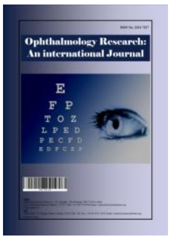

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Bird Migration with Visual Avian Navigation & Nest Nidification: The Spatial Linear Geometries Georeferencing Functionality

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Problem: Bird migration (eye): Georeferencing procedure with clues, rules, functionalities, and restrictions, for avian navigation and nest nidification.

Literature Knowledge: Computer vision (sensor): Robot self-referencing with the Perspective-n-Point pose estimation technique.

Aim: Hypothesis introduction and proving ("The birds also follow the same georeferencing procedure like robots in avian navigation and nest nidification").

Methodology: (a) Reference data, images, and photography acquisition and 4-means layering (eBird dataset, Flickr imagery, CORINE land covering, and Volunteered Geographic Information);
(b) Image processing; and (c) GIS spatial overlay analysis.

Results: Statistical spatial analysis using data of the GIS overlays (the 4 layers). Correlation matrix (Avian navigation and nest nidification in low-density urban areas as these are affected by spatial linear geometries and land cover types).

Conclusion: A statistically satisfactory approach to the introduced hypothesis.

Potential Applications: Human spatial cognition and movement behavior; Children's motor control and coordination.

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Keywords: Birds visual avian navigation; birds nest nidification; spatial linear geometries; georeferencing; GIS spatial overlay.

1. INTRODUCTION

Birds and all animals on earth, including humans, live in a complex, physical world through which they must move. In the last decades, the study of bird migration focused on two main topics; the discovery and description of migratory routes and destinations, and the investigation of the mechanisms that regulate temporal (e.g. summer) and spatial patterns (e.g. power transmission cables or train lines in birds traveling flyways and pathways).

"Also, according to the bibliography (nature research/scientific reports), the magnetic "compass" (i.e. the photochemical magnetoreception in their eye, thanks to cryptochrome-based magnetoreceptors in birds' retina and the bird's eye protein Cry4) is an important biophysical tool of birds' avian navigation system, which allows migratory birds to solve complex georeferencing tasks on traveling in flyways for spring and wintering locations" [1,2].

In this case, the cryptochrome-based photochemical magnetoreception in birds' eyes (located in the retina's central part) is considered the primary biophysical avian navigation tool.

Also, according to bibliography and scientific reports (nature research) low-density structured environments rich in trees, flora, and vegetation, as well as urban woodlands with roads, railways, and power lines should be regarded as the auxiliary georeferencing avian navigation tool (Fig. 1).

Fig. 1. Bird migration with visual avian navigation
Picture by courtesy of Michelle Starr [2]

Birds' visual avian navigation & migration: "Currently, the focus in birds' avian migration is more on the ecological and evolutionary aspects of bird migration, and their relevance for conservation policy. While migration strategies' endogenous regulation and heritability have been studied in detail, their interaction with the environment has received far less attention. Moreover, little is known about the fitness consequences, which are ultimately responsible for birds' avion navigation rules and functionalities, birds' population levels, and nests' locations in migration strategies" [1,3].

"Of relevance are the relationships between the requirement and availability of resources (i.e. fuel), and the need to balance these two factors with the allocation of time between rest and flight. The optimal strategy in this will depend on many factors. Research on e.g., wheatears, godwits, and grey plovers shows that these factors can be successfully studied with the combination of field observations, field experiments, and research under controlled conditions. These approaches are further developed within the Institute of Avian Research (IAR)" [4].

"An aspect of avian migration that has so far received little attention is its importance within the complete life history of an individual. The speed of migration may affect arrival time in the breeding area, which may in turn determine the quality of the obtained breeding territory or nest site, leading to a strong cascade of effects on fitness. Only the study of migration within a complete life-history framework can thus ultimately explain and predict responses to a changing environment" [5].

It is important to emphasize that, nowhere in the literature the influence to birds' avian navigation and nest nidification, of constructions with a specific geometry of a linear form is mentioned (low-density urban areas).

Recent literature knowledge about visual navigation & georeferencing: Despite some differences, the visual process and geometric structure of the eye of humans and birds are broadly the same (the so-called pinhole model) [1,6,7].

The cutting-edge technology "machine vision" follows the same (geometric) structure of vision, namely the pin-hole camera model (i.e. the perspective of the pin-hole camera model). The pin-hole camera model describes the mathematical relationship between the coordinates of a point in three-dimensional space and its projection onto the image plane of an ideal pinhole camera, where the camera aperture is described as a point and no lenses are used to focus light (Fig. 2).

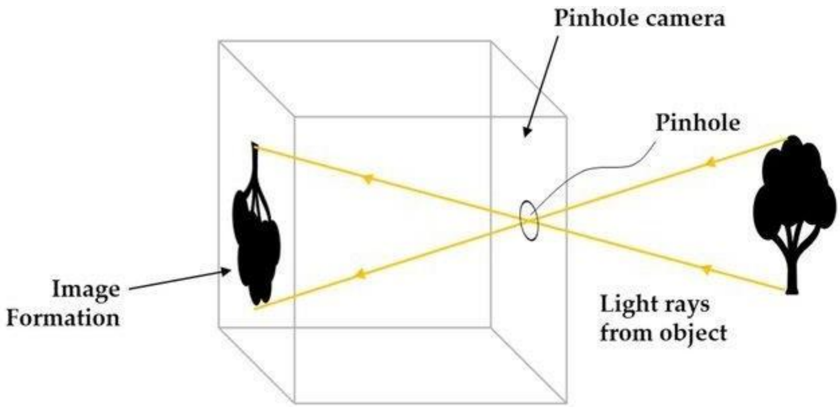

Fig. 2. The pin-hole camera model
Picture credit: [8]

Even more, in machine vision, the robot computes its own temporal position (pose determination) and navigation routes (georeferencing) by recognizing PnP ("*Perspective-n- Point*") shapes and mutually parallel or orthogonal line pairs in observed linear or rectangular image-geometries usually found in natural imagery and normally occur in low-density constructed urban environments (spatial linear geometries) [8,9,10].

In the present work, the original concept of "*spatial (PnP) linear geometries*" is introduced and documented in sub-Section 2.3. Subsequently and for research tactical purposes, a hypothesis is stated in sub-Section 2.4 (that birds follow the same visual process for georeferencing as robots in machine vision) which is then approached for statistical proving.

The paper is organized as follows: In Section 2 ("*Motor Vision (Robot, Bird, Human) - Hypothesis*"), the sensor-based machine (robot) vision, the eye structure, and the similarities/differences in geometry between humans and birds are discussed. Also, in this Section, the innovative concept is introduced, and the hypothesis is stated.

In Section 3 ("*Methodology*"), the acquired references and imagery, as well as the in-situ field-work data (photography) for the trial birds-watching area are discussed, followed by a GIS spatial overlay of the four (4) layers involved. In

Section 4 ("*Results and Discussion*"), the statistically produced correlation matrix related to birds' nest nidification and the 4-layers acquired data, is presented. Also, in this Section, a statistically satisfactory approach, based on the correlation analysis, for the introduced hypothesis proving is discussed.

