The Relationship between the Built World and the Nesting Habits of the European White Stork: A Case Study of Segovia, Spain

The European white stork (Ciconia ciconia) is listed as an Annex I species by Directive 2009/147/EC, adopted by the European Parliament and the Council of the European Union on 30 November 2009. This calls for special protective and supportive measures to be taken to create, maintain, or re-establish the biotopes the species relies upon for continued survival. This paper is anchored around a critical question pertaining to this topic—namely, given the historically urban nature of the species, how can the built world play a more supportive role in the nesting habits of Ciconia ciconia? Looking at the minutiae of the urban built environmental conditions of Segovia (Castille y Leon, Spain), the research seeks to understand whether there are specific built world parameters that play a supportive or hindering role in the urban nesting preferences of the European white stork. The existing discourse has tended to investigate this topic from a macro scale, oftentimes glossing over the weight exerted by the built world, in favor of a strictly ecological or resource-based analyses to the question. The findings presented within this paper on the other hand offer a more fine-grained exploration of the subject matter, underscoring that specific built world and built-world-to-habitat connections do appear to exert significant influence over the nesting preferences of the European white stork—namely, variations in height in the roofscape, total area of the potential nesting-location, roof slope and tree species, the strength of views to the habitats used for daily hunting and foraging by the species, and proximity to busy traffic arteries. These findings not only frame further avenues for built-environmental research for scholars and researchers involved in this physical-ecological intersection, but also begin to shape a potential fine-grained toolkit for urban planners, policy makers, ecologists, landscape architects and architects to help support the intricate entanglement between the built environment and ecological systems, specifically in the context of the viability of urban sites for Ciconia ciconia, a species which plays a significant role within ecosystem food chains, as well as sociocultural narratives across Europe.

Introduction

The European Parliament and the Council of the European Union formally adopted Directive 2009/147/EC on November 30, 2009. This directive noted: (1) the serious ecological and sociocultural threat posed by declining numbers of wild bird species across the EU; (2) that the conservation and support of migratory bird species, which constitute a majority of the wild bird species in Europe, required trans-frontier efforts and responsibilities; (3) that these conservation efforts are necessary "in order to obtain the Community's objectives regarding the improvement of living conditions and sustainable development"; and (4) that further scientific research is required in order to more thoroughly understand best practices for conserving and supporting these species. (Council of the EU 2009, 7-

8). Within this Directive, the European white stork (*Ciconia ciconia*) can be found under Annex I, which is reserved for species considered to be in danger of extinction, vulnerable, considered rare, or requiring particular attention (Council of the EU 2009, 9). In this light, the document calls for the creation, upkeep, or re-establishment of biotopes required to support the species listed therein (Council of the EU 2009, 8).

This paper is structured as an instrumental case study focused on the city of Segovia (Castille y Leon, Spain), an urban stopover site during the spring and summer months for the migratory European white stork (*Ciconia ciconia)* population. Although the population size varies slightly from year to year due to the presence (or lack thereof) of newborns, over the three migratory seasons coinciding with this study (2021-2023), field observations marked the presence of 24 active nests (across 14 locations) supporting pairs of storks, as well as 3 other urban sites supporting singular storks not constructing nests. The built environment of Segovia contains a wide variety of building typologies, heights, sizes, and so on; and the active nesting sites for the European white stork population are situated across various portions of this diverse urban roofscape and atop urban treetops. The nearby wetlands and meadows bound to the Rio Eresma and the Arroyo Clamores serve as critical foraging and hunting grounds for the species.

While much of the existing discourse concerning European white stork nesting behavior is anchored around macro-scale issues such as resource availability and ecosystem viability, this paper delves into the finer-grain characteristics of the built world, as well as the urban fabric's relationship to the surrounding ecological conditions, in order to gain insight into the urban nesting preferences of *Ciconia ciconia*. What the research begins to suggest, is that the urban built environment needs to be not only recognized as a critical part of the European white stork biotope, but also understood in much greater detail in order to be refined and reshaped so as to best support the (hopefully) increasing population of this Annex I species across the EU.

An initial survey of the urban fabric of Segovia for instance unveils seemingly-comparable potential nesting locations, which are preferentially weighed quite differently by the European white stork population. At one end of the spectrum is the Torreon de Arias Davila (Figure 01), located in the Casco Antiguo neighborhood of the city. This tower is seemingly an ideal nesting spot for white storks, equipped with manmade nesting platforms to support such activity. However, aside from a lone stork resting, intermittently, upon its roofscape during some spring / summer seasons, the tower has been consistently devoid of any type of active stork nesting since 2018; and based on informal interviews with locals, this has been the case for as far back as anyone interviewed can recall (at least two decades). On the other end of the spectrum, is the belfry of the Iglesia Santos Justo y Pastor (Figure 02), located just a few minutes away, in the El Salvador neighborhood of the city. This tower's roofscape has consistently supported five active nests since 2018; and based on informal interviews with locals, this number has been maintained as far back as 2009. Prior to that date, it could not be verified whether the number of active nests was four or five in count, although it is clear the density of nests therein has been stable for some time.

Figures 1. *02 – 2023 photographs of the Torreon de Arias Davila (left), showing one of the two nesting platforms, vacant, upon its roofscape and of the Iglesia Santos Justo y Pastor (right) showing four of the five active stork nests upon its roofscape*

The question that underpins this research—why is this the case? Are there specifics of the European white stork's nesting preferences that have not been studied heretofore, that can help shed light on why this type of occupancy discrepancy is observed? What are the built-world details that are influencing this species' nesting location selection process?

