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Green facades support biodiversity in urban environment – A case study from Poland

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Abstract: Green walls, along with green roofs, parks, and vertical gardens, belong to the green infrastructure of cities, which will encompass the majority of humanity in the coming decades. Green infrastructure benefits both urban residents and nature in the urban landscape, although there is no scientific consensus on the extent to which green walls, especially green facades, impact biodiversity in cities. This study examined the influence of green facades on the richness of mammals, birds, and invertebrates, considering the species and age of the plants comprising the green facade in a medium-sized city located in southwestern Poland. It was found that the implementation of green facades significantly enhances species' biodiversity compared to non-vegetated walls. Four synanthropic bird species were nesting on green facades: Eurasian collared dove (*Streptopelia decaocto*), blackbird (*Turdus merula*), house sparrow (*Passer domesticus*) and woodpigeon (*Columba palumbus*). For the beech marten (*Martes foina*), the green facades are a hunting ground for birds and their eggs. This simple and effective method of creating green walls provides benefits to local wildlife by creating habitats, shelter, and foraging opportunities for selected species. However, it is difficult to determine whether green facades contribute to the formation of ecological corridors in urban environments. The study also examined the social aspect related to the establishment and maintenance of green facades on the surveyed buildings.

Keywords: biodiversity, green facades, green infrastructure, green walls, synanthropic species

INTRODUCTION

Green walls, specifically green facades (GFs later in the text), alongside green roofs, parks, and vertical gardens, are among the ways of reintroducing greenery into cities, representing a cost-effective and technologically undemanding type of "green infrastructure" (Manso and Castro-Gomes, 2015; Liberalesso *et al.*, 2020; Teotónio, Silva and Cruz, 2021). The development of green infrastructure (GI later in the text) is supported in many countries of EU, China, USA, UK, and Singapore on legal and economic levels. The leading arguments promoting the implementation of GI, (and so GFs) include climate improvement in cities, precipitation interception, noise reduction, air pollution mitigation, protection from overheating, and enhancing the well-being of residents (Communication, 2013; Garmendia *et al.*, 2016; Matusik, 2017; Tiwary, Godsmark and Smethurst, 2018; Assimakopoulos *et al.*, 2020; Fernández and Peek, 2020; Hewitt, Ashworth and MacKenzie, 2020; Tomson *et al.*, 2021; Vera, Viecco and Jorquera, 2021; Roshan, Moghbel and Farrokhzad, 2022; Susca *et al.*, 2022). Less attention has been given to the impact of GFs on biodiversity in cities, although it remains a topic of debate internationally (Opoku, 2019; Wang *et al.*, 2020). It has been recognised that the appealing concept of "green planning" conceals many unknowns and potential threats, necessitating research on the impact of GI and GFs on urban biodiversity (Garmendia *et al.*, 2016; Mayrand and Clergeau, 2018). However, the number of publications concerning the impact of GFs on biodiversity is still limited, with the topic being addressed to a limited extent or yielding inconclusive findings (Francis and Lorimer, 2011; Collins, Schaafsma and Hudson, 2017; Mayrand and Clergeau, 2018; Ascione *et al.*, 2020). Previous analyses suggest a minimal chance of creating ecological corridors within cities based on green walls and roofs. On the other hand, buildings with implemented GI improve conditions for synanthropic species and provide space for additional species (Köhler, 2008; Chiquet, Dover and Mitchell, 2013; Madre *et al.*, 2015; Chen *et al.*, 2020; Wang *et al.*, 2020; Wooster *et al.*, 2022). It should be emphasised that one of the very important factors qualifying investments in architecture and urban planning is mitigating the effects of climate change and the impact on local biodiversity. Implementing GI and GF meets these challenges. However, there is no scientific consensus regarding the direct impact of GFs on biodiversity. So far, research on the biodiversity of various groups of organisms in relation to GFs and the influence of the age of GFs in relation to synanthropic bird species is fragmentary or concerns metropolises of highly developed countries located in the intertropical climate zone. In this respect, this work complements the knowledge regarding cities from less developed countries located in the temperate climate zone (Chiquet, Dover and Mitchell, 2013; Newman, 2014; Filazzola, Shrestha and MacIvor, 2019; Chen *et al.*, 2020). The aim of this study was to examine to what extent and for which species the implementation of GFs is beneficial, as well as to determine the relationship between the age of GFs and the local increase in species biodiversity for mammals, birds, and arthropods. The study also included information on climbing plant species, their growth history on the surveyed structures, and the attitude of property owners towards GFs. Property owners' attitudes towards GFs, along with legal solutions, are a key determining factor in their implementation.