In Section 5 ("*Conclusion – Potential Applications*"), it is concluded that the visual georeferencing and nest nidification of birds (like robots) follows spatial (PnP) line geometries, shapes, and mutually detect parallel or perpendicular line pairs normally found in low-density structured urban areas. Finally, in this Section, the study of the influence of spatial (PnP) linear geometries georeferencing functionality on human spatial cognition and movement behavior (e.g. children's motor control and coordination) could be considered as potential new applications.

2. MOTOR VISION (ROBOT, BIRD, HUMAN) - HYPOTHESIS

2.1 Robot Vision

"Computing the position and orientation of an object (known as the object pose problem in CAD and robotics) has important applications, such as camera calibration, determining sensor location (in digital photogrammetry), tracking and object detection (in robotics), etc. This calculation is based on images of feature points in photography when the geometric configuration of the object is known in advance" [9,10,11].

The camera pose estimation & the "Perspective-n-Point" (PnP) term: "In computer vision, the pose of an object is often estimated from camera input by the process of pose estimation. This information can then be used, for example, to allow a robot to manipulate an object or to avoid moving into the object based on its perceived position and orientation in the environment" [12].

"The machine vision term *Perspective-n-Point* is referred to the problem of estimating the pose of a calibrated camera given a set of n 3-D points in the world and their corresponding 2-D projections in the image. The camera pose consists of six (6) degrees of freedom (DOF), which are the rotation (roll, pitch, and yaw) and the 3-D translation of the camera with respect to the world" [11,13,12].

In Styliadis, et al. paper [11], "a technique is presented for modeling indoor scenery based on digital images, photo-derived intra-component, geometric and topologic constraints, object-oriented graphic databases containing 3-D parametric models, and a rough (generic) CAD model. This new method is based on mutually parallel or perpendicular line pairs in observed rectangular shape images usually found in photography. In man-made environments, rectangular shapes can be seen everywhere".

"It is thus convenient to use rectangular shapes for pose and object determination in photogrammetric engineering (close-range space rejection) and robotics (robot location)" [14,15].

From the bibliography [11,13,14,15,12] presented above it is clear that in machine vision, the robot is georeferenced continuously (i.e., with a temporal functionality) by using spatial (PnP) linear geometries.

2.2 The Eye Structure (Bird, Human)

Birds and all animals on earth, including humans, live in a complex, physical world in which they must navigate if they are to survive and perhaps leave some ungrateful children as a genetic legacy. Animals must perceive the features of the physical world. This is because many of these features - such as cliffs, quicksand, predators, and sharp sticks - can lead to injury or death. Others, like food and water, are necessities that animals need to survive [5].

Thanks to evolution's long, brutal march through natural selection, animals have senses that serve as important tools for survival. Senses helped ancestors gather data about the environment, avoid danger, and locate vital resources.

"A garden warbler with an attached portable device for the local application of oscillating magnetic fields is displayed in Fig. 3. Yellow circumference schematically shows the eyeball projection on the picture plane" [1].

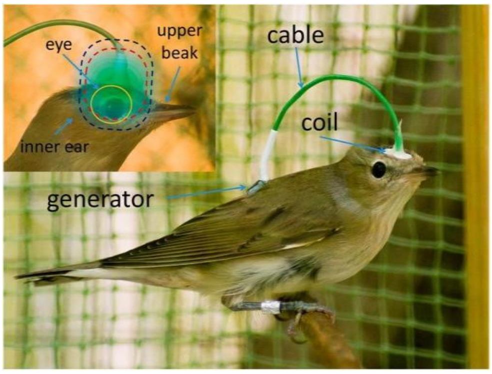

Fig. 3. A garden warbler with an attached portable device for local application of oscillating magnetic fields
Picture by courtesy of Julia Bojarinova et al. [1]

Human eye vs. bird eye: the same geometric structure: The geometric structure of humans and birds is roughly the same [16,17]. Of course, according to bird vision expert Graham Martin (Emeritus Professor in the School of Biosciences at the College of Birmingham, UK), there are some differences that do not call into question the above general statement [18,19].

How is the human eye similar to the eye of a bird?: "Both birds and humans have photoreceptive 'cones' in the retina, located at the back of the eye. These cones allow us to see colored light. The human eye contains 10,000 cones per square millimeter, while songbirds, for example, have up to 12 times as many, or 120,000 cones per square millimeter" [20].

The retinas of birds have about three times as many sensory cells as human retinas (both retinas are located at the back of the eye). So, like a camera with three times as many pixels, birds have much sharper vision than average humans do. Owls, in particular, have large retinas that give them no color but a maximum black-and-white vision in very low light.

Normal human vision is described as "20/20 level" vision, i.e. having 20/20 vision means normal or average visual acuity. Some people have a vision that's better than 20/20, like 20/15 or 20/10. This means that they can see something 20 feet away (like a line on an eye chart) that most people can see when they're 15 feet away (the 20/15 vision case) or 10 feet away (the 20/10 vision case) (Fig. 4a).

Birds devote a huge amount of space to visual processing, and they have a highly developed sense of sight which allows them to easily spot prey. Eagles, for example, have excellent 20/5 level vision compared to an average human who only has 20/20 vision. This means Eagles can see things from 20 feet away that the average human can only see from 5 feet away (Fig. 4b).

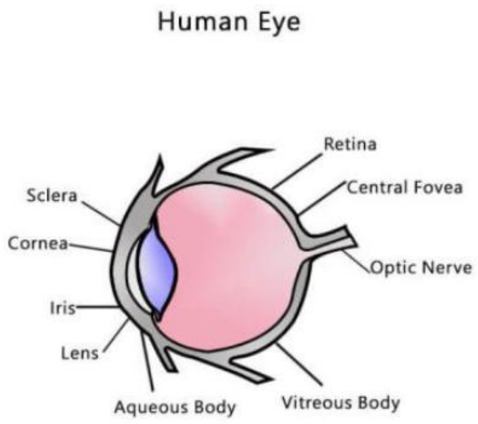

Fig. 4a. A 20/20 level normal (average) human vision. The photoreceptive 'cones' in the retina are located at the back of the eye
Picture by courtesy of Ivan Phillipsen [20]

The bird's eye anatomy: The following Fig. 5 displays the bird's eye anatomy and structure.

2.3 Introducing an Innovative Concept

In the present work, first, the original concept of "*spatial (PnP) linear geometries*" is introduced and documented to describe the PnP shapes and the detected line pairs that are parallel or perpendicular to each other in observed on-images geometries with rectangular shapes, usually found in urban environments (sub-Section 2.3).

Subsequently, a hypothesis is stated (that birds follow the same visual process for georeferencing as robots in machine vision) which is then approached for proving (a statistically satisfactory proving approach based on a synthesis of evidence from eBird datasets, Flickr images, CORINE land cover types, in-situ photography, and statistical analysis/correlation matrix).