In answering these questions, this research seeks to understand:

- How the minutiae of our urban built environment are entangled with the European white stork nesting preferences.
- How we can reshape or refine *existing* conditions in the urban fabric in order to support a long-term and growing European white stork population.
- How we can reshape and refine *new* urban development proposals, specifically those located along the migratory paths of the European white stork, to best leverage the ecological potentials of these new urban developments.

Background

The following literature review is structured around three discursive queries: (1) What is the ecological role played by the white stork? (2) What are the parameters influencing the white stork's nesting preferences And (3) what is the relationship between the built environment and the white stork?

Czarnecka and Kitowski (2013) categorize the white stork as an ecosystem engineer. This refers to:

> "Organisms that directly or indirectly modulate the availability of resources to other species by causing physical changes in biotic and abiotic matter. They create, modify or maintain existing habitats. […] they affect energy and matter flows in an ecosystem by creating or destroying living space, and thereby altering environments of other organisms" (Czarnecka and Kitowski 2013, 1-2)

This label is applied to white storks due to their impacts upon species pools and physical habitats while foraging and engaging in predatorial activities in surrounding ecosystems, and due to their habit of building long-standing and large nests which support "a new range of habitat niches, which can be used by a variety of organisms" (Czarnecka and Kitowski 2013, 2).

The diversity of species supported by white stork nests has been extensively documented, falling under the umbrella of the habit of commensal nesting, wherein multiple species will inhabit a broader nest structure—in this case, the white stork nest. Zbyryt et al (2017, 1), in their analysis of 233 white stork nests in northeast Poland for instance, documented house sparrows (*Passer domesticus),* tree sparrows (*Passer montanus),* as well as starlings (*Sturnus vulgaris)* engaged in such commensal nesting with the white stork. Boev (2019, 1-2) noted five avian species simultaneously engaged in commensal nesting with a singular white stork nest. Czarnecka and Kitowski (2013, 2) also note the frequently-noted co-occupation of the nest by kestrels *(Falco tinnunculus)*, grey wagtails *(Motacilla alba),* as well as vertebrates such as the Norway rat *(Rattus norvegicus)* and the striped field mouse (*Apodemus agrarius)*. Kronenberg (2017, 84-85) in turn notes that the soil in the white stork nest serves as a habitat for saprophagous mites.

The white stork also plays a critical role in seed dispersal within ecosystems. In the study conducted by Czarnecka and Kitowski (2013, 1) for instance, an average of 9937 seedlings were noted per white stork nest, belonging to 97 different taxa, with significantly higher percentages belonging to ruderal species and weeds. Many of these seedling species were also found in herbivore dung (horse, cattle, sheep, deer, rabbit, etc.,), and thus transported to the nest via the use of dung as a nesting material by the white stork (Czarnecka and Kitowski 2013, 8-9). Dylewski et al (2021, 337) also assert that beyond just seed dispersal, the nests themselves can serve as habitat for the seeds of ruderal species to germinate and grow. With their nests behaving as seed banks and germination sites for various species of flora, as well as *Ciconia ciconia*'s daily foraging and seasonal migration behavior, the white stork behaves "as a link in the multi-step dispersal chain and also facilitates the long-distance dispersal of some plant species, especially those with limited dispersal capabilities" (Czarnecka and Kitowski 2013, 9).

White storks tend to have a lifespan of around 2-3 decades, and begin breeding around 2-3 years of age (Barbraud et al 1999, 469). Nests can be found in isolation or in colonies. Bachir et al (2013, 485), for instance, studying the population in Batna, Algeria, noted colonies supporting up to 23 breeding pairs. Breeding pairs often return to pre-established nests, however competition for these nests can often be quite strong (Tobolka 2013, 402).

Documented nesting locations for the white stork are varied—including trees, roofs, cliffs, electrical pylons, chimneys, antenna, poles, etc. Barbarin et al (2021, 11), studying the white stork population in northern Spain, noted the highest proportion in trees (49.0%) and buildings (28.8%). Molina (2004, 2-3), analyzing the white stork population throughout Spain noted a similar breakdown, specifying that the most common tree species for nesting was the holm oak, followed by the poplar tree and ash tree.

In other regions, different distributions of nesting locations have been observed. Studying the populations of Northern Macedonia, Stamkowska et al (2020, 87) documented the highest percentage of white storks (62.4%) nesting in overhead transmission pylons. Similarly, Denac (2015, 101), studying the population in Slovenia, noted that most nests were situated on poles (81%) and chimneys (18%). Tryjanowski et al (2008, 38) and Vaitkuviene and Dagys (2014, 289) also noted this abandonment of traditional nest structures in favor of vertical man-made elements such as electricity poles. The destruction of vernacular architectural typologies is presumed to play a critical role in this this shift of nesting location preferences to man-made structures such as pylons and poles (Denac 2015, 107).

Important to note—the specific elements inherent to vernacular architectural typologies, and how or why they historically supported white stork nesting behavior, is not noted in the literature.

The proximity of high-quality foraging territories is understood to be a critical factor influencing the nest location preferences of the white stork (Janiszewski et al 2013, 178). Despite this critical tie to the resource-rich habitats, counterintuitively, the white stork is also one various avian species that has tended to nest in proximity to, or within, urban ecosystems. Particularly in Europe, the species has become deeply intertwined with long-established sociocultural narratives within various regions (Ferger et al, 2016).

