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Review

# Assessing Ecological Gains: A Review of How Arthropods, Bats and Birds Benefit from Green Roofs and Walls

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**Abstract:** Because of the immense amount of infrastructure in cities, the introduction of vegetation into these constructions is expected to play a critical role in reducing the heat island effect, in mitigating the effects of climate change, and in supporting habitat connectivity and associated biodiversity. Although there is the perception that these solutions can improve the biodiversity of cities, their real value is still unclear. This paper focuses on two aspects of urban greening: green roofs and green walls. It provides a systematic review on biodiversity present in green roofs and walls, through an exhaustive worldwide literature analysis. Arthropods, bats, and birds were the three taxonomic groups analyzed in the papers included in our review. We observed a strong increase in the number of recent publications, thus demonstrating a growing interest in this topic. In summary, we found that green roofs/walls offered additional opportunities for plants and animals to thrive in urban environments because of habitat creation and greater spatial connectivity. In addition, the enhancement of other ecosystem services such as stormwater management and heat island mitigation was noted. By incorporating green features into urban design and planning, cities can support biodiversity while also improving the overall sustainability and livability of urban spaces.

**Keywords:** green infrastructures; nature-based solutions; biodiversity; arthropods; bats; birds

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**Citation:** Tiago, P.; Leal, A.I.; Silva, C.M. Assessing Ecological Gains: A Review of How Arthropods, Bats and Birds Benefit from Green Roofs and Walls. *Environments* **2024**, *11*, 76. https://doi.org/10.3390/environments11040076

Academic Editor: Yiannis G. Matsinos

Received: 31 January 2024
Revised: 19 March 2024
Accepted: 5 April 2024
Published: 10 April 2024



## 1. Introduction

Even though the survival of the human species is dependent on biodiversity [1], more than 60% of global ecosystem services are degraded or unsustainably managed [2], and biodiversity is declining worldwide [3]. Biodiversity is dependent upon healthy and intact aquatic and terrestrial ecosystems; the accelerated loss of healthy ecosystems and their associated biodiversity is impacting human well-being [4]. Thus, addressing biodiversity conservation is vital [5], but while global biodiversity loss has accelerated in recent decades, people have become increasingly urban. Urban areas have doubled since 1992 and, in comparison with 2020, are projected to expand between 30% and 180% until 2100 [6]. The accelerated rate of urbanization is one driver of these biodiversity losses; however, urban areas offer opportunities to mitigate these losses and to support the well-being of their occupants.

One of the best options to address urban challenges is to promote nature-based solutions that provide environmental, social, and economic benefits [7,8]; however, urban centers show space constraints. Therefore, green roofs and green walls can be alternatives to promote green areas despite space limitations and were defined within the EU biodiversity strategy 2030 as urban approaches to address climate change and help to reverse urban problems [9].

Green roofs and walls, also named "eco-roofs/walls", "living roofs/walls", or "roof/walls gardens", are solutions with vegetation in their top layer [10]. Depending on the type of building and type of green roof, they can be installed in underused infrastructure [11,12]. The building capacity, roof accessibility, roof drainage, type of green roof, and associated extra weight are some of the main concerns to be taken into account. When installed, these new structures help to green gray construction projects and improve connections to other urban green spaces. Today, these solutions can provide several environmental, economic, and social benefits, such as decreasing energy consumption and the urban heat island effect, as well as contributing to a reduction in stormwater losses and a reduction in habitat depletion (see [13] or [14] for a general review).

Although many cities have already invested in these nature-based solutions [15], decision-makers have been demanding quantification of the expected benefits and the corresponding balance with the expected costs. Some methodologies have been developed, namely cost–benefit and multicriteria analysis, but environmental benefits such as biodiversity are still often neglected when valuing these solutions, due to difficulties in their quantification [16].

Since urbanization is contributing to a decline in global wildlife populations [17], it is essential to increase and improve urban wildlife habitats, namely by introducing vegetation in buildings, and to know how to value this improvement. Although some authors have discussed the importance of green roofs and walls for biodiversity (e.g., [18,19]), there are some aspects that still need to be clarified and quantified.