MATERIALS AND METHODS

RESEARCH HYPOTHESIS

The main aim of the work is to answer whether walls with green facades (GFs) in the city of Opole differ significantly in terms of the richness of species of arthropods, birds and mammals inhabiting them compared to walls without installed green infrastructure. The null hypothesis is understood as the lack of statistically significant differences. The alternative hypothesis indicates statistically significant differences in the occurrence of arthropods, birds or mammals. For each of these three groups of organisms, research and testing were carried out separately.

The second research hypothesis is understood as the existence of a positive correlation between the age of creeping plants on the building walls and the number of nests of synanthropic bird species. The null hypothesis indicates the lack of a positive correlation between the age of the creeping plants and the number of observed nests, while the alternative hypothesis indicates the existence of a strong relationship between the age of the creeping plants and the number of bird nests located on the walls covered with the plants.

STATISTICAL ANALYSIS

The relationship between the age of climbing plants and the number of observed bird nests was calculated using Spearman's correlation coefficient after conducting the Kolmogorov–Smirnov test to check for the normal distribution of the data. For independent data (number of arthropods on GFs and objects without greenery), conditions for the *t*-Student test were assessed by performing Levene's test for homogeneity of variances. The statistical significance of differences was set at $p = 0.05$. In case the assumptions for the t-Student test were not met, the non-parametric Mann–Whitney U test was conducted. The effect size was calculated based on Cohen's *d*, which is a measure of the standardised difference between two group means. Cohen's *d* was computed as the ratio of the difference between the means of the two groups to the pooled standard deviation. For independent data (number of bird nests on the four types of infrastructure), the significance of differences was assessed using the Kruskal–Wallis test, followed by post-hoc Tukey's test.

SELECTION OF OBJECTS AND STUDY LOCATIONS

Field research was conducted in the city centre of Opole, located in southwestern Poland (Fig. 1). Opole is a provincial city with a population of approximately 130,000 residents. The city centre is predominantly characterised by multi-story residential buildings ranging from 2 to 10 floors in height. The study area covered a surface area of 4 km^2. Within this area, the study focused on 15 buildings with established direct GFs and 5 walls, fences, and enclosures adorned with climbing plants (Tab. 1). Direct GFs refer to walls of buildings covered with climbing plants rooted directly in the ground, without any irrigation systems installed.

As controls, walls of the same or nearby buildings within a radius of 100 m from the surveyed objects were used, which did not have GFs nor vertical gardens and had a comparable

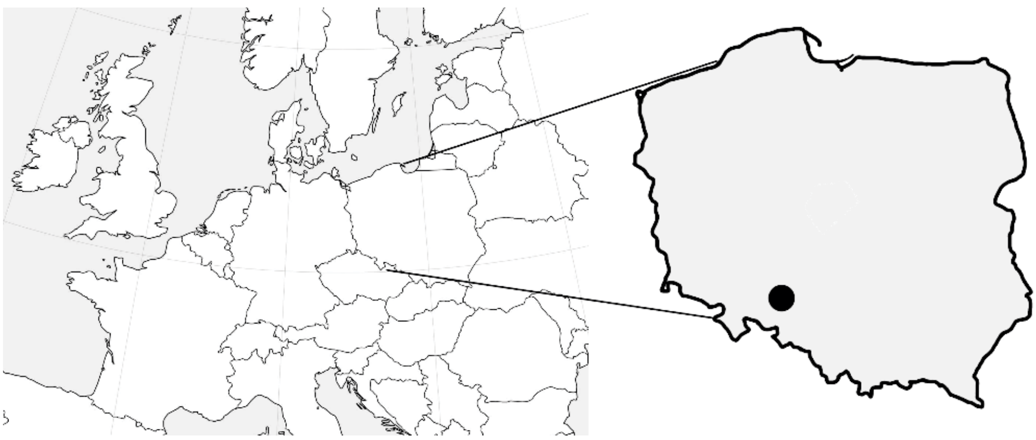

Fig. 1. Location of the city of Opole, where field research was carried out; source: own elaboration based on FreeWorldMaps. net (no date)

Table 1. Characteristics of studied buildings with direct green facades (GFs)