> "Villages, towns, and cities often provide habitat substitutes for birds. Cliff-nesting birds such as swifts *(Apus sp.)* and House Martins *(Delichon urbica)* find building facades or chimneys substitute for breeding habitat. Sand Martins *(Riparia riparia)* and Honey Eaters *(Merops apiaster)* use abandoned sand quarries for breeding. Peregrine Falcons *(Falco peregrinus)* have colonized cities and now breed successfully on the top of skyscrapers. They prey on city birds, many of which use urban parks as substitutes for their original forest habitats. Cavity-nesting birds use holes in walls as a substitute for holes in old-growth trees and rock outcrops. Tree-dwelling bats live in urban parks, where they occupy tree-bark crevices (e.g., Popa-Lisseanu et al. 2009). White storks *(Ciconia ciconia)* breed on top of roofs or antennae instead of on top of big trees." (Martinez Abrain and Jimenez 2015, 596)

According to Roshnath et al (2019, 314) predation pressure bears a significant weight upon nesting preferences, and may help explain why certain bird species have historically preferred to nest within urban ecosystems wherein since predation pressure is significantly low—a phenomenon Martinez-Abrain and Jimenez (2015, 596) refer to as the *scarecrow effect*. Hmamouchi (2020, 1) however notes that in Rabat, the less-built-up portions of the urban fabric appear to be more attractive for white stork nesting locations.

For urban birds, the habit of nesting within urban ecosystems can offer advantages as well as disadvantages. On one end of the spectrum, urban nest locations can provide birds with footholds that are optimal for breeding conditions, with lowered predation pressures, and in close proximity to fertile foraging and hunting grounds (Reynolds et al 2019, 843). On the other end of the spectrum, urban sites can function as ecological traps with lowered quantity and diversity of critical prey and biomass, wherein crucial habitat characteristics and dynamics are gradually being lost due to increased urbanization (Reynolds et al 2019, 843).

In terms of predatory behavior, the White stork has been documented to prey upon species that are known to cause significant damage to crops, for instance the common vole *(Microtus arvalis),* brown locusts *(Locustana pardalina)* as well a range of caterpillar species (Kronenberg 2017, 85). Due to their daily interaction with surrounding ecosystems, both in a predatory and foraging context, the white stork serves as a good indicator of environmental quality and species biodiversity.

On the micro end, analyses have been conducted on white stork blood and feathers to assess heavy metal concentration within the local environment (Kronenberg 2017, 84). Gut biome compositions of white storks were also directly connected to local habitat conditions, with those utilizing landfill sites for foraging purposes showing negatively impacted bacterial compositions. Increased rates of E.coli, as well as increased levels of antibiotic resistant bacteria, were observed in colonies in close proximity to urban waste sites (Hofle et al 2022, 11). The number of anthropogenic debris items in white stork nests in turn serves as an indicator of anthropogenic contamination of the surrounding environment, as well as the impact of said environmental contamination upon the nesting behavior of other local bird species (Jagiello et al 2020, 30897).

On the macro scale, direct connections between white stork population numbers and local environmental conditions are readily observed. In Lithuania and various post-Soviet countries in the 1990s for instance, the white stork population increased dramatically in tandem with the reduction of intense farming practices, the fragmentation of large-scale collective monoculture-oriented farming, and the expansion of rewilded habitats (Vaitkuviene and Dagys 2015, 148). A reverse trend being observed in Lithuania now, with the re-emergence of intense and large-scale monocultural agriculture (this time privatized), is expected to have an observable negative impact on the stork population in the years that follow (Vaitkuviene and Dagys 2015, 150).

The proximity of landfills or waste dumps to white stork populations convey mixed narratives. Djerdali et al (2021, 944-45) for instance note that proximity to rubbish dumps, "providing a constant and predictable food source," increase breeding success. However populations in close proximity to landfills did not experience increased breeding success when rainfall was lower than average climatic conditions—the reason being that reduced rainfall negatively impacts the populations of small invertebrate prey that new stork hatchlings depend upon in the first phases of their life (Djerdali et al 2021, 944-945; Tryjanowski et al. 2009, 390).

This finding is supported by Bialas et al (2021, 1) which notes that landfills appear to be more often relied upon late into the breeding season, and frequented more by non-breeding white storks (Bialas et al 2021, 1). Peris (2003, 82-83) also conveys a comparable mixed narrative concerning landfills, in that they open up a staple food source to white stork populations, but simultaneously increase the likelihood that juvenile storks ingest undigestible and hazardous anthropogenic items.

Over the years, the increased frequency of white stork nesting upon pylons and electrical poles has brought various problems for the species. Balmori (2005, 114-115) notes that the white stork's thin skull makes their brains more susceptible to radiation and microwaves emitted via such infrastructures. The findings of Vaitkuviene and Dagys (2014, 289) support this, observing that the current-generated electromagnetic frequencies via overhead electricity line poles and pylons produced "a significant negative effect on the breeding success" of birds nesting directly on said infrastructures. Janiszewski et al (2015, 39) also noted a lowered reproductive success in storks actively nesting upon such human infrastructure in comparison to treescapes.

The entanglement of the European white stork with the built environment is potentially a rather old relationship. According to Kopij (2017, 110) it is likely that the white stork started nesting within human settlements as far back as the Neolithic period. Despite this length of time, there is still a minimal understanding of how the white stork instinctively evaluates the potentials of possible nesting locations. Much of the literature points to the importance of the proximity of resource-rich habitats, specifically wetlands and meadows. While some studies have experimented with how to support re-occupancy habits (Zybyrt 2021, 1), and others have indicated that the species appear to prefer smaller towns over larger cities (Kopij 2017, 110), as a whole there is a deep gap in the literature explaining the built-world parameters influencing the species' instinctive location preferences.