Although previous review papers have analyzed the evolution in the number of studies examining the potential of these infrastructures to benefit biodiversity [20–22], the present work provides a systematic and updated review on qualitative and quantitative research evidence on the worldwide use of green roofs and green walls by three taxonomic groups: arthropods, bats, and birds. These taxonomic groups were chosen due to their ability to freely inhabit green roofs and walls, their relative conspicuousness, and their provision of important services in urban areas, such as pollination and pest control [23]. So, our main objective was (i) to present a refreshed summary of what is already known about the use and importance of green roofs and walls for arthropods, bats, and birds. To achieve this, we performed a systematic search of the existing scientific literature using specific keywords. Moreover, we sought to (ii) identify the direct and indirect benefits presented in various studies and (iii) provide a detailed discussion of the main scientific questions, methods, and contributions of green roofs and walls to the three studied taxonomic groups identified in the papers included in our review. Cities can be a key player in global efforts to conserve and restore biodiversity, and enhancing the quality and permeability of urban infrastructures is crucial to support the presence and movement of organisms.

## 2. Methods

This paper used available electronic journal databases to identify papers concerning the biodiversity benefits of green roofs (GRs) and green walls (GWs).

### 2.1. Literature Search

The All Databases function of Clarivate Analytics Web of Science™ was used, in January 2024, to systematically search for relevant peer-reviewed articles. A general search was carried out in the Science Citation Index Expanded (SCI-Expanded) using the following combination of terms: [("green roof*" OR "green wall*") AND biodiversity]. This retrieved a total of 423 articles, which were examined to identify those that focused on the study of animal species and their use of green roofs or green walls. Moreover, we performed a more specific search for articles with a focus on our target groups: [("green roof*" OR "green wall*" OR "living roof*" OR "living wall*")] AND [("bird*" OR "arthropod*" OR "insect*" OR "bats")], which retrieved a total of 95 documents.

*2.2. Data Extraction and Analysis*

For all the articles, the metadata associated with each publication were downloaded and organized into a single document. Specifically, we extracted data from the following Web of Science fields: authors (AU), article title (TI), source title (SO), author keywords (DE), abstract (AB), author address (C1), and publication year (PY). However, as not all references contained a complete metadata record, when necessary, the article was consulted. The total database of articles (518) was reviewed in order to eliminate all repetitions and articles that did not focus on our target groups.

We used publication year to analyze the temporal tendencies of scientific production on GRs/GWs and our focus groups by calculating the total number of publications per year. Information related to country was collected for all publications. A flowchart of this process is presented in Figure 1.