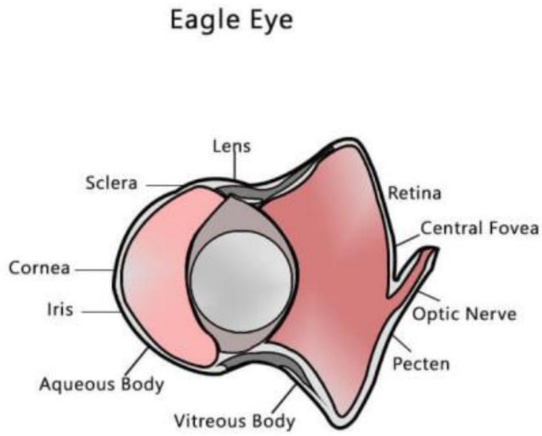

Fig. 4b. A 20/5 level eagle vision. The photoreceptive 'cones' in a bird's retina are located at the back of the eye as well, having 3x sensory cells as human retinas to gather that much data that quickly.
Picture by courtesy of Ivan Phillipsen [20]

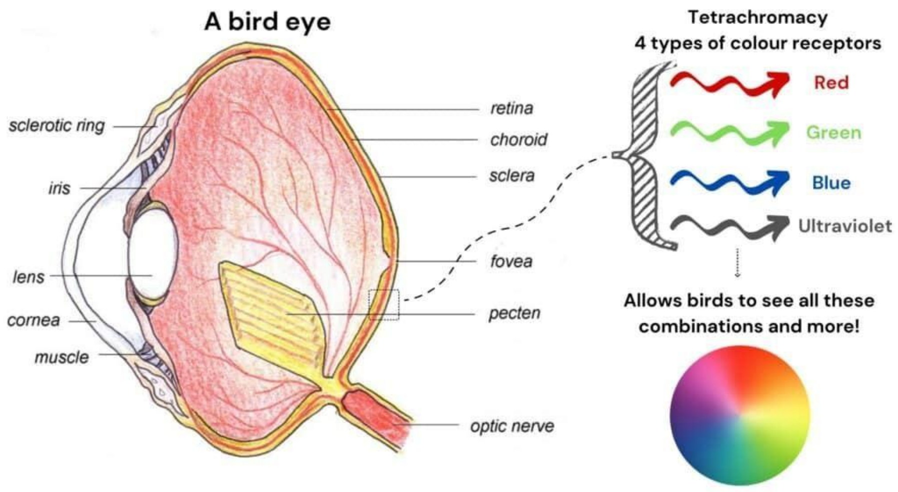

Fig. 5. Bird's eye anatomy
Picture by courtesy of Ivan Phillipsen [20]

2.4 Introducing a Hypothesis

For research tactical purposes a hypothesis is introduced in sub-Section 2.4. The stated hypothesis assumes that birds follow the same visual process in georeferencing as robots (machine vision, pose determination). Then, according to correlation matrix analysis in sub-Section 4.1, it is "proved" as a statistically satisfactory approach that birds in their avian navigation and in nest nidification also follow the same visual process in georeferencing as robots. A "proof" based on a synthesis of evidence (eBird datasets, Flickr images, CORINE land cover types, and in-situ photography) and a statistical analysis/correlation matrix.

Hence, the paper reasoning that birds, apart from their primary biophysical magnetic "compass" and the auxiliary georeferencing avian navigation tools (low-density structured environments rich in trees, flora, and vegetation, as well as urban woodlands with roads, railways, and power lines), also follow for georeferencing the same as robots' visual avian navigation process based on "spatial (PnP) linear geometries".

3. METHODOLOGY

In this Section the data acquisition is discussed in sub-Section 3.1 while in sub-Section 3.2 a GIS overlay analysis for these data is presented.

3.1 Field Experiments in Birds Watching Area (eBIRD, Flickr, CORINE, in-situ & VGI)

3.1.1 The study area

The trial birds-watching area is located at Possidi, Chalkidiki, Northern Greece) (Fig. 6).

3.1.2 The data acquisition channels (eBird datasets, Flickr imagery, CORINE land cover types, in-situ & VGI photography)

The data acquisition procedure is related to geo-tagged raster imagery and photography, was performed between August – September 2022 and it is based on the following four input channels.

(a) eBird basic dataset (EBD): "The EBD is the core dataset for accessing all raw eBird observations and associated metadata. The EBD is updated monthly (15th of each month) and is available by direct download through https://science.eBird.org to any logged-in user after completion of a data request form" [21]. "eBird provides open data access in several formats to logged-in users, ranging from raw data to processed datasets geared toward more rigorous scientific modeling" [22].

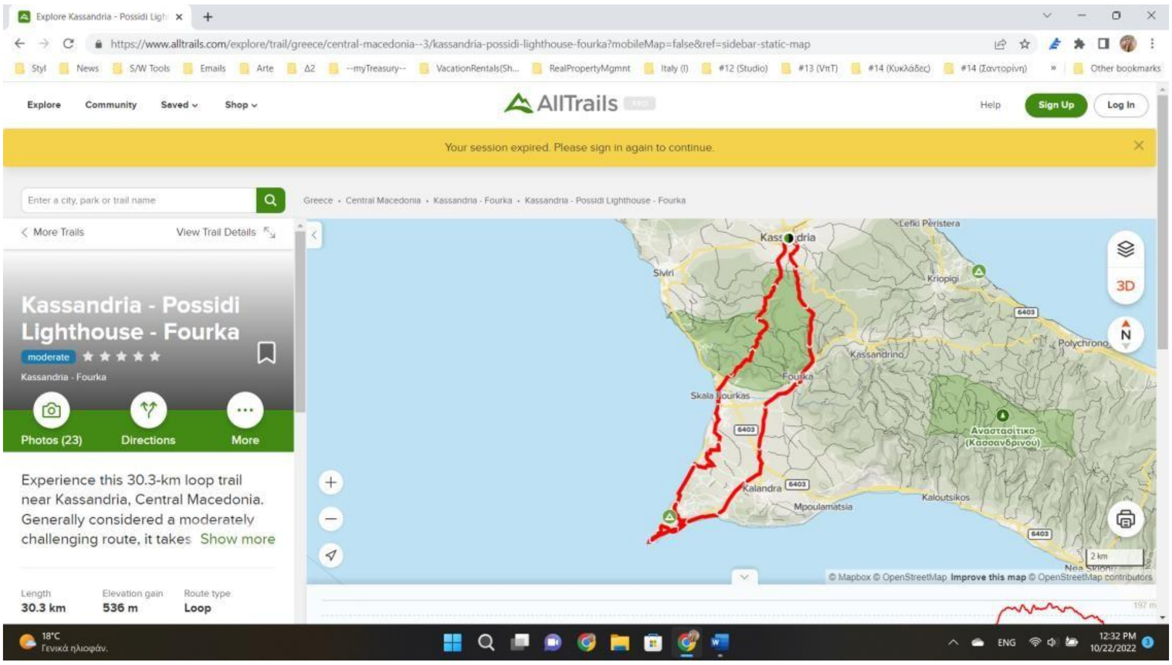

Fig. 6. Birds' watching area – The bounding box
(Possidi / Chalkidiki, Greece). Print screen credit: AllTrails.com app, San Francisco, CA

(b) Flickr sharing application: The Flickr is an online photo management and imagery-sharing application for uploading, downloading, sharing, and organizing content [23]. For the trial case, birds' route distributions in Flickr imagery were compared to available eBird data as references. Hence, Flickr imagery can be a possible complementary data source for georeferencing science.

Flickr as one of the largest photo-sharing platforms has been used in various environmental analyses from natural disaster prediction to wildlife monitoring. In this article, bird photos from Flickr have been downloaded and used to illustrate the spatial distribution of bird locations in Possidi area / Chalkidiki / Greece, and most importantly to see the correlation between the location of birds' nests, the cover types, and the spatial (PnP) linear geometries.