GFs object no.	Building type	Height of the wall (m)	Creeping plant species	Height of the plants (m)	Known/ estimated age of plants (y)	Faced towards
1	educational	15	*Parthenocissus tricuspidata*	6	21	west, south, east
2	educational	15	*Parthenocissus tricuspidata*	12	20	west, south
3	educational	15	*Parthenocissus tricuspidata*	10	>75	west, south
4	educational	15	*Parthenocissus tricuspidata*	15	>75	west, south
5	administrative	15	*Hedera helix*	15	40	west, south, east
6	administrative	15	*Parthenocissus tricuspidata*	5	15	south
7	cultural	10	*Parthenocissus tricuspidata*	10	>25	north, west
8	cultural	30	*Hedera helix*	12	13	west, south, east
9	private	8	*Parthenocissus tricuspidata*, *Hedera helix*, *Vitis vinifera* L.	8	>50	south
10	private	10	*Parthenocissus tricuspidata*	10	25	south
11	private	15	*Parthenocissus quinquefolia*	10	10	west
12	private	10	*Parthenocissus tricuspidata*	10	>30	west, south
13	private	8	*Parthenocissus tricuspidata*	8	15	south
14	private	12	*Parthenocissus tricuspidata*	12	27	south
15	private	15	*Parthenocissus quinquefolia*	8	>15	south
16	wall/fence	8	*Parthenocissus tricuspidata*	8	>25	south
17	wall/fence	3	*Hedera helix*	3	>10	west
18	wall/fence	3	*Aristolochia macrophylla* Lam. *Parthenocissus tricuspidata*	3	9	west
19	wall/fence	3	*Parthenocissus quinquefolia*	3	>10	south
20	wall/fence	2	*Fallopia aubertii*	2	7	east

Source: own study.

proportion of green areas within a radius of 50 m (if possible). Bare walls refer to walls without windows, ledges, balconies, or other installations, but with gaps under eaves and/or cavities in the insulation layer or specially suspended nesting boxes. In order to compare the abundance of flying arthropods and those inhabiting bushes and trees, as well as to compare ornithofauna, the research also covered patches of urban greenery with trees and shrubs at a distance of no less than 100 m from the GFs walls.

SOCIAL ATTITUDE TOWARDS GREEN FACADES

The attitude of property owners/managers towards GFs was examined using survey questions sent by e-mail, delivered in person (n = 10) or during interviews (n = 10). Eight questions concerned, respectively: the known date of planting the vines, whether the planting was intentional, what was the reason for planting and the selection of species, what are the positive effects of planting on the residents/employees of the facility, what are the negative effects of planting on the residents/employees of the facility, whether the vines are cared for and what are the annual costs, what are the plans for further growth of these vines, and finally would you decide to use vines on the property again in the future.

Gender, age, religion and other social variables of the respondents did not matter.

SURVEY OF ARTHROPODS

Insect counts were conducted at the height of 1.5–2 m above ground level on two types of infrastructure: those having implemented GFs and those without it. Sticky traps (yellow adhesive boards) were set up on 20 May and replaced regularly every three days until 1 June giving an overall four sessions for each surveyed object. After each session, the captured arthropods on the adhesive board on both sides were counted, and the board was then replaced. For each object, the total number of captured arthropods was recorded and compared with a nearby object without green facades. The diversity of arthropods was assessed at the family level. The period of arthropod research was dictated by the weather window and, above all, the lack of flowering period for most vines, which would significantly distort the research results.

OBSERVATIONS OF BIRDS AND MAMMALS

Birds were observed during the morning hours (from sunrise to one hour after sunrise), midday hours (from noon to one hour after noon), and evening hours (from sunset to one hour after sunset) in the winter and spring seasons in 2023 under conditions without precipitation and strong winds. In total, 150 h were spent in sessions of 15 min each observing buildings with GFs, buildings without greenery, and nearby urban greenery. Binoculars and a photographic set with a focal length of 400 mm were used for observations. The observer dressed in neutral colours or remained seated in a parked vehicle and took his position 10 min prior to the start of observations to avoid disturbing the animals. Nests present on the green facades from the previous and current seasons were counted.