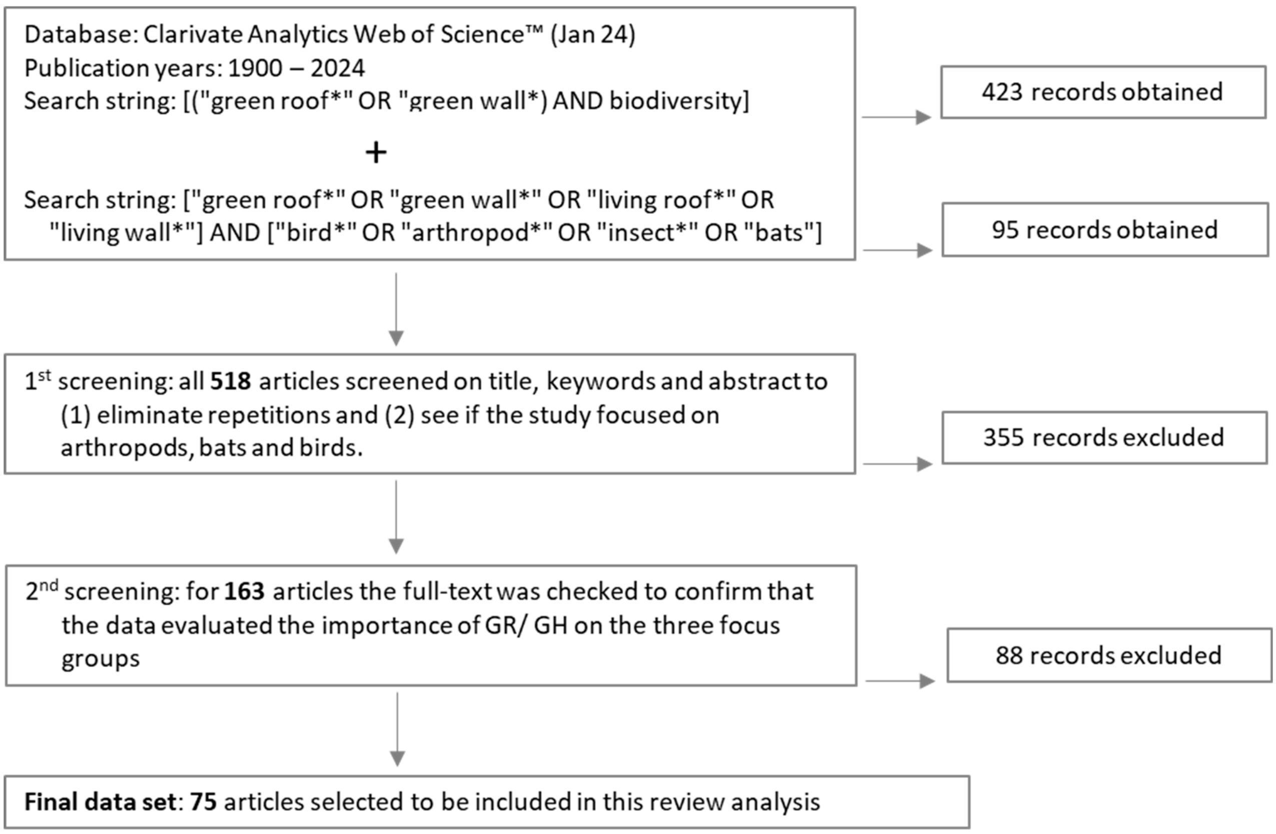


**Figure 1.** Systematic overview of publication selection process and data extraction. The final dataset consisted of 75 scientific articles that were used in our review analysis.

## 3. Results

*3.1. General Overview of Arthropods, Bats, and Birds in Green Roofs and Walls*

We retrieved a total of 75 publications, from 2006 to January 2024, focusing on GRs/GWs and arthropods, bats, and birds. Only two publications were identified up to 2010, but since then, there has been a growing increase in this topic, reaching a maximum of 13 publications per year in 2022.

The analyses of the retrieved articles revealed that most of the studies that focused on biodiversity actually assessed plant species richness and diversity. However, as already mentioned, we were interested in analyzing the biodiversity that freely occupies these infrastructures, so we focused on the subset of 75 studies that examined the presence of arthropods and birds, of which 68 were case studies and 7 were review papers (Table S1).

Out of these 68 case studies, 55 conducted comparisons between different areas. Among these, 24 compared different types of green coverings and green walls, while

31 compared the results obtained from green coverings to other types of coverings (e.g., gray coverings or urban gardens).

Of the seven review papers, two covered all three taxonomic groups, one covered arthropods and birds, one covered only birds, and three covered only arthropods. All these articles analyzed green coverings, and two also analyzed green walls (Figure 2). Table 1 presents a more detailed summary of the 68 papers that present case studies.