(c) Corine land cover types / Copernicus Land Monitoring Service (part of the Copernicus Programme)**.** Copernicus is a European programme for monitoring the Earth, in which data is collected by Earth observation satellites and combined with observation data from sensor networks on the earth's surface.

"Once collected the data is then processed, providing reliable and up-to-date information within six thematic areas. These areas are: land, marine, atmosphere, climate change, emergency management, and security. Various organizations manage and deliver these six thematic information services" [24].

Copernicus Land Monitoring Service (CLMS) provides geographical information on the land cover to a broad range of users in the field of environmental terrestrial applications. This includes land use, land cover characteristics and changes, vegetation state, water cycle, and earth surface energy variables. CLMS products are divided into five categories:

Systematic biophysical monitoring, Land cover & land use mapping, Thematic hotspot mapping, Reference data, and Ground motion service. These categories enable applications to be developed in a wide range of areas. These include spatial and urban planning, Forest management, Water management, Agriculture and food security, Nature conservation and restoration, Ecosystem accounting, and Mitigation of climate change.

(d) In-situ photography & VGI (Volunteered Geographic Information): In-situ close-range photography was performed in the trial area once the Flickr imagery indicated sufficient density in bird flocks, nests, and spatial (PnP) linear geometries. Even more, and for additional data acquisition, a VGI survey was carried out.

"Also, social media data are becoming potential sources of the called "passive" VGI (Volunteered Geographic Information) and citizen science" [25]. "VGI refers to georeferenced data created by citizen volunteers. VGI has proliferated in recent years due to the advancement of technologies that enable the public to contribute geographic data. VGI is not only an innovative mechanism for geographic data production and sharing but also may greatly influence GIScience and geography and its relationship to society. Despite the advantages of VGI, VGI data quality is under constant scrutiny as quality assessment is the basis for users to evaluate its fitness for using it in applications. Several general approaches have been proposed to assure VGI data quality but only a few methods have been developed to tackle VGI biases" [25].

In the discussed trial, VGI [25] and location-based environmental monitoring [26] have been applied in in-situ field surveys in the birds' observation area for spatial (PnP) linear geometries spatial and visual documentation, land cover types recording, and birds' nests' georeferenced photography.

3.1.3 Chi-square (or $\chi 2$) test of independence

The chi-square test of independence is an inferential statistical test, meaning that it allows drawing conclusions about a population based on a sample. Specifically, it allows concluding whether two or more variables are related in the population. It is a statistical hypothesis test that is valid to perform when the test statistic is chi-squared distributed under the null hypothesis, specifically Pearson's chi-squared test and variants thereof. Pearson's chi-squared test is used to determine whether there is a statistically significant difference between the expected frequencies and the observed frequencies in one or more categories of a contingency table.

In the standard applications of this test, the observations are classified into mutually exclusive classes. If the null hypothesis that there are no differences between the classes in the population is true, the test statistic computed from the observations follows a χ2 frequency distribution. The purpose of the test is to evaluate how likely the observed frequencies would be assuming the null hypothesis is true. Test statistics that follow a χ2 distribution occur when the observations are independent. There are also χ2 tests for testing the null hypothesis of independence of a pair of random variables based on observations of the pairs.

Chi-squared tests often refer to tests for which the distribution of the test statistic approaches the χ2 distribution asymptotically, meaning that the sampling distribution (if the null hypothesis is true) of the test statistic approximates a chi-squared distribution more and more closely as sample sizes increase [https://en.wikipedia.org/wiki/Chi-squared_test].

In the presented trial four (4) chi-square tests of independence have been applied to illustrate the association between birds' nest nidification and the contrast pixel gray coloring (split in three categories >80%, 40-80%, <40%) detected in (i) the raster eBird datasets, (ii) the raster Flickr images; (iii) the CORINE land cover classes; and (iv) the raster in-situ and VGI photography of spatial (PnP) linear geometries. The statistically significant association between nest nidification and these four variables is described in Section 4 ("Results and Discussion").

(A) Raster images acquisition (eBird datasets, Flickr imagery, CORINE land cover types)

The next five Figures present the study area as well as the data points that indicate the position of the collected Flickr images (Figs. 7-11).

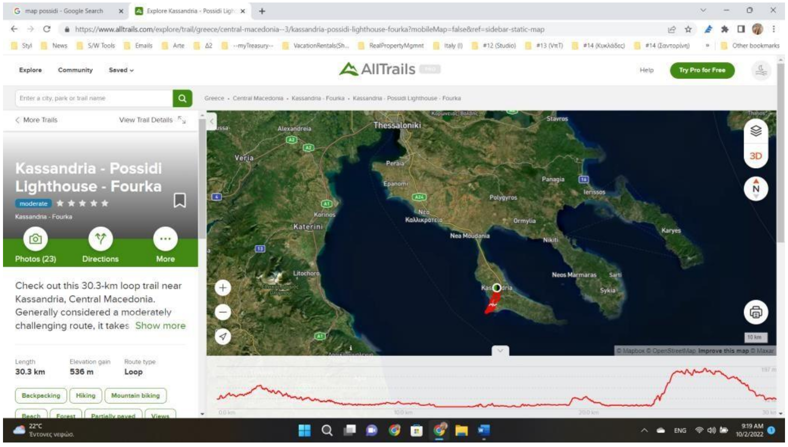

Fig. 7. eBird datasets & Flickr imagery: Peninsula of Chalkidiki, Greece
The overlay image was composed by eBird (www.ebird.org), and Flickr (www.flickr.com) layer images and created on September 28, 2022. Print screen credit: AllTrails.com app, San Francisco, CA

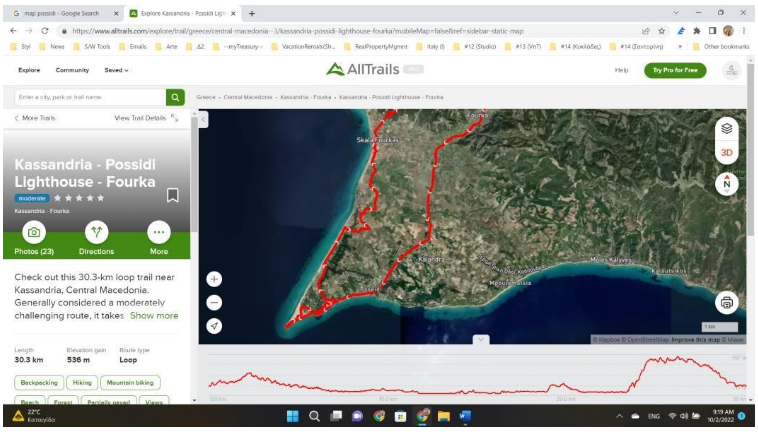

Fig. 8. eBird datasets & Flickr imagery for the birds' watching area
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com), and CORINE (https://land.copernicus.eu) layer images and created on September 28, 2022.
Print screen credit: AllTrails.com app, San Francisco, CA