RESULTS AND DISCUSSION

RESEARCH OBJECTS AND SOCIAL ATTITUDE TOWARDS GREEN FACADES

The study analysed a total of 20 objects ranging in height from 2 to 30 m. These included fences (walls, hedges) and buildings (schools, universities, private houses, cultural institutions). Each object was covered with climbing plants, with a minimum width of 3 m and a minimum height of 2 m. Selected objects included in the observations are shown in Photo 1. Among the analysed buildings, 65% were covered with Boston ivy (*Parthenocissus tricuspidata*), 30% with common ivy (*Hedera helix*), 15% with five-leaved ivy (*Parthenocissus quinquefolia*), and 5% each with Dutchman's pipe (*Aristolochia macrophylla Lam.*), Aubert's dodder (*Fallopia aubertii*), and grapevine (*Vitis vinifera* L.). Three objects were covered by two species simultaneously, while one object was covered by three species simultaneously. In 90% of cases, the planting of climbing plants was intentional. All respondents appreciated the role of green facades as an alternative to traditional green infrastructure. No one reported any issues of moisture on walls covered with climbing plants. The only technical issue associated with their presence was the need for regular pruning, especially around eaves and gutters. For perennial climbing plants with woody and thick branches, the use of anchors to secure the plants to the walls was necessary to prevent them from breaking under their own weight or in strong winds. Fifteen percent of respondents emphasised the need for mesh screens on windows during the flowering period of climbing plants due to the increased presence of pollinators.

The main reason for the existence of GFs in the study area was their intentional planting, in some cases several decades ago. The decision to implement direct GFs in all analysable cases was driven by an awareness of their positive role in the urban environment, both for the surroundings and the buildings themselves. During direct conversations, building owners or managers expressed also a lack of understanding of direct GFs among some habitants or infrastructure users. According to Collins, Schaafsma and Hudson (2017), public awareness regarding the impact of GI and GFs on quality of life and biodiversity in the city ranges from 54% to 75%. Therefore, there is significant potential in the urban environment and society for raising awareness and implementing GI, which the author considers a win-win initiative.

The maintenance costs of direct GFs were subjectively assessed as low or almost negligible compared to the maintenance of other types of green infrastructure. The most preferred species for direct GF was the Boston ivy (*Parthenocissus tricuspidata*) due to its dense and aesthetic appearance, fast growth rate and coverage, and richness of colours in the autumn season. It is worth noting that no one complained about moisture accumulation on the walls covered with climbers.

In the author's assessment, there is potential in public utility buildings such as schools, which have large surface areas and provide an opportunity for students to interact with greenery (McCullough, Martin and Sajady, 2018). These buildings can serve as platforms to promote sustainable development and the implementation of greenery, which brings social, climatic, and ecological benefits.

ARTHROPOD DIVERSITY

The presence of arthropods was determined using adhesive boards and categorised at the family level. To compare the diversity of their occurrence, photographs of the boards were taken, and then the captured insects and spiders were counted. Examples of results from 72-hour sessions using adhesive boards are shown in Photo 2. The arthropod diversity data were compared between two types of objects: those with GFs and objects without GFs within a 50 to 100 m distance. The data were analysed in two ways: as the average of the total number of captured arthropods in all 4 sessions per object and similarly as the average of the number of represented families (Tab. 2).

The sticky traps used in the study proved effective for capturing families and superfamilies of insects, such as Aphididae (aphids), Culicidae (mosquitoes), Cercopidae (spittlebugs), Muscidae (flies), Syrphidae (hoverflies), Tenthredinidae (sawflies), Apidae (bees), Cerambycidae (longhorn beetles), Aphrophoridae (spittlebugs), Coccinellidae (ladybirds), Cantharidae (soldier beetles), Libellulidae (dragonflies), Formicidae (ants), and Vespidae (wasps), as well as spiders from the families Agelenidae