Methodology

This research took place from March 2021 to May 2023, covering three nesting seasons of the European white stork population in the city of Segovia, a relatively small municipality in Castille y Leon, Spain. The habitual locations of the stork population in the city were documented and catalogued. A total of 17 locations were noted. 14 of these were active nesting locations, and 3 were locations where singular storks were intermittently observed, however did not produce nests.

All the stork locations were found in the Casco Antiguo, San Lorenzo, and El Salvador neighborhoods of the city. To be clear, the study was not limited to these neighborhoods, rather, these are simply the neighborhoods that support the entire stork population of the municipality. A total of 24 nests were observed, with some locations supporting multiple nests.

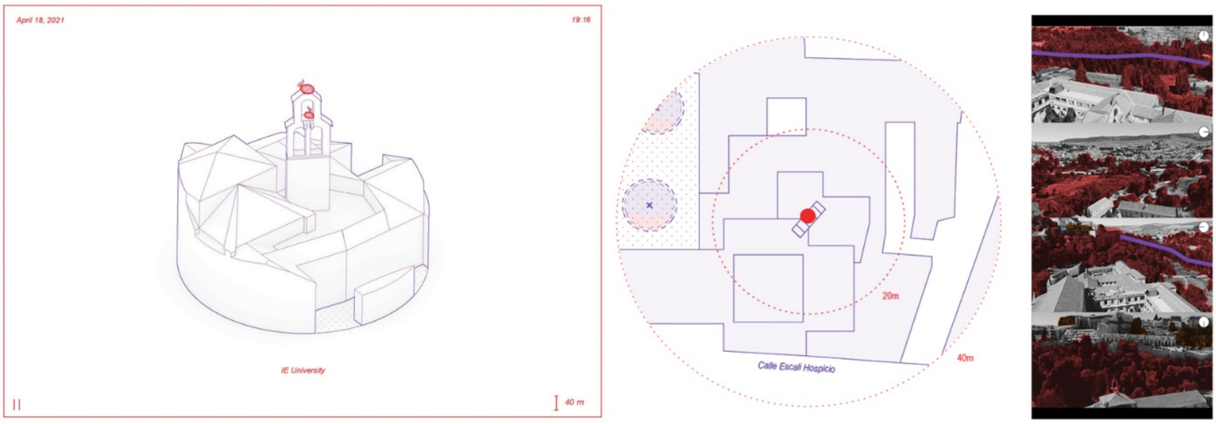
One important aim of the study was to create as complete a possible catalogue of the European white stork nesting locations in the city. Yet due to the nature of these nests, often located in high locations with low visibility from the street level, and due to simple human error, it was suspected that some nesting locations may be overlooked. To counteract this potential error, the city was combed through multiple times, by various members of the research team, at different times of the day during the nesting season. Residents were also informally interviewed to see whether there were other hard-to-view yet locally known nesting locations being overlooked.

Figure 3. *Map of the Iberian Peninsula and its surrounding context, with the central location of Segovia highlighted*

Figure 4. *Aerial view of Segovia, showing the 17 habitual stork locations observed in the city. The white arrows indicating active nesting locations; and the purple arrows indicating locations supporting consistent stork activity but without nests being produced*

The 17 locations were analyzed through a combination of field work, architectural drawing, and GIS mapping. For the latter, ArcGIS and Google Earth Pro were the main software applications utilized. For each location, the following data points were collected: (1) whether storks were actively nesting at the location; (2) the number of nest(s) present; (3) the difference in height between the roofscape or treescape location and the nearest adjacent built world condition (whether roofscape, streetscape, or landscape); (4) the nature of the slope of the roofscape / treescape location (steep, shallow, flat); (5) the surface area of the location; (6) whether there was a clear or hindered line of sight to the nearby hunting / foraging grounds for the species, consisting of the wetlands and meadows bound to the Rio Eresma and the Arroyo Clamores; (7) the horizontal distance to such hunting / foraging grounds; and (8) the location's adjacency (or not) to busy traffic arteries. In the latter point, this was measured based on whether or not roads adjacent to the location supported multiple bus routes, since in Segovia, the main bus routes are also the significant traffic arteries of the city. For cataloguing purposes, an axonometric and plan drawing of each location were produced, as well as reconstructed panoramic imagery of what is visible from the nesting location (from the viewpoint of the storks), highlighting the wetland and meadow locations within such views.

Figure 5. *Sample analytical drawings/visuals produced for one location, showing the axonometric drawing, plan, and field-of-view imagery produced for the purposes of analysis*



While it would have been ideal also to obtain aerial photographic imagery of the habitual white stork locations via the use of drones, this was decided against to avoid any possible disturbance to the local stork population, particularly any newborn hatchlings that maybe in the nests.

Results and Findings

This research seeks to understand whether certain physical parameters of the built environment influence the nesting location preferences of the white stork population in Segovia. Six such characteristics were assessed.

- The difference in height from the nesting location to the highest adjacent building.
- The slope of the surface of the potential nesting area.
- The total area of the potential nesting area.
- Whether there was a clear or hindered line of sight to the nearby wetland and meadow areas—typical habitats wherein European white storks are noted to engage in foraging and predatorial activities.
- The horizontal (straight-line) distance from the potential nesting area to the nearest wetland or meadow areas.
- Whether the nesting area was immediately adjacent to busy traffic arteries. In this case, this was measured based on the adjacent roads supporting (or not) multiple bus routes. In Segovia, roads supporting multiple bus lines are also significant traffic arteries of the city.

