areas. Green areas, including parks, but also vacant lots are relevant for the nest locations of the species and they are decreasing with recent urbanisation and reurbanisation processes [10,74,86]; thus, their conservation and management should be part of the strategies for House Sparrow conservation. Preserving old architecture and refurbishing buildings with open clay tiles can maintain nesting sites for birds. To protect biodiversity, local, regional, and national laws should consider implementing compensatory measures [87]. In Spain, installation of traditional roofs with open clay tiles in new buildings, particularly in outskirts and recent neighbourhoods, support significant breeding populations of House Sparrows, indicating that adherence to such architectural practices in new buildings and urbanisation can promote a Sparrow-friendly environment [87]. Our study provides further evidence of the importance of old buildings for the conservation of House Sparrows. Their decline due to modern architectural trends reduces nesting site availability, potentially impacting urban populations [32,42,55]. However, recent research suggests that urban House Sparrow populations may not be limited by nesting site availability in medium-sized cities with urban designs similar to those in our study [88,89]. Further investigations are needed to address this question.

The divergent results between our study and those conducted in other countries suggest that management policies may need to be tailored to specific locations or regions as nesting site selection can vary significantly between countries and even within urban zones. Therefore, these analyses are essential for studying the breeding ecology of species inhabiting diverse habitats. A broader-scale study encompassing multiple cities across a latitudinal gradient would be necessary to further explore these patterns.

5. Conclusions

A multivariate approach is advantageous for studying the urban nesting ecology of House Sparrows because of the heterogeneous and complex breeding habitat with multiple combinations of variables provided by the urban matrix, aspects that cannot be accounted for by univariate approaches. Specific nest site preferences vary between urban sectors, indicating that House Sparrow nests are not randomly located in urban areas. Nests tend to be closer to parks, schools, vacant plots, city limits, and surrounding crops, where greater vegetation cover provides abundant food sources. Building characteristics significantly influence nest site selection, with low-rise terraced houses being consistently preferred across urban areas where they are present. Traditional roofs with open clay tiles are favoured for nesting, while modern architectural trends reduce nesting opportunities. Preserving green areas and old architectural styles in modern buildings (e.g., open clay tiles) is essential for maintaining nesting sites and promoting House Sparrow conservation in Mediterranean urban areas. Adherence to these conservation measures may also benefit other hole-nesting species and urban wildlife reliant on green spaces.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/urbansci8030108/s1>, Figure S1: Different roofs of the buildings studied for the House Sparrow nests and random points: (A) open Arabic clay tile; (B) closed Arabic clay tile; (C) flat tile; (D) asbestos; (E) no roof/terrace. See Table 1 and Table S1; Figure S2: Relation of the quantitative variables describing the gradients of House Sparrow nests and environment and the first three dimensions resulting from FAMD. Only the variables with the strongest relationship ($R > 0.4$) are shown. Each point represents a nest (full point) or a random point (empty point) classified by sectors with colours. The trends are represented by lines using Generalized Additive Models

(GAMs); Figure S3: Density plots and selection index (blue line) of the continuous variables for House Sparrow nests and random points from the study area of the Mediterranean Spain. Discontinuous red line is the threshold for the positive selection index (>1.0); Figure S4: Relation of the quantitative variables describing the gradients of House Sparrow nests and the first three dimensions resulting from FAMD. Only the variables with the strongest relationship ($R > 0.4$) are shown. Each point represents a nest (full point) or a random point (empty point) classified by sectors with colours. The trends are represented by lines using Generalized Additive Models (GAMs); Table S1: Description of environmental variables recorded at House Sparrow nests and random points. Note that nest placement variable was only available for nest points; Table S2: Percentage of the categorical variables analysed for the 584 House Sparrow nests and 300 random points from the study area, separated by urban sectors. Chi-squared tests were carried out to explore association of the categorical variables between nests and random points.

Author Contributions: Conceptualization, E.B.-P., G.M.L.-I. and J.A.G.-D.; methodology, E.B.-P. and G.M.L.-I.; software, E.B.-P. and G.M.L.-I.; validation, E.B.-P. and G.M.L.-I.; formal analysis, E.B.-P. and G.M.L.-I.; investigation, E.B.-P.; resources, E.B.-P.; data curation, E.B.-P.; writing—original draft preparation, E.B.-P.; writing—review and editing, E.B.-P., G.M.L.-I. and J.A.G.-D.; visualization, E.B.-P. and G.M.L.-I.; supervision, G.M.L.-I. and J.A.G.-D.; project administration, E.B.-P., G.M.L.-I. and J.A.G.-D.; funding acquisition, E.B.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was conducted with no external funding, and the fieldwork was self-financed by E.B.-P.

Data Availability Statement: The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Acknowledgments: We acknowledge the two anonymous reviewers who improved the previous version of this paper.

Conflicts of Interest: The authors declare no conflicts of interest.

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