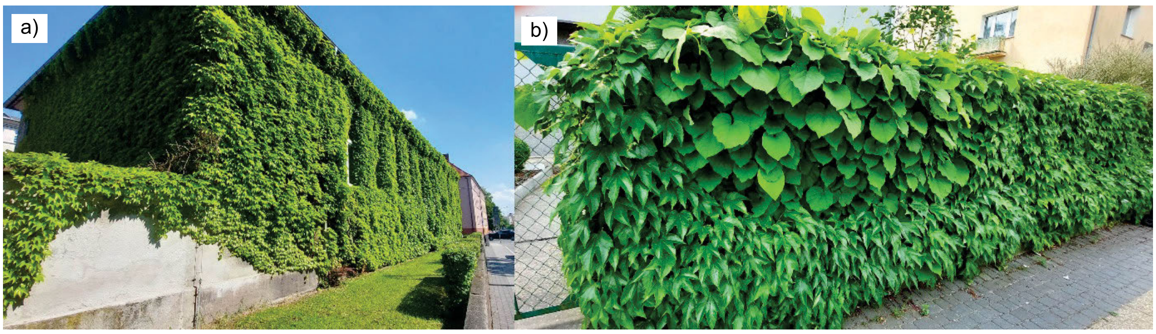

Photo 1. Examples of buildings covered with vines in the central part of Opole: a) the gymnasium of Tadeusz Kościuszko Electrical School Complex covered with Boston ivy (*Parthenocissus tricuspidata*), b) a section of the fence covered with Boston ivy (*Parthenocissus tricuspidata*) and Dutchman's pipe (*Aristolochia macrophylla*) (phot.: *G. Oloś*)

Photo 2. Examples of captured arthropods on the boards hung for a period of 72 hours (phot.: *G. Oloś*)

Table 2. Data on arthropods survey on objects without green facades (GFs) and with GFs

Object no.	Mean number of represented families	*SD*	Min	Max	Mean number of collected arthropods	*SD*	Min	Max
Control (without GFs)								
1	3.75	0.50	3	4	496.0	99.70	380	623
2	3.25	0.50	3	4	134.0	32.60	99	178
3	5.75	0.96	5	7	591.0	122.00	431	720
4	2.75	0.96	4	2	33.7	7.32	28	44
5	3.50	1.00	3	5	172.0	8.45	161	180
6	2.00	0.82	1	3	18.7	2.50	16	22
7	3.25	0.50	3	4	93.2	39.30	63	151
8	3.75	0.50	3	4	165.0	46.80	119	230
9	3.75	0.96	3	4	94.5	21.70	72	124
10	4.75	1.50	3	5	223.0	26.80	194	257
11	1.25	0.50	3	6	16.5	2.08	14	19
12	2.25	0.50	1	2	25.0	7.53	17	34
13	2.75	0.96	2	3	41.2	23.20	9	61
14	4.50	1.29	2	4	172.0	64.40	86	232
15	4.25	0.50	3	6	116.0	34.90	88	167
16	2.75	0.50	4	5	28.7	3.30	29	33
17	5.75	1.71	2	4	321.0	92.00	206	430
18	5.00	0.82	3	8	167.0	62.10	77	219
19	3.50	1.00	3	5	82.7	13.10	65	95
20	3.50	0.58	3	4	53.7	10.40	40	65
With GFs								
1	3.50	1.00	3	5	21.5	4.20	16	26
2	2.75	0.50	2	3	18.7	5.38	12	24
3	5.75	0.96	5	7	90.5	15.80	73	108
4	5.50	0.58	5	6	92.7	16.80	68	105
5	4.50	0.58	4	5	57.0	11.70	47	74
6	8.00	2.16	6	11	159.0	38.80	123	201
7	3.00	1.41	2	5	33.5	4.80	29	40
8	3.75	0.50	3	4	51.7	16.00	33	72
9	7.50	3.00	6	12	50.2	10.90	34	57

cont. Tab. 2

Object no.	Mean number of represented families	*SD*	Min	Max	Mean number of collected arthropods	*SD*	Min	Max
10	5.50	2.08	3	8	116.0	17.50	97	136
11	4.50	1.00	3	4	42.0	24.01	18	66
12	2.25	0.96	1	3	20.2	8.50	12	32
13	5.75	2.22	5	9	77.0	15.80	9	61
14	3.00	1.15	2	4	14.7	3.10	86	232
15	3.25	1.26	2	5	20.7	5.50	13	26
16	5.75	2.06	4	8	134.7	57.80	76	201
17	4.50	1.29	3	6	72.5	17.30	53	94
18	4.75	1.71	3	7	66.0	11.50	51	76
19	4.25	0.96	3	5	26.2	12.50	15	44
20	4.25	1.71	2	6	31.7	13.20	19	50

Explanations: *SD* = standard deviation.
Source: own study.

(funnel-web spiders), Lycosidae (wolf spiders), and Gnaphosidae (ground spiders).