Table 1. *Chart summarizing the full findings concerning the 17 noted stork locations in Segovia. Those highlighted in light grey indicating locations which supported an intermittent stork occupant, but with no active nest being built*

Nest Name	Location	Difference in height to adjacent bldg (m)	Slope of surface (flat, shallow, steep)	Surface area (sq.m.)	Line of sight to wetlands or meadow? (clear/hindered)	Horizontal distance to wetlands or meadow (m)	Number of nests	Immediately adjacent to active traffic artery?	Notes
Calle de Pedro Brizuela	1	2	shallow	4	clear	225	1	no	occupied nest
Plaza de la Reina Victoria Eugenia	2	18	flat	10	clear	140	4	no	occupied nest
Plaza de la Merced	3	21	flat	4	clear	160	2	no	occupied nest
Torre de Arias Dávila	4	16	shallow	42	hindered	350	0	yes	intermittent stork, no nest
Iglesia de la Santisima Trinidad	5	3	shallow	54	clear	360	2	no	occupied nest
Monasterio Monjas Dominicas	6	8	shallow	72	clear	340	1	no	occupied nest
IE University	7	6	flat	4	clear	90	1	no	occupied nest
Hotel Capuchinos	8	3	shallow	4	clear	240	1	no	occupied nest
Iglesia de los Santos Justo y Pastor	9	11	shallow	62	clear	275	5	no	occupied nest
Iglesia de San Salvador	10	9	shallow	63	clear	380	2	no	occupied nest
Iglesia de San Sebastián	11	10	shallow	65	clear	610	1	no	occupied nest
Iglesia San Lorenzo	12	14	shallow	35	clear	180	1	no	occupied nest
Factory Chimney	13	35	flat	2	clear	70	1	no	occupied nest
Rio Eresma Chimney	14	18	flat	2	clear	40	1	no	occupied nest
Ruins of Iglesia San Agustin	15	19	flat	4	clear	390	1	no	occupied nest
Calle Licenciado Peralta	16	2.5	flat	3	hindered	385	0	no	intermittent stork, no nest
Casa de las Cadenas	17	3	shallow	110	clear	260	0	yes	intermittent stork, no nest

Locations and their immediate surroundings

Of the 17 habitual stork locations examined throughout the course of this research, 14 contained actively occupied nests, and 3 contained no nests but supported singular storks intermittently spending the spring / summer season. While some data was initially gathered about the number of storks and hatchlings present at each active nest, this was not included in this paper due to the difficulties of obtaining reliable data in this area without the active use of aerial / drone photography, or continuous camera footage.

All habitual stork locations were situated upon high points of the built environment. For all locations examined, there were no higher points than the location itself within, at minimum, a 25m radius. The highest percentage of these habitual stork locations were on the roofscapes of belfry towers of buildings initially constructed for religious uses, i.e., churches or monastic complexes (locations 1, 5, 6, 7, 8, 9, 10, 11, 12, 15, and 16). The second largest portion of locations were the tops of trees in plazas (locations 2 and 3). Contrary to the findings of Molina (2004, 2-3) which indicated the most common tree species for nesting in Spain as the holm oak, poplar tree, or ash tree, the European white storks in Segovia were consistently situated atop cedar and fir trees—*Cedrus libani*, *Cedrus deodora* and *Abies pinsapo* to be precise. The third most-commonly observed nesting location was the tops of disused industrial chimneys (locations 13 and 14). The remaining categories of stork supporting locations consisted of large urban multistory houses initially constructed by aristocratic families from the city (i.e. *palacios*) containing some manner of tower typology (locations 4 and 17), and more-conventional multi-story residential structures within the city containing some manner of vertical extension to their roofscape (location 1).

Figures 6-8. *Photographs of locations 12 (left), 2 (middle), and 13 (right) taken in May 2023 by principal author, showing some of the different nesting locations habitually occupied by white storks in Segovia*

All of the stork-supporting locations were found within the urban fabric. While there were similar species of tall cedar and fir trees, as well as pylons and electrical poles, in close proximity to wetland habitats in the landscapes immediately surrounding the city, there were no storks or stork nests readily observed in this terrain. This offers a wrinkle to the expanding narrative within the contemporary literature that European white storks are beginning to prefer vertical manmade structures such as pylons and electrical poles over more traditionally-observed nesting locations (Tryjanowski et al 2008, 38; Vaitkuviene and Dagys 2014, 289), and also supports the concept of the *scarecrow effect* noted by Martinez-Abrain and Jimenez (2015, 596) whereby the cityscape, lowering predation pressures, becomes a preferable landscape for white stork nesting. Such lowered predatory activity is readily observed in Segovia, with the much-greater presence of the red kite (*Milvus milvus)* and common kestrel (*Falco tinnunculus)* hovering above the grasslands, pine groves, and wetlands immediately surrounding the city, and their much-diminished presence in the city itself. To be clear, this predatory discrepancy is not due to an innate fear of the cityscape itself, but rather is likely due to the fact that hinterland ecosystems provide more consistent food sources for such predatory species when compared to ecosystem of the city proper. Their habitual allotment of hunting time would by extension tend to be concentrated in the areas of greater reward—i.e., the hinterland as opposed to the city—and by extension trigger an avoidance of the urban fabric itself.