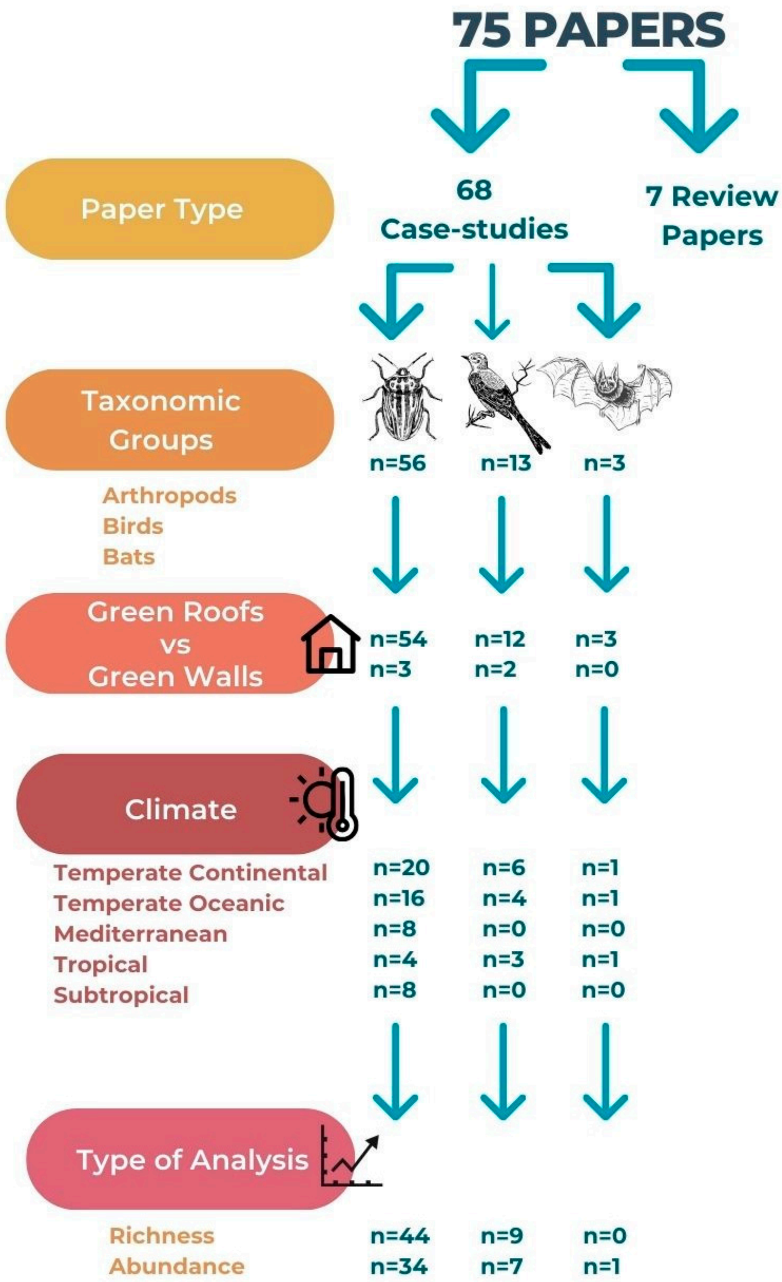


**Figure 2.** Summary of the results for the 75 retrieved papers on GRs/GWs covering the study of arthropods, bats, and birds in different climates and with different data analysis methods.

Out of the case studies, 56 papers dealt with arthropods (with 54 focusing on green roofs and 3 on green walls). In terms of climate, 20 studies were conducted in regions with a continental temperate climate, 16 in an oceanic temperate climate, 8 in a subtropical climate and Mediterranean climate, and 4 in a tropical climate. Furthermore, 44 studies assessed species richness, while 34 focused on arthropod abundance. Looking at specific groups, 18 papers analyzed pollinators and 8 analyzed Collembola and soil arthropods

(Figure 2 and Table 1). Considering birds, 13 of the case studies analyzed this taxonomic group, with 12 focusing on green roofs and 2 examining green walls. In terms of climate, six studies were conducted in regions with a continental temperate climate, four in oceanic temperate climates, and three in tropical climates. Regarding the type of analysis, nine studies assessed species richness, while seven focused on abundance. Additionally, three analyzed articles covered both taxonomic groups, and two examined both green roofs and green walls simultaneously. Only three studies worked with bats, all in green roofs, and one of them focused on abundance. Considering the climate, one was conducted in a continental temperate climate, another in an oceanic temperate climate, and the last one in a tropical climate (Figure 2 and Table 1).