The median total number of captured insects on walls without GFs was 94.5, while for walls with GFs, it was 53. The test for homogeneity of variances yielded a negative result: coeficient for homogenity comparison (f-ratio) = 39.91 and $p < 0.001$. Therefore, to assess the significance of differences in the overall number of insects, the Mann–Whitney U test was used. The alternative hypothesis was accepted as the p-value was smaller than the predetermined level of significance. The results of the U Mann–Whitney test revealed a statistically significant difference between the examined groups (U_1 = 5173.5, U_2 = 1933.5, $p < 0.001$). The Cohen's d value for comparing the overall number of captured insects between these two data sets is 0.8474. This indicates that the difference between the means of the sets is about 0.85 standard deviations, suggesting a moderately large difference between these groups, with a higher number of captured insects observed in the walls without GFs.

The median values of represented insect families were 4 for walls with GFs and 3 for control walls. The test for homogeneity of variances yielded a negative result: f-ratio = 5.45, p = 0.02. Therefore, to assess the significance of differences in the number of represented insect families, the Mann–Whitney U test was used. The alternative hypothesis was accepted as the p-value was smaller than the predetermined level of significance. The results of the U Mann–Whitney test revealed a statistically significant difference between the examined groups (U_1 = 2225.5, U_2 = 4174.5, $p < 0.001$). The Cohen's d value for comparing the number of represented insect families between walls with GFs and control walls is –0.5889. This indicates a moderately large difference between the groups, where walls with GFs tend to have a higher number of insect families than control walls.

The results indicating the higher abundance of invertebrates, with aphids playing a leading role, outside the GF-covered walls were surprising. On a single sticky plate in one session, there were over several hundred adult winged aphids observed. It is possible that the lack of nearby vegetation made the yellow sticky plates more attractive compared to when they were placed within green plants. However, the diversity of invertebrates was found to be greater on buildings with GF. No spiders were captured on structures without GF. These observations align with the findings of Madre *et al.* (2015). The higher abundance of insects outside the GF structures may be attributed to the relatively easy movement of flying insects in the urban environment, while spiders have limited migration capabilities and are more closely associated with specific patches of habitat. In a 2019 review (Filazzola, Shrestha and MacIvor, 2019) on the impact of various GIs on biodiversity in urban space, only two studies included the impact of green walls (without distinguishing whether they were vertical gardens or GFs) on invertebrate biodiversity, and the results of comparisons of green walls with walls without greenery were inconclusive. In this aspect, this work fills the knowledge gap.

OBSERVATIONS OF BIRDS AND MAMMALS

A total of 13 bird species were observed within the green facades (GFs), including four nesting species. For non-nesting birds, the GFs served as foraging areas. In the case of swifts, which do not perch except in their nesting sites, their presence was determined based on regular flyovers near the GFs. Examples of observed nests belonging to blackbirds (*Turdus merula*), Eurasian collared doves (*Streptopelia decaocto*), and common woodpigeons (*Columba palumbus*) are shown in Photo 3. The nesting behaviour of house sparrows (*Passer domesticus*) was determined based on the continuous presence of a male and female entering the same location, where plant material accumulated over the years by other birds, creating a nesting chamber. In a 2019 review (Filazzola, Shrestha and MacIvor, 2019) on the impact of various green infrastructures (GIs) on biodiversity in urban space, only one study reported the number of bird nests in relation to green walls. In addition to the work of Chiquet, Dover and Mitchell (2013), there are no others in this field, while the work of Chen *et al.* (2020) indicates the positive role of selected creeping plant species for migrating birds, but does not provide data on nesting. The identification of four nesting bird species in light of limited scientific data should be considered as a piece of significant information.