Figures 9-10. *Photographs of the landscape conditions surrounding the city, as seen looking south from Location 02 (Plaza de la Reina Victoria Eugenia, which contained a stork colony of 4 nests situated atop various fir and cedar trees). Although comparable tree species are present in this surrounding landscape, there are no storks or stork nests observed therein*

None of the actively occupied nesting areas were found immediately adjacent to busy bus routes —specifically, roads which supported several municipal bus lines. In Segovia, these busy bus routes are also the main car traffic arteries of the city. The nesting location found closest to such a busy road condition was nest 12, located on the church belfry in the main plaza of San Lorenzo (see Figure 06). However even there, the belfry is situated towards the middle of the church, with the surrounding architecture of the church buffering it from the active bus routes (see Figure 11). While some storks were found intermittently occupying rooftops adjacent to busy roads (locations 4 and 17 specifically), there were no active nests found in direct adjacency to any busy road condition. Location 17 is particularly interesting in this regard, as it satisfies all the other parameters noted in Section 3.0, aside from its adjacency to a busy traffic artery. Overall, nests were always located in conditions where the surrounding built environment served as some form of buffer from urban traffic arteries. This seems to add a layer of reasoning behind the finding of Hmamouchi (2020, 1) which notes that white storks prefer less-built up portions of the city—namely, that white storks may avoid direct adjacency to active traffic lanes in the city, possibly as an evolved preferential trait to avoid potential harm to hatchlings. Noise pollution may also be an influencing factor here, although the close (but not immediate) proximity of Location 12 to a significant bus artery of the city, seems to counter this.

Figure 11. *Aerial view of Location 12 (circled in yellow), situated atop the belfry of the church in the main plaza of San Lorenzo*

Height, Slope, and Nesting Area

All the locations supporting storks, regardless of whether a nest was present or not, maintained some difference in height from the surrounding cityscape. This difference in height from the nesting location to the highest adjacent building (or built-world condition), ranged from a minimum of 2m to a maximum of 35m, with an average of 11.7m. The lowest difference was observed in location 1 (2m), which was located on top of the roofscape of a small vertical projection of a conventional multi-story residential building. The greatest difference in height (35m) was observed in location 13, situated on top of a disused industrial chimney (see Figure 08).

These differences in height are likely preferred by the white stork as an evolved instinct for lowering predatory pressures for susceptible newborn storks. However in observing urban stork behavior, there appears to be another benefit to this, in that it often allows for storks to disembark from their nests by gently leaping from the nesting area and then gliding, as opposed to expending significant energy flapping their wings to reach the necessary clearance from the cityscape.

All of the roofscapes or treetops supporting active storks were either flat or shallow sloped. This varied from a completely flat condition (found on treetops, chimney-tops, as well as certain belfry towers) to an approximately 4:12 roof slope. Situated across the city, there were tower typologies that satisfied most of the other parameters noted in Section 3.0, with the exception that their roofscapes were much steeper—these locations have never been observed supporting stork habitation, whether of a long- or short-term nature, throughout the course of this study.

The preference for shallow or flat conditions is likely tied to practical concerns of nest construction, and the inherent complications of doing this on steeper slopes. While the difficulties posed by steeper roofs may perhaps be overcome via the construction of man-made nesting platforms, such platforms have not been constructed in such steeper-roofed locations in the city of Segovia, so it is unclear if they would be utilized by white storks for nesting.

The preference for cedar and fir trees for nest building locations also appears to be tied to practical concerns of the nest building process. The prickly needles composing the foliage of these trees provide a significant amount of friction, likely aiding in the construction of the initial nest layers, as well as supporting the nest's long-term stability. Since these are evergreen species, they would also maintain these stabilization qualities across seasons—an important factor for species such as the white stork which have a tendency of returning to the same nests across their lifetimes. These findings challenge some portions of the existing literature which found a nesting preference for "chimneys and pylons rather than trees and roofs" (Bialas et al 2019, 4154).

The total roofscape or treetop area supporting habitual stork locations also varied significantly, ranging from a minimum of 2sq.m. to a maximum of 110sq.m. The average was 31.8sq.m. The smallest locations (2sq.m.) were the tops of disused industrial chimneys (locations 13 and 14, supporting actively-nesting storks). The largest (110sq.m.) was the Casa de la Cadenas roofscape in a monastic complex (location 17, supporting an intermittent non-nesting stork). The largest area supporting actively-nesting storks in turn was Location 06 (72sq.m.).

While there is a wide range of roofscape areas, there does appear to be some parameter of maximum nesting area influencing stork nesting behavior. In the neighborhood of El Carmen and Nueva Segovia for instance, there are tall multistory residential buildings that satisfy all of the parameters noted in Section 3.0, in proximity and with direct line of sight to wetlands and meadows suitable for hunting and foraging. The smallest of these roofscapes however are approximately 300sq.m. in area. Throughout the course of this study, no type of stork occupation was ever observed atop these residential structures, or upon any structure whose roofscape exceeded 110sq.m. While this clearly isn't a set-in-stone number, this observation does seem to indicate that storks show preference for locations that appear to be smaller-scale "platforms" situated apart (via a difference in height) from the rest of the cityscape.