From the total 68 analyzed case studies, only 4 worked with more than one taxa (arthropods and birds (3); arthropods and bats (1)).

**Table 1.** Detailed summary of the main results for the 68 retrieved papers on GRs/GWs divided into taxonomic category, green infrastructure, and climate type.

| **Taxonomic Category** | | **Green Infrastructure** | **Climate Type** | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Temperate Continental** | **Temperate Oceanic** | **Mediterranean** | **Subtropical** | **Tropical** |
| Arthropods | Several groups | Green roof | 7 | 6 | 5 | 5 | 2 |
| | | Green wall | 2 | 0 | 0 | 0 | 0 |
| | | Both | 0 | 0 | 0 | 0 | 1 |
| | Pollinators | Green roof | 7 | 3 | 1 | 1 | 1 |
| | | Green wall | 0 | 0 | 0 | 0 | 0 |
| | | Both | 0 | 0 | 0 | 0 | 0 |
| | Collembola and other soil arthropods | Green roof | 4 | 7 | 1 | 0 | 0 |
| | | Green wall | 0 | 0 | 0 | 0 | 0 |
| | | Both | 0 | 0 | 0 | 0 | 0 |
| | Parasitoid wasps | Green roof | 0 | 0 | 1 | 0 | 0 |
| | | Green wall | 0 | 0 | 0 | 0 | 0 |
| | | Both | 0 | 0 | 0 | 0 | 0 |
| | Vectors of human diseases | Green roof | 0 | 0 | 0 | 2 | 0 |
| | | Green wall | 0 | 0 | 0 | 0 | 0 |
| | | Both | 0 | 0 | 0 | 0 | 0 |
| Birds | Birds | Green roof | 6 | 3 | 0 | 0 | 2 |
| | | Green wall | 0 | 1 | 0 | 0 | 0 |
| | | Both | 0 | 0 | 0 | 0 | 1 |
| Bats | Bats | Green roof | 1 | 1 | 0 | 0 | 1 |
| | | Green wall | 0 | 0 | 0 | 0 | 0 |
| | | Both | 0 | 0 | 0 | 0 | 0 |

### *3.2. Benefits of Green Roofs and Walls for Arthropods, Bats, and Birds*

From the 75 papers included in our analysis, we identified the benefits most mentioned by the authors for the three studied taxonomic groups. Following this, we divided the benefits into direct and indirect categories, which are presented in Table 2. The main direct benefits identified by the authors were habitat creation, species diversity, and connectivity. The indirect benefits were less clear, but some studies mentioned stormwater management, heat island mitigation, and air quality improvement. The few papers that studied the benefits of green walls to biodiversity highlighted the direct benefits of habitat creation and species diversity.

**Table 2.** Summary of the main direct and indirect contributions of green roofs and green walls for arthropods, bats, and birds mentioned in the 75 analyzed papers.

| Benefits of Green Roofs/Walls | | | Contributions |
|---|---|---|---|
| Biodiversity | Direct | Habitat Creation: | • Create new habitats for a variety of plant and animal species.<br>• Provide nesting sites, food sources, and shelter for insects, birds, and small mammals.<br>• Vegetation helps to support a diverse range of organisms, including pollinators and other beneficial insects. |
| | | Species Diversity: | • Increase species diversity in urban environments.<br>• Attract a broader range of wildlife by introducing native plant species. |
| | | Connectivity: | • Can serve as ecological corridors, allowing wildlife to move between fragmented habitats in urban areas.<br>• Facilitate the dispersal of seeds, insects, and small animals. |
| | Indirect | Stormwater Management: | • Can absorb and retain rainwater, reducing the amount of runoff that carries pollutants into waterways.<br>• Help maintain water quality and support aquatic biodiversity in urban areas. |
| | | Heat Island Mitigation: | • Mitigate the urban heat island effect by reducing the temperature of buildings and surrounding areas.<br>• Create more favorable conditions for plant and animal species, particularly those sensitive to heat stress. |
| | | Air Quality Improvement: | • Help improve air quality by trapping and filtering pollutants, such as particulate matter and airborne toxins, benefiting both human and urban ecosystem health. |

## 4. Discussion

This systematic review provides an overview of the published scientific information on green roofs/green walls and the three main taxonomic groups with the ability to disperse and inhabit these new habitats (arthropods, bats, and birds), and a comprehensive understanding of the impact of these green infrastructures on urban biodiversity.