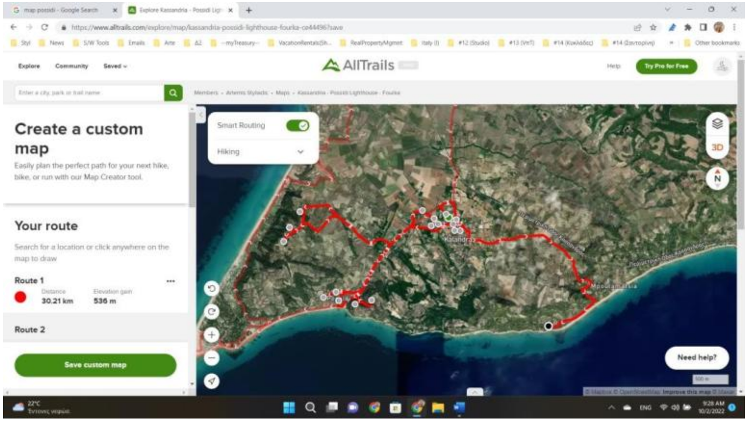

Fig. 9. Bird migration: The Temporal dimension (Summer 2022 imagery)
The overlay image was composed by eBird (www.ebird.org), and Flickr (www.flickr.com), layer images and created on September 30, 2022.
Print screen credit: AllTrails.com app, San Francisco, CA

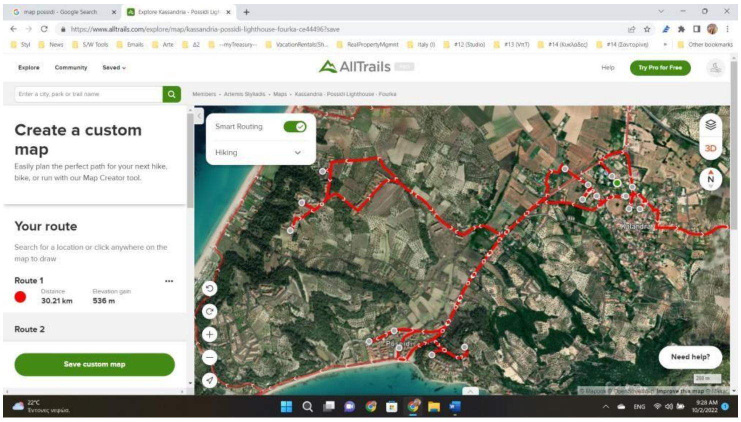

Fig. 10. Bird migration: The Spatial patterns dimension (Birds' traveling flyways in Possidi area / Chalkidiki, Greece)
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com), and CORINE (https://land.copernicus.eu) layer images and created on September 30, 2022.
Print screen credit: AllTrails.com app, San Francisco, CA

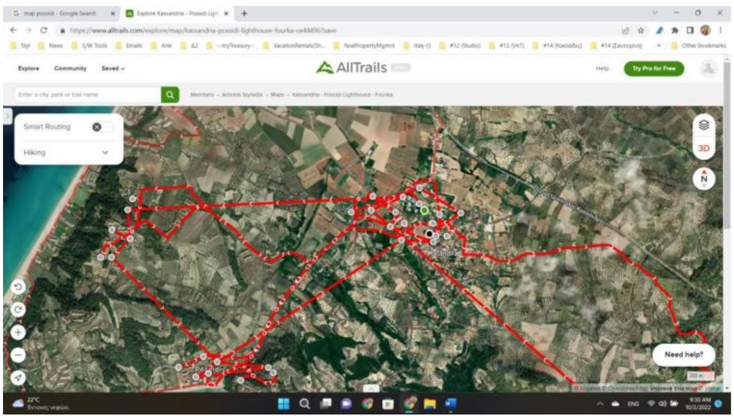

Fig. 11. Bird migration: demonstrating both, temporal and spatial patterns (birds' traveling pathways in Possidi area in Summer 2022 / Chalkidiki, Greece)
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com), and CORINE (https://land.copernicus.eu) layer images and created on September 30, 2022. Print screen credit: AllTrails.com app, San Francisco, CA

3.1.4 Flickr imagery filtering

The first step was to download the images and then to apply filters to them in order to obtain clean data for image processing analysis. On the Flickr API the following four requirements were set just before beginning the raster image downloading:

- The media was set to download only images and not videos.
- The starting date was set as the first of August 2022.
- Only raster images with geo-location were downloaded.
- In order to find only images with flocks of birds, the correct tag (birds) had to be identified.

"Flickr has two types of tags: user-generated tags, which are added by Flickr contributors, and machine-generated tags, which are added to images using Flickr's artificial intelligence. So, the machine-generated tags were set as any, and the user-generated tags were set as bird" [26]. As a result, the raster images as well as their metadata were obtained (geo-location, date, image URL, image ID, and a list of all tags for each image).

Following the raster images downloading, two major filters were applied to the dataset: (i) image filtering; and (ii) tag filtering (Fig. 12).

The final dataset includes the Flickr tag, image ID, and the geo-locations for the raster image from the Institute of Avian Research (IAR), the German Ornithological Society (DO-G), and the journal Vogelwarte [4] (Figs. 13, 14).

3.1.5 Birds distribution and image processing analysis

"After obtaining the filtered dataset, in order to visualize the density (expressed in contrast gray coloring) of distribution of bird observations in the study area, image processing techniques and kernel density analysis (KDE) were used" [27,28]. "Kernel Density Estimation (KDE) is a non- parametric technique for density estimation in which a known density function (the kernel) is averaged across the observed data points to create a smooth approximation" [28].

Moreover, to explore the distribution of the data in local low-density areas enjoying high density gray coloring indicating birds presence, two additional datasets were created: (i) the CORINE land cover values for each observation point within various land cover classes; and (ii) the in-situ and VGI raster photography.

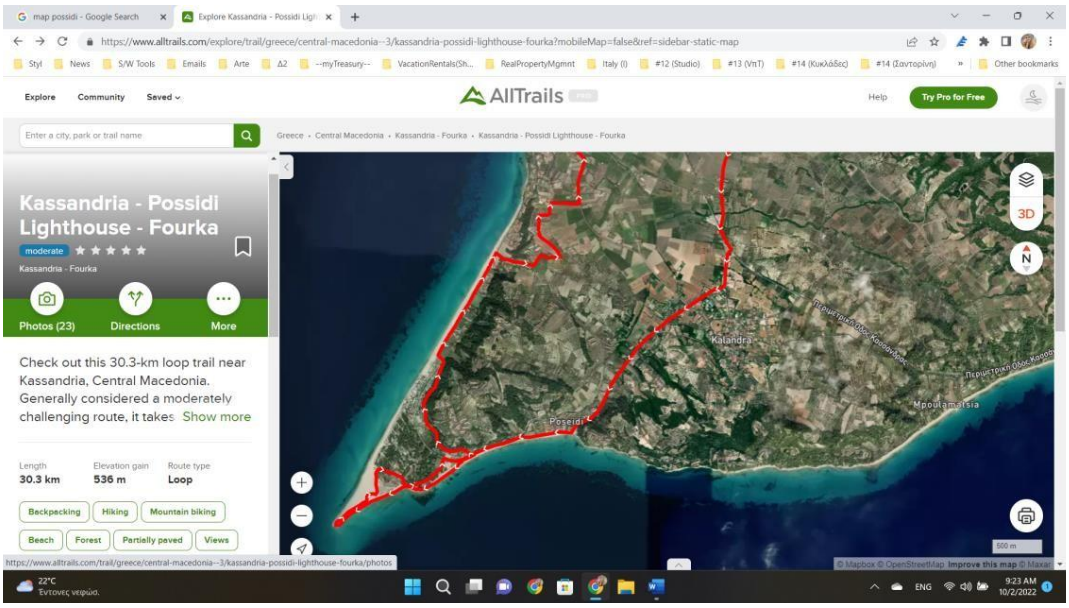

Fig. 12. eBird datasets & flickr imagery: filtering the birds' watching area (Fourka, Possidi, Possidi lighthouse / Chalkidiki, Greece)
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com), and CORINE (https://land.copernicus.eu) layer images and created on September 28, 2022.
Print screen credit: AllTrails.com app, San Francisco, CA