Relationship to Wetlands

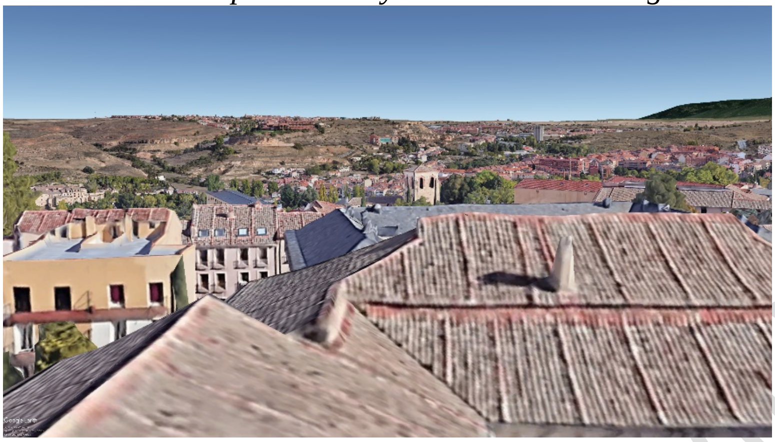
The proximity of the nesting locations to a wetland or meadow foraging / hunting areas varied significantly, from a minimum of 40m to a maximum of 390m. The average distance was 246m. Location 14, situated on top of a disused industrial chimney maintained the closest distance to the wetlands (40m). Locations 15 and 10 were on the upper end of this range, being 390m and 385m distance from the nearest meadow or wetland condition. Important to note—all of the nearest wetland or meadow conditions outside of the city proper were at some point observed supporting white storks engaging in hunting / foraging behavior during the timeline of the study. Whereas urban parks, regardless of the time of day, were never found to support such white stork activity.

Within the ranges presented here, being at the upper end of this spectrum did not appear to influence the viability or popularity of a nesting location. Location 9, for instance, being 275-m away from the nearest viable habitat, supported the highest number of active stork nests (5 total) of all locations. Given the white stork's transnational migratory habits, it is likely that proximity to hunting / foraging habitat, especially at these ranges, would not influence nesting preferential behavior.

As opposed to proximity, having a direct line of sight to the meadow or wetland habitat however does appear to play a role within nesting location preferences of white storks in the city. All of the locations supporting active nests had unobstructed lines of sight to a nearby meadow or wetland habitats. This was verified through the use of the terrain and 3D built environment tools in Google Earth Pro and ArcGIS. Location 16 for instance, despite satisfying all of the other requirements presented in Section 3.0, exhibited obstructed lines of sight to nearby wetland or meadow habitats (Figure 12). This location supported an intermittent stork, which while present for most of the season, was never observed building a nest.

There is also a commonality with regard to lines of sight that appears to bind the most-active nesting locations—location 2 with 4 nests and location 9 with 5 nests. From these two locations, storks not only have strong lines of sight to meadows and wetlands, but also see significantly wider sweeps of these habitats when compared to other nesting locations. Location 2 is situated at the western tip of the cityscape, wherein the wetlands bound to the Rio Eresma as well as the wetlands bound to the Arroyo Clamores are uniquely within sight and easy reach (Figure 13). And from location 9, a uniquely-wide view of the wetlands of the Rio Eresma is offered.

Figures 12-13. *Differences in views of location 16 (an intermittent stork, no nests) versus location 2 (4 nests). Location 2 also offers comparable views to the wetlands in the opposite direction; whereas location 16's view of the nearest resource-rich habitats are hindered by the cityscape, offering only views of the more-arid landscape commonly observed around Segovia*



One hypothesis that emerges from these findings is that this generally-unobstructed view to the wetland or meadow habitat is potentially not linked to vision at all, but rather to the preference for a clearer flight path from the nest to the habitats and vice versa. The unobstructed line of sight in other words maybe simply be a byproduct of this flight-based preference. There is also the possibility that there is an instinctive drive to maintain a more-consistent line of sight back to the nest throughout the hunting / foraging process, or to inculcate within newborn storks a direct connection to the habitats they will use for hunting / foraging. This preference for unobstructed lines of sight to the hunting / foraging habitats is not directly discussed in the existing literature.

Synthesis

Based on these findings, *Ciconia ciconia* appears to prefer to construct nests:

- Within urban environments, even when comparable more-rural nesting conditions are available.
- Upon locations elevated from the immediately-adjacent built environment (varying from 2m – 35m, with an average of 11.7m in this study).
- Upon locations not too large in overall area (varying from 2sq.m – 72sq.m., with an average of 27.5sq.m. in this study)
- Upon roofscapes which have either flat or shallow sloped conditions (an approximately 4:12 slope being the maximum observed herein), or upon treetops of evergreen fir or cedar species.
- Upon locations which offer generally-unobstructed views to the wetland or meadow habitats used by the species for daily hunting and foraging activities.
- Upon locations not directly adjacent to busy traffic arteries.

The first four of these parameters (urban-centric, height difference, area, roof slope and tree species) are factors that appear to decrease predation pressures and aid in the practicalities of nest construction. Across the timeline of this study, and across the wide range of roofscapes observed in Segovia, no storks, nesting or otherwise, were ever noted in locations that did not satisfy these four requirements. For instance, shallow urban roofscapes elevated above the surrounding cityscape, were never observed supporting storks or stork nests when the roofscape area was over the maximum noted (72sq.m. in the scope of this study). This does not indicate that 72sq.m. is the actual limit of white stork nesting location preferences, however it does indicate that the area of the potential location does appear to exert causal weight upon the white stork's instinctive calculus. Similarly, small urban roofscapes elevated above the surrounding cityscape, were never observed supporting storks or stork nests, when the roof slopes were above the 4:12 maximum noted in this study. Once more, this does not indicate that the 4:12 slope is the maximum, just that slope plays a factor in white stork nest location preferences.