From the bibliographic research, one can identify a significant increase in publications in 2022, which may indicate a growing interest in the importance of these infrastructures for biodiversity. Typically, biodiversity and other intangible benefits such as well-being or health improvement were lacking in the studies, especially when compared to other more technical analysis such as the evaluation of energy performance, water management, or air quality [14].

Most of the retrieved publications were associated with more developed countries, primarily located in the Northern Hemisphere, such as in North America and Europe. In the Southern Hemisphere, Australia and Argentina stood out. This result may indicate the presence of more GRs/GWs in these countries or a higher level of research interest in this area. In fact, several municipalities of developed countries worldwide, mainly in Europe and North America, have defined incentive policies to promote the installation of green roofs and/or green walls, typically classified into six different categories: tax reductions, financing, construction permits, sustainability certification, obligations by law, and agile administrative processes. This option has also contributed to disseminating the use of these constructive solutions [15].

The papers consulted addressed these subjects by raising various scientific questions, employing different methodologies, and arriving at different conclusions regarding the identified benefits of green roofs and walls. These will be summarized and reviewed in the following sections of the Discussion.

### *4.1. What Are the Main Scientific Questions That Have Been Analyzed in the Connection between the Taxonomic Groups Selected and Green Roofs/Walls?*

From the analysis of the studies present in our review, we found that researchers have been examining several key scientific questions regarding the relationship between arthropods, bats, and birds and green roofs/green walls, namely the following:

**How does the presence of GRs/GWs impact local biodiversity?** Many studies aimed to understand the effects of these vegetated structures on the abundance, diversity, and composition of plant and animal species in urban environments. For example, Deng and Jim (2017) studied how the spontaneous colonization of plants and bird visits occurred in a green roof in humid tropical Hong Kong [24], and Eakin et al. (2015) aimed to assess the potential of green roofs as habitats for birds [25]. Most of the authors identified a positive effect of these structures on the three taxonomic groups analyzed.

**What design and management strategies optimize biodiversity outcomes in GRs/GWs?** Researchers have identified the most effective approaches for selecting plant species, creating suitable habitats, and implementing maintenance practices to enhance biodiversity in these structures. Salman and Blaustein (2018) investigated how the choice of planted species influences the abundance and richness of arthropods on green roofs [26], and Kyrö et al. (2020) assessed the significance of various biophysical roof characteristics in shaping arthropod assemblages [27].

**How do green walls and roofs contribute to urban connectivity and ecological corridors?** Studies have investigated the potential of these vegetated elements to serve as steppingstones or linkages for wildlife movement across fragmented urban landscapes. In fact, the presence of ecological corridors has been identified as one of the key determinants of urban biodiversity [28], connecting different habitat patches. For example, Braaker et al. (2017) analyzed how environmental variables, such as connectivity among sites, influenced species richness and functional diversity and found that green-roof arthropod diversity increased with greater connectivity and plant species richness, regardless of the substrate depth, height, and area of the green roofs [29]. Kyrö et al. (2018) enhanced the importance of connectivity between green roofs and ground-level habitats to maximize their potential as habitats for beetles [19].

**What is the role of green walls and roofs in promoting native species conservation?** Researchers have assessed the capacity of these structures to support indigenous plant and animal species, including rare or threatened ones, and the potential for restoring local biodiversity. Tonietto et al. (2011) examined the potential role of urban green roofs in conserving native pollinators in the Chicago region, comparing them to reference habitats [30]. Regarding birds, Belcher et al. (2019) investigated the impact of vegetation on different types of building green spaces on native and introduced bird species of Singapore [31], making important recommendations for the provision of trees to attract birds.