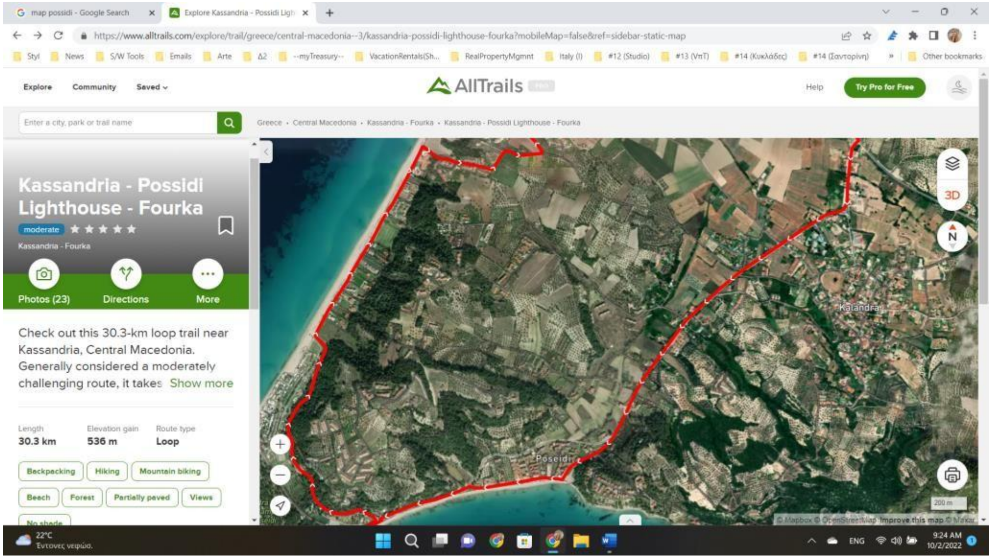

Fig. 13. eBird datasets & Flickr imagery: The Flickr tag and the Image ID
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com), and CORINE (https://land.copernicus.eu) layer images and created on September 29, 2022.
Print screen credit: AllTrails.com app, San Francisco, CA

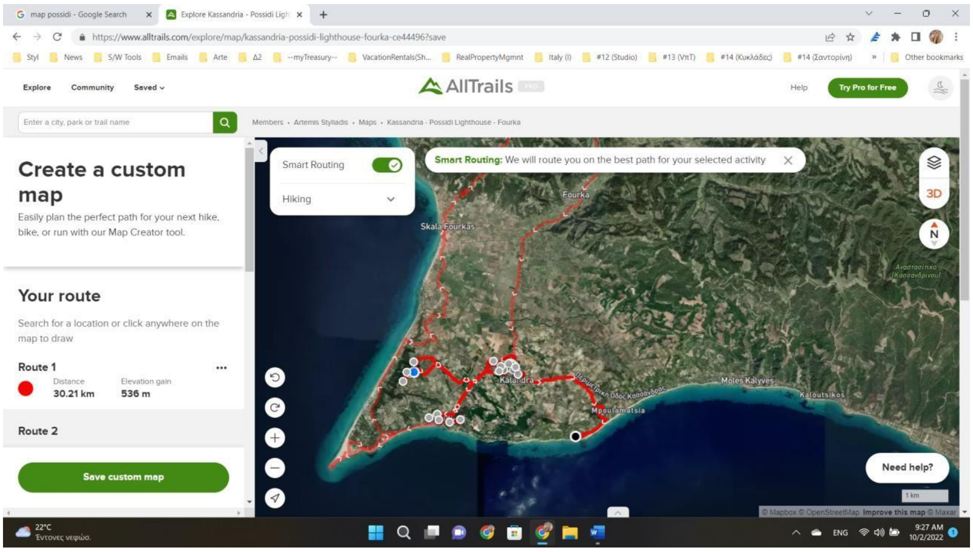

Fig. 14. eBird datasets & Flickr imagery: The geo-locations for the image
The overlay image was composed by eBird (www.ebird.org), and Flickr (www.flickr.com) layer images and created on September 29, 2022.
Print screen credit: AllTrails.com app, San Francisco, CA

"Thus, the frequency of birds' observations within different land cover types was observed, and four chi-square test of independence were performed to explore the association between (i) birds' nest nidification and eBird metadata and references; (ii) birds' nest nidification and raster Flickr images; (iii) birds' nest nidification and land cover classes; and (iv) birds' nests nidification and spatial (PnP) linear geometries" [29,30,31].

(B) Raster images acquisition (In-situ photography, VGI photography)

An in-situ photography campaign was performed on October 8, 2022 in local low-density areas enjoying high density gray coloring indicating birds presence according the eBird datasets, Flickr imagery, and CORINE land cover classes analysis.

Fig. 15. Birds' nests on a low-density structured environment rich in trees, flora, and vegetation and with many "spatial (PnP) linear geometries"
Photo by courtesy@Ch. Basdekidou (Article's author)

Fig. 16. Birds' nests on a low-density structured environment rich in trees, flora, and vegetation and with many "spatial (PnP) linear geometries"
Photo by courtesy@Ch. Basdekidou (Article's author)

Fig. 17. Birds' nests on a low-density structured environment rich in trees, flora, and vegetation and with many "spatial (PnP) linear geometries"
Photo by courtesy@Ch. Basdekidou (Article's author)

In the observation area (Possidi / Chalkidiki), there are many constructions (e.g., houses, maisonettes, and villas) rich in “spatial (PnP) linear geometries” structures in a low-density structured environment rich in trees, flora, and vegetation. In the performed photography campaign many birds' nests and many birds' traveling flyways, routes, and pathways were photo-caught (Figs. 15, 16, 17).

On the other hand, in the same environment (Possidi / Chalkidiki, rich in trees, flora, and vegetation) but in constructions without “spatial (PnP) linear geometries” birds' nests didn't find (Fig. 18).

In the same observation area (Possidi/ Chalkidiki), there are also constructions (e.g., churches) with non-linear structures in environments poor in trees and flora. In these constructions no birds' nests and no birds' traveling flyways, routes, and pathways were noticed (Figs. 19, 20).

3.2 The 4-Layers GIS Overlay Spatial Analysis

“The adapted overlay methodology was the operation of comparing variables among the three multiple coverages (EBD reference data, Flickr imagery, and CORINE land cover). In the performed overlay analysis new spatial data sets were created by merging the data from these three input data layers (EBD, Flickr, and CORINE). Overlay analysis is one of the most common and powerful GIS technique” [32].