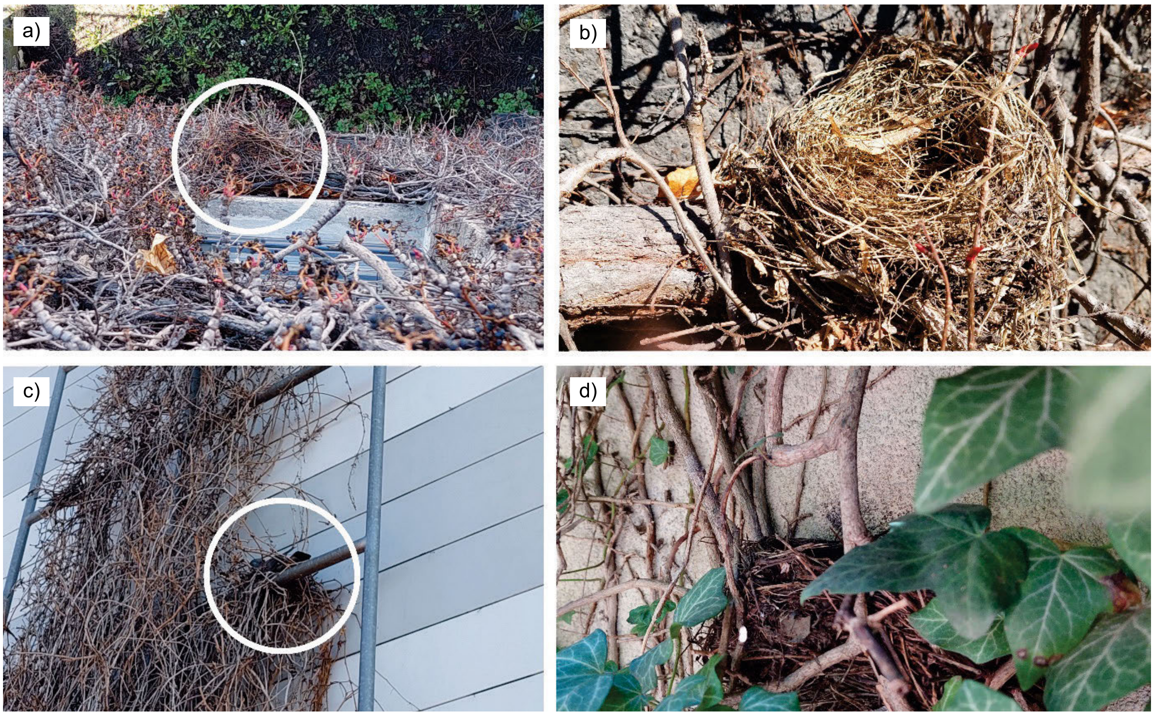

Photo 3. Examples of the nests of: a) Eurasian collared dove on the wall covered with Boston ivy, b) Eurasian blackbird on an old branch of Boston ivy, c) wood pigeon among Virginia creeper, d) Eurasian blackbird among mature English ivy (phot.: *G. Ołoś*)

The highest density and number of nests were observed on the western and southern walls of the Tadeusz Kościuszko Electrical School Complex (Photo 4). Based on interviews with residents and staff members, as well as the trunk thickness and plant range, it was inferred that this Boston ivy was planted before, during, or shortly after World War II. It covers walls with a total length of over 50 m and a height of 5 m. Thanks to its dense network of vines, it serves as a breeding site for successive generations of Eurasian blackbirds. Among all the objects included in the study, only two were covered by such ancient Boston ivy, and it was on these walls that the highest number of synanthropic bird nests were found. In other cases, nests were scarce. The observed bird species on the GFs, as well as on the surrounding walls of other buildings, trees, and shrubs, were compiled in Table 3.

The correlation between the known or estimated age of climbers and the number of bird nests was calculated using the Spearman test after checking for non-normal distribution of the data. Obtaining a result of $r_s = 0.80683$, with p (2-tailed) < 0.001, indicates a very strong and statistically significant correlation between the age of climbers and the number of nests. Nests were only present on climbers older than 10 years, and the highest number of nests was observed on the oldest climbers in the city. The study examined the nesting patterns of birds across four types of infrastructure and employed statistical analyses, including the Kruskal–Wallis test and post hoc Tukey's test. The results revealed significant differences in the number of observed nests among the infrastructure types (Kruskal–Wallis test, $p < 0.001$). Post hoc Tukey's test indicated that the highest number of nests was observed on GFs, followed by walls with crevices, balconies,

Photo 4. Location of 19 nests (mainly belonging to blackbirds) present on half of the western wall of the gymnasium hall of the Tadeusz Kościuszko Electrical School Complex in Opole, covered by over 70-year-old Boston ivy (phot.: *G. Ołoś*)

Table 3. List of species recorded on areas with green facades (GFs; n = 20) and other infrastructure (n = 60) in the centre of Opole