**What are the ecological benefits provided by GRs/GWs?** Besides investigating the habitat provision for wildlife, some studies also focused on the ecosystem services offered by GRs/GWs, such as their contributions to air quality improvement, temperature regulation, and stormwater management, because these ecosystem services are directly related to biodiversity upscaling. This was the case of Partridge and Clark (2018), who found that green roofs had a higher abundance and richness of birds and arthropods than conventional roofs during migration and breeding seasons [32].

By addressing these scientific questions, researchers strive to deepen the understanding of the interactions between biodiversity and GRs/GWs, ultimately informing the development of sustainable and biodiverse urban environments.

### *4.2. What Methods Have Been Used to Address These Questions, and What Comparisons between Urban Infrastructures Have Been Made in This Field?*

Mainly five methodologies have been employed to address the stated research questions and to compare biodiversity in different urban infrastructures with biodiversity in GRs/GWs.

**Field Surveys:** Researchers used several field surveys to collect data on the species richness, abundance, and composition of plants and animals through systematic sampling methods, such as transects or quadrats. In GWs, where access was limited, studies promoted field surveys such as bird observations at a distance and for a defined period of time [18]. When access was possible, site evaluation surveys using point and transect counts for birds and butterflies [33] seemed to be efficient, and the use of pitfall traps to investigate the impact of local and landscape factors on arthropod communities [19] was also common.

**Experimental Design:** Experimental approaches were also used and involved setting up controlled experiments with replicates to compare the biodiversity outcomes of different design features, such as plant species composition, substrate depth, or watering regimes. For example, a green-roof experiment was conducted by Deng and Jim (2017) in a humid tropical area with the objective of monitoring the spontaneous colonization of plants and bird visits [24], with positive results both in spontaneous plant species establishment and the creation of habitats where bird species can find food resources and nesting sites. Stefania et al. worked on an experimental fruit field in Bucharest, hosting a green wall, in order to determine the attractiveness of beneficial insects, like pollinators and aphid eaters [34].

**Comparative Studies:** Several studies made comparisons between different types of urban infrastructures, including green walls, green roofs, conventional roofs, and other green spaces, such as parks or gardens. By comparing biodiversity measures, ecosystem services, and environmental factors among these infrastructures, researchers determined the specific contributions of GRs/GWs to urban biodiversity. For example, Chiquet et al. (2013) compared the abundance of birds on 27 green walls with that on 27 bare walls and similar surroundings, concluding that birds were far more abundant on green walls [18]. Regarding arthropods, Madre et al. (2015), for example, examined the effects of four different types of building façades on spider and beetle populations in Paris: bare concrete walls (used as a control), a climbing plant, a felt layer, and a substrate module. They found a clear influence of the façade type on arthropod assemblages, and the lowest richness and abundance were identified on bare walls [35]. So, both previous studies mentioned a positive effect of green walls on biodiversity.

**Modeling Approaches:** Modeling techniques were used to simulate and predict the potential impacts of these infrastructures and included species distribution models, connectivity analysis, and ecosystem service modeling to estimate the ecological benefits and connectivity potential. Braaker et al. (2017) conducted a study in the city of Zurich, where they investigated the community composition of arthropods on 40 green roofs and 40 ground-level green sites. They used generalized linear models to analyze how environmental variables, such as area, height, vegetation, and connectivity among sites, influenced species richness and functional diversity [29].

Through these methodologies, researchers can gather empirical data, perform statistical analyses, and generate evidence-based findings regarding the biodiversity outcomes of GRs/GWs. By comparing different urban infrastructures, they can also identify the unique contributions and benefits of these vegetated structures in supporting urban biodiversity and ecosystem functioning.

### *4.3. What Were the Main Identified Contributions of Green Roofs and Green Walls to Urban Biodiversity?*

The systematic literature review performed in the present paper undeniably shows that GRs/GWs provide additional green spaces in densely developed urban areas. Overall, these areas provide valuable opportunities for enhancing biodiversity in urban environments since they offer habitats, promote species diversity, facilitate ecological connectivity, and contribute to various other ecosystem services, as described in Table 2. A summary of some examples is given below.