Fig. 18. No Birds' nests on a low-density structured environment rich in trees, flora, and vegetation but poor in “spatial (PnP) linear geometries”
Photo by courtesy@Ch. Basdekidou (Article's author)

Fig. 19. A Non-linear structure (Church) in a natural environment without trees and without PnP linear geometries→ No Birds' nests found
Photo by courtesy@Ch. Basdekidou (Article's author)

Fig. 20. A Non-linear structure (Church) in a natural environment with few trees and without PnP linear geometries→ No Birds' nests found
Photo by courtesy@Ch. Basdekidou (Article's author)

"For the birds' watching area located in Chalkidiki / Northern Greece (Fig. 6), nine (9) geo-tagged Flickr imagery -which was downloaded using the Flickr API (Application Programming Interface)" [26]- was acquired, analyzed (image processing following by field / in-situ measurements and observations), and used as the geo-data layer; in conjunction with four (4) eBird datasets used as the reference-data layer; and three (3) CORINE land cover types related to trees, flora, and vegetation used as the environmental/natural-data layer [24].

Then, the ESRI's GIS client software (ArcGIS; provided by the Int'l Hellenic University / Dept of Forest & Natural Environment Sciences / GIS laboratory) and spatial analytics technology [33], as well as the AllTrails.com app [34] were used for an overlay spatial (GIS) analysis for gathering and analyzing the following data: nests location (spatial intelligence functionality), birds presence density, low-density (or high-density) constructed urban (or rural areas), spatial linear (or curved) geometries, and land cover types) from all of these three layers and used later as input in the paper's Section 4 ("Results and Discussion").

3.3 Quantifying the Acquired from the GIS Overlay Spatial Analysis Data

The GIS overlay spatial analysis produces raster imagery data that must be quantified to be useful for statistical spatial analysis purposes (sub-Section 4.1).

For this purpose, and with an image-to-ground scaling of 1:1.000, the recognized gray darkness areas (with 1-pixel accuracy) are classified into the following three (3) categories (Table 1):

Local areas classified as Category A have the lowest detected birds' presence, Category B classification cited a middle presence, and Category C referred to the highest ones. The classification settings were defined according to real-world on-ground observations.

The overlay analysis is used to combine the characteristics of the four datasets (layer I: eBird metadata and references; layer II: raster Flickr images; layer III: land cover classes; and layer IV: spatial (PnP) linear geometries) into one.

Table 1. Classification settings for the GIS overlay spatial analysis

Category	Percentage of gray darkness/squared inch on the raster image (Scale 1:1.000)	Number of nests' nidifications per 100 m^2 ground (on average)	Local areas (about 10 acres)
A	80+% - 100%	0 .. 0.5	Without nature and PnP geometries
B	40+% - 80%	0.5 .. 1	Rich just in nature
C	0% - 40%	>1	Rich both in nature and PnP geometries

The specific locations or areas that have a certain set of attribute values should be defined, that is, match the criteria specified in Table 1. Obviously, and for accuracy reasons, the combined layer should be tested against layer V: nest nidification (raster images from in-situ surveys and VGI photography).

“This approach is often used to find locations that are suitable for a particular use or are susceptible to some risk. For example, some GIS spatial analysis projects overlay layers of vegetation type, slope, aspect, soil moisture, and so on, to find areas susceptible to wildfire” [33].

In raster GIS overlays, each cell of each layer references the same geographic location. That makes it well suited to combining characteristics for numerous layers into a single layer. In the presented trial case, numeric values were assigned to each characteristic, allowing a mathematical combination of the involved layers and the assignment of a new value to each cell in the output layer.

Below is an example of the raster GIS overlay applied to the trial case. Three raster layers (Flickr image, nature, and PnP geometries) are ranked for development suitability on a scale of 1 (image) to 1.000 (ground). When the layers are added, each cell is ranked on a scale of 3 (birds nest nidification/acre) to 21 (birds nest nidification/acre) (Fig. 21).

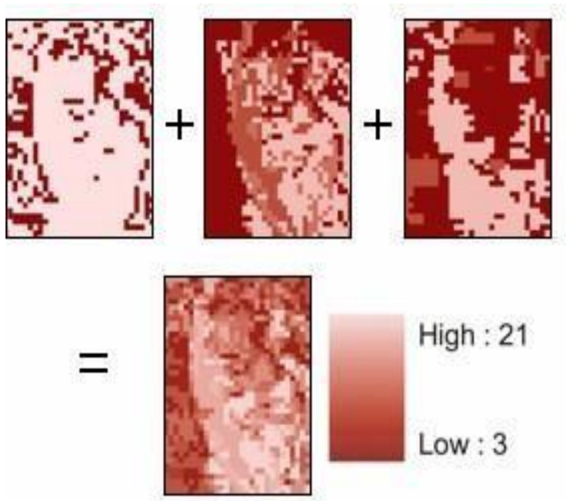

Fig. 21. A raster GIS overlay example for the birds watching area
(Possidi/Chalkidiki/Greece)
Picture by courtesy@Ch. Basdekidou (Article’s author), and of ESRI ArcGIS raster software [33]

4. RESULTS AND DISCUSSION

4.1 Statistical Spatial Analysis – Nest Nidification (Five Variables Correlation)

In this Section, the input data for performing a statistical spatial analysis are nests’ location (spatial intelligence functionality), birds routes tracking, birds’ presence density, low-density (or high-density) constructed urban (or rural areas), spatial linear (or curved) geometries, and land cover types; from all of the three layers (i.e. eBird dataset, Flickr imagery, and CORINE land types).

“Correlation is a statistical term describing the degree to which two or more variables move in coordination with one another” [35]. In the trial case, the variables are five: (i) the nest nidifications; (ii) in eBirds datasets/flock of birds detected in traveling paths or pathways; (iii) in Flickr images/flock of birds detected in traveling paths or pathways; (iv) in CORINE imagery/the classified land cover classes, and (v) In in-situ photography/the spotted spatial (PnP) linear geometries.

“For the trial case four chi-square tests of independence were performed to explore the association between (i) birds’ nest nidification and eBird metadata and references; (ii) birds’ nest nidification and raster Flickr images; (iii) birds’ nest nidification and land cover classes; and (iv) birds’ nests nidification and spatial (PnP) linear geometries [29,30,31]. Following the Cramer’s V metric was computed as a result of the test” [36].

“In statistics, Cramér's V (sometimes referred to as Cramér's *phi* and denoted as φc) is a measure of association between two nominal variables, giving a value between 0 and +1 (inclusive). It is based on Pearson's chi-squared statistic and was published by Harald Cramér in 1946” [37,38]. “Cramer’s V is a metric to measure the strength of association between two variables. It ranges between 0 to 1, which values above 0.5 indicating a strong association.

In the trial case, the result of the chi-square test illustrated a statistically significant association between birds’ nests and land cover types (with Cramer’s V= 0.5209 and p-value < 0.0001); and a very strong statistically significant association between birds’ nests and spatial (PnP) linear geometries (with Cramer’s V= 0.6312 and p-value < 0.0001)” [37,38].