While the precise dynamic behind the habitat-view parameter requires further study to understand in full, there is an observable trend here as well. While singular storks were found in roofscapes that satisfied the parameters noted with the exception of this quality (generally-unobstructed views to meadows or wetlands), there were never any active *nesting* that took place within such locations. The case of location 16 in particular is noteworthy here. This location satisfies all of the parameters above with the exception of offering unobstructed views to hunting / foraging habitats. Across the timeline of this study, a singular intermittent stork was observed in this location. However, it has never constructed or began the construction of a nest on site. Location 4 is in a comparable situation, however in addition to offering obstructed views of relevant habitats, it is also located immediately adjacent to a busy urban traffic artery. The fact that Location 4 has never been observed supporting an active-nesting stork, also seems to add another layer of consideration to the argument put forth by Mainwaring (2015, 17), that man-made nesting platforms may lure avian species to unideal nesting areas. In this case, no white stork has been lured into nesting at this location, despite the presence of said platforms.

Conclusions and Implications

The European white stork is a seasonal citizen in many cities, big and small, across the European Union, occupying micro niches of the urban roofscape and treescape for significant portions of the year. What this research begins to show is that the contemporary understanding of *Ciconia ciconia*'s preferential calculations concerning potential urban nesting sites is quite limited. The species is not simply weighing availability of resources and habitat conditions, but clearly surveying and assessing the built world in a rather detailed manner.

Despite the presence of viable vertical structures outside of the city's boundaries, whether in the form of cedar and fir trees, and electrical pylons and poles, the entire stork population of the city of Segovia limited their active nesting behavior to the interior portions of the urban fabric. While much of the literature accurately observes that European white stork nesting behavior, across Europe, appears to favor vertical man-made structures such as pylons and poles (Tryjanowski et al 2008, 38; Vaitkuviene and Dagys 2014, 289), what this paper shows is that this is unlikely to be some overarching evolutionary shift being observed within the stork population. Rather, the preference for pylons and poles is more likely linked to the decline of vernacular architectural typologies that once supported the stork population across the continent (Denac 2015, 107) and based on these findings, still does have the capacity to support active stork nesting behavior in significant ways.

Unfortunately, much of the existing literature has tended to gloss over the built world conditions impacting stork nesting behavior, or to compartmentalize the built environment as a neutral background while focusing on the foraging and hunting habitat dynamics of *Ciconia ciconia's* biotope. While it is evident that the European white stork has a preference for high points in the city, the layers impacting nesting behavior beyond this factor have not been investigated previous to this paper. With this previously limited understanding, municipal resources have been mobilized to construct manmade nesting platforms in locations already ill-suited for nesting activities (e.g., Location 4 in Segovia). The perpetual vacancy of these sites not only serves as evidence to this point, but also acts as a hurdle for future micro-interventions of this manner, since there is no academic body of knowledge that can take a rigorous stance on how to maximize the potential for supporting active nesting behavior of the species. This paper hopefully is the first foray into this area of inquiry.

What these findings begin to show is how the European white stork situates a critical element of its biotope (e.g., the nest) within rather particular niches of the built world. These physical niches are readily found within older urban forms across the Iberian Peninsula due to the common presence of tower typologies in the form of belfries within religious architectures or towers of multi-story aristocratic residential complexes. Within newer urban developments, there is a significant paucity of such built environmental micro-zones. Even if one looks within the confines of Segovia, e.g., the neighborhood of Nueva Segovia or the Segovia masterplan authored by David Chipperfield in 2008, these types of niches and tower typologies are by and large absent from contemporary built environmental projects. Wide-sweeping and fairly-homogeneous roofscapes are observed in their stead, lacking any of the parameters that would seem to support European white stork nesting preferences noted in this study.

On a micro scale, these results challenge some of the existing presumptions within the literature, namely that the specifics of the nesting location itself "does not impact the occupation probability" (Bialas et al 2019, 4154). More importantly however, what is uncovered here is that the details of the built environment appear to impact occupation probability of *Ciconia ciconia* in a noteworthy manner.

These findings begin to inform:

- That the urban environment should be considered and understood an integral part of the biotope of *Ciconia ciconia.*
- How *existing* built environmental conditions can be leveraged or refined to conserve or support (hopefully growing) white stork occupation of the urban fabric.
- How to better pinpoint portions of the *existing* built environment as high probability nesting locations, and as a consequence, as ideal locations upon which to build nesting supportive micro-infrastructure (e.g., nesting platforms).
- How *new* urban developments, particularly those located along white stork migratory routes, can be refined and reshaped (prior to construction), with relatively minor adjustments to the architectural typologies and urban-form characteristics being utilized, in order to increase their capacity to support a growing European white stork population in the long-term.

The European white stork, a migratory ecosystem engineer listed within Annex I of Directive 2009/147/EC, in addition to supporting critical ecological functions, is also deeply intertwined with significant local and regional sociocultural narratives across the European continent. Within the domain of ecotourism, there is even a specific strand focused on the observation of storks, which brings for instance, 2000-5000 tourists annually to stork villages in Poland (Czajkowski et al 2012, 1). If simple, strategic, low-cost refinements of existing or proposed built environmental conditions can be set in motion to help support a growing stork population, aside from the ecological and sociocultural benefits noted prior, positive and recurring impacts to the local economy can also be leveraged by municipalities. What this research offers is the beginning of an understanding of how the urban environment forms an integral part of the European white stork biotope, and how it can be subtly refined by urban planners, policy makers, ecologists, landscape architects and architects, to help reinforce the productive entanglement between the physical and ecological layers of the built world.

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