**Habitat Creation:** The implementation of GRs/GWs in urban environments can help to create new habitats for a variety of plant and animal species, providing nesting sites, food sources, and shelter for insects, birds, and small mammals. Belcher et al. (2019) showed that GRs/GWs supported a higher number of bird species and a greater abundance of urban native birds than control roofs and walls without vegetation. Additionally, they identified certain building design elements, such as the height and presence of specific plants, that supported different species groups, suggesting that the different ecological requirements should be taken into consideration when designing a building's green space [31]. Partridge and Clark (2018) demonstrated that green roofs had significantly more birds than conventional roofs and that they were used as stopover habitats during migration and foraging habitats in the breeding season. They concluded that implementing green roofs in urban landscapes can help increase available habitats for birds and partially alleviate the loss of habitats caused by increasing urbanization [32]. However, in another study, the same authors surprisingly concluded that bird activity and species richness did not increase after the installation of the green-roof plots. They assumed that these results may be due to the relatively small size of the plots or the fact that they were located on buildings within urban parks. Therefore, they argued that it is important to take into account the size and characteristics of the landscapes surrounding green roofs, especially within a larger and potentially higher-quality habitat [36].

Wang et al. (2017) found that both common and rare species of birds and butterflies exhibited reproductive behaviors in tropical urban roof gardens. Height, area, and plant selection played important roles in determining their attractiveness to wildlife [33]. Tonietto et al.'s (2011) work indicated that native bees can be found on green roofs, although their abundance and diversity are lower compared to reference habitats. The patterns observed in bee communities were influenced by habitat characteristics at both the site and landscape scales. For example, bee abundance and richness were positively correlated with larger proportions of green space in the surrounding landscape, and, at the site scale, bees benefited from greater plant diversity [30].

Although there are very few studies that analyze the connection between green walls and biodiversity, Chiquet et al. (2013) presented preliminary findings on the value of green walls for urban birds. They concluded that birds used green walls for various reasons, including nesting, food, and shelter, but were not found on bare control walls. Therefore, encouraging householders and businesses to grow vegetation up walls may provide a range of resources for birds in urban areas without the need for expensive additional land [18].

**Species Diversity:** One of the advantages of these green infrastructures is the introduction of native plant species with consequences of increasing animal species. For example, Deng and Jim's (2017) work revealed that extensive green roofs supported the successful establishment and reproduction of both local common ruderal plant species and common urban bird species [24]. Kyrö et al. (2020) identified roof height and vegetation as the primary local drivers of arthropod abundance. They concluded that vegetated roofs of varying heights and sizes benefit common generalist species but appear to lack rare native specialist species and may inadvertently introduce non-native species if imported plant materials are used [27]. In 2022, another work from the same group of researchers found that roofs and ground sites exhibited similar levels of species richness. However, they differed in terms of community composition: over time, the roofs gradually developed more similarities between themselves rather than closely resembling their adjacent ground-level habitats. The authors observed an increase in species richness over time on both the roofs and ground-level sites. However, the roofs consistently hosted fewer species compared to the ground sites, and only a few species were unique to the roofs. Additionally, the proportion of predators increased on the roofs but not at ground level [37].

**Connectivity:** Green roofs play an important role in enhancing connectivity between urban habitats, serving as ecological corridors and facilitating the dispersal of seeds, insects, and small animals. The study by Kyrö et al. (2018) reported an absence of wingless species, highlighting the importance of enhancing connectivity between green roofs and ground-level habitats to support a wider range of species and fostering biodiversity in urban environments [19]. Moreover, Braaker et al.'s (2017) study found that green-roof arthropod diversity increased with greater connectivity and plant species richness, regardless of the substrate depth, height, and area of the green roofs. The study emphasized the significance of integrating green roofs into urban planning policies that aim to improve