Table 2. Statistical Spatial Correlation of the Birds' nest nidification distribution (eBird datasets, Flickr imagery, CORINE land cover types, In-Situ & VGI photography)

Layer	Min	Max	Mean	Std
SDM_eBird datasets	0.0920	1.0000	0.2145	0.2090
SDM_Flickr imagery	0.4283	1.0000	0.5332	0.1337
CORINE land cover types	0.4509	1.0000	0.5512	0.1308
PnP photography from In-Situ & VGI surveys	0.5677	1.0000	0.6244	0.1212

Table 3. The covariance matrix

Layer	SDM_eBird datasets	SDM_Flickr imagery	Birds' Nest nidification locations and Flying/Traveling flyways, routes & paths	CORINE land cover types (Natural environment with water, trees, and plants)	PnP Linear geometries (Mutually parallel or perpendicular line pairs in observed rectangular shape images)
SDM_eBird datasets	0.00848	0.01224	0.01230	0.01212	0.01242
SDM_Flickr imagery	0.01224	0.02075	0.01220	0.01207	0.01262
Birds' Nests locations and Flying/Traveling flyways, routes & paths	0.01230	0.01220	0.00790	0.01273	0.01263
CORINE land cover types (Natural environment with water, trees, and plants)	0.01212	0.01207	0.01273	0.00809	-
PnP Linear geometries (Mutually parallel or perpendicular line pairs in observed rectangular shape images)	0.01242	0.01262	0.01263	-	0.00786

Table 4. The correlation matrix (birds' nests' locations and flying/traveling routes, paths, and pathways; land cover types; Spatial PnP linear geometries)

Layer	Birds' Nests locations and Flying/Traveling flyways, routes & paths	Land Cover types (Natural environment with water, trees, and plants)	PnP Linear geometries (Mutually parallel or perpendicular line pairs in observed rectangular shape images)	Rich Natural Lands with trees & Many PnP Linear geometries
Birds' Nests locations and Flying/Traveling flyways, routes, and paths	1.00000	0.66732	0.73655	0.90703
Land Cover types (Natural environment with water, trees, and plants)	0.66732	1.00000	0	0.50448
PnP Linear geometries (Mutually parallel or perpendicular line pairs in observed rectangular shape images)	0.73655	0	1.00000	0.51087
Rich Natural Land with trees & Many PnP Linear geometries	0.90703	0.50448	0.51087	1.00000

"Table 2 illustrates the Statistical Spatial Correlation of the Birds' Nests distribution (eBird datasets, Flickr imagery, CORINE land cover types, and PnP photography from in-situ and VGI surveys). Moreover, informing the contributors about the value of their data in helping scientific projects can motivate them to contribute higher-quality data" [26].

Table 3 presents the Covariance Matrix as it has been generated from (i) Table's 1 data (Statistical Correlation of the Birds' Nests distribution: eBird datasets & Flickr imagery); (ii) Birds' Nests locations and traveling routes, paths, and pathways; (iii) Land cover types; and (iv) Spatial (PnP) linear geometries.

"Finally, Table 4 demonstrates the Correlation Matrix. The Pearson correlation coefficient is used to examine the strength and direction of the linear relationship between these three continuous variables: (i) Birds' Nests locations and traveling routes, paths, and pathways; (ii) Land cover types; and (iii) PnP linear geometries. The correlation coefficient can range in value from −1 to +1. The larger the absolute value of the coefficient, the stronger the relationship between the variables" [31].

A very strong positive correlation relationship (r = 0.90703) has been found between the layers "*Birds' Nests locations and Flying/Traveling routes & paths*" and "*Rich Natural Lands with trees & Many Spatial (PnP) Linear geometries*". The birds prefer to travel in routes/paths/pathways and to build up nests in constructed natural environments rich in trees, flora, and vegetation, as well as with many spatial (PnP) linear geometries (Table 3).

4.2 Hypothesis – A Statistically Satisfactory Approach

Hence, this very strong correlation relationship (r = 0.90703) should be interpreted as a great georeferencing utility and functionality in birds' migration procedure [30]. Hence, this should be regarded as a statistically satisfactory approach of confirmation for the case introduced in sub-Section 2.4 (Hypothesizes that birds follow the same visual process for georeferencing as robots in machine vision).

The confirmation ("proof") is based on a synthesis of evidence from eBird datasets, Flickr images, CORINE land cover classes, in-situ and VGI photography, and statistical analysis/correlation matrix, that birds also follow the same visual process for georeferencing based on "spatial (PnP) linear geometries" as robots.

5. CONCLUSION – POTENTIAL APPLICATIONS

Conclusion: The birds, apart from their primary biophysical magnetic "compass" and the auxiliary georeferencing avian navigation tool, also follow the same visual avian navigation process for georeferencing based on "spatial (PnP) linear geometries" as robots.

In this paper, after introducing and documenting the innovative concept of "*spatial* (*PnP) linear geometries*", a statistically satisfactory approach is reasoning that birds' visual georeferencing procedure follows (like robots) the PnP closed forms and georeferencing functionalities derived from several detected mutually parallel or perpendicular line pairs in observed rectangular shape images usually found in natural and low-density structured environments. The presented research is based on available recent (August and September 2022) eBird datasets, Flickr imagery, and CORINE land cover reference layer data, as well as in-situ and VGI photography (October 2022) from the Possidi trial area in Chalkidiki, Northern Greece.

The proposed methodology observes the temporal and spatial distribution in acquired raster images of both, the birds' traveling pathways and the birds' nest nidification, as well as determines whether there is any association (correlation) between (i) this spatial distribution (ii) the land cover types (natural environment with or without trees, flora, and vegetation), and (iii) the spatial (PnP) linear geometries.

The results illustrated that the data are more concentrated near natural environments with trees and water pockets in low-density urban areas with many constructions rich in spatial (PnP) linear geometries. A very strong positive correlation relationship (r = 0.90703) has been found between the layers "*Birds' Nests locations and Flying/Traveling flyways, routes & paths*" and "*Rich Natural Lands with trees & Many spatial (PnP) Linear geometries*".

The birds prefer to travel in routes/paths/pathways and to nidificate nests in low-density constructed natural environments rich in trees, flora, and vegetation, as well as with many PnP linear geometries (Section 4, Table 3).

Moreover, a statistically significant association was observed between birds' traveling pathways (spatial patterns of observations/data from Flickr imagery); birds' observers' behavior; land cover types; and spatial (PnP) linear geometries.

Finally, in this paper, it was stated that birds, apart from their primary biophysical magnetic "compass" (cryptochrome-based magnetoreceptors) and any auxiliary georeferencing avian navigation tools (low-density structured environments), also follow for georeferencing similar to robots' visual motor process based on "spatial (PnP) linear geometries".

Potential applications: As potential future applications should be examined the study of the influence of the introduced "spatial (PnP) linear geometries" georeferencing functionality on human spatial cognition and movement behavior (and particularly on children with motor control and coordination disorders).

Open research issues: In future research on bird avian migration, the study of metabolic physiology and the biochemical basis of migratory behavior should be examined. Technological advancement in physiological and biochemical analyses -in particular- has contributed to this, as it now allows to study of these aspects. The scope of this research work extends beyond birds because of its biophysical context.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

DATA AVAILABILITY

All data generated or analyzed during this study are included in this published article (and its Supplementary Information files) and they are available from the author on reasonable request.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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