Species	Trees and bushes		GFs		Bare walls		Walls with crevices, balconies, and parapets	
	O	*N*	*O*	*N*	*O*	*N*	*O*	*N*
Turdus merula	+	3	+	43	+	0	+	1
Streptopelia decaocto	+	2	+	2	+	0	+	2
Passer domesticus	+	0	+	1	+	4	+	4
Columba palumbus	+	1	+	1	–	0	+	0
Corvus monedula	+	0	+	0	+	2	+	1
Pica pica	+	1	+	0	+	0	+	0
Sturnus vulgaris	+	1	+	0	+	1	+	1
Columba livia f. urbana	+	0	–	0	+	1	+	3
Apus apus	+	0	+	0	+	3	+	3
Parus major	+	1	+	0	+	0	+	0
Erithacus rubecula	+	0	+	0	–	0	+	0
Asio otus	+	0	+	0	–	0	+	0
Phoenicurus phoenicurus	+	0	+	0	–	0	+	0

Explanations: *O* = observation of the species on a particular type of infrastructure, *N* = nesting (number of nests observed on the studied infrastructure).
Source: own study.

and parapets ($p < 0.05$). These findings suggest that GFs provide favourable nesting conditions for birds, highlighting their potential role in supporting urban biodiversity and emphasising the importance of incorporating such green infrastructure in urban planning and design.

During the observations, the occasional presence of the European hedgehog (*Erinaceus europaeus*), the brown rat (*Rattus norvegicus*), and the beech marten (*Martes foina*) was recorded in the immediate vicinity of GFs. Only the beech marten was observed on the branches of climbers, clearly foraging for food. All the observed individuals were also seen near control structures, which are walls of buildings without GFs, as well as within local tree stands, shrubs, and lawns.

Among the observed climbing plants, *Parthenocissus tricuspidata* formed the most dense and spatially vertical thickets. Consequently, it was the most preferred by selected bird species for nesting. According to Perini and Rosasco (2013), significant benefits from implementing GF are typically observed after an average of 20 years. In some surveyed locations in Opole, the GF structures were significantly older, and their impact on the richness of synanthropic bird species in terms of nesting aligns with the cited observations. Increasing biodiversity and creating habitats for singing birds are valuable in themselves. Additionally, this improves the well-being of urban residents, making society happier (Cameron *et al*., 2020). Apart from the house sparrow and blackbird, nesting of two pigeon species was observed: Eurasian collared dove and common wood pigeon, which are two more species than reported in the study by Chiquet, Dover and Mitchell (2013). The nesting of common wood pigeon on a green facade, according to the author's knowledge, has not been previously documented, as these birds prefer to nest in trees, with less than 10% of the population choosing urban infrastructure for this purpose (Ó hUallacháin, 2014; Fey *et al*., 2015). Furthermore, it was shown that nesting was not limited solely to the upper parts of the climbing plants on the wall, as the lowest nest of a blackbird was located at a height of 1 m above ground level. The presence of redstarts and great tits foraging for small invertebrates among the climbing plants indirectly indicates the local diversity and abundance of insects and spiders. Moreover, the fruits of Boston ivy serve as a food source for all local thrush species in winter. Therefore, even a single-species GF, when it reaches an appropriate size (in other words when it reaches 10 or more years), creates a habitat for a diverse group of synanthropic bird species.

The individual observations of mammals do not allow for conclusions regarding the "stepping stones" concept for mammal or other organism migrations (Chen *et al*., 2020). However, GFs certainly create patches of habitats that are utilised by various vertebrate and invertebrate species, providing urban areas with the opportunity for local biodiversity growth.

GFs are considered the highest-ranking among different types of green wall systems in terms of benefits and drawbacks, although they are surpassed by hydroponic or cassette systems in terms of biodiversity (Perini and Rosasco, 2013; Madre *et al*., 2015). The findings of this study seem to confirm this, both in terms of invertebrate and bird species present on the surveyed GF structures versus the bare walls. The subjective low costs incurred by owners/managers in maintaining the climbing plants in good condition is also an important factor. GF provides a cost-effective and efficient way to implement green infrastructure in urbanised areas, where space for more traditional greenery is often very limited. This brings many benefits, including enhancing local biodiversity at the level of insects, spiders, birds and (probably) mammals.

CONCLUSIONS

1) Nests of four bird species were found on walls covered with green facades.
2) Walls with green facades where plants have reached over 10 years of age show the highest number of synanthropic bird nests compared to other types of green and non-green infrastructure.
3) Walls with green facades exhibit a lower abundance of insects but a higher number of represented arthropod families.
4) Green facades support the biodiversity of birds and arthropods in urban spaces.
5) The impact of green facades on mammal biodiversity in urban space requires further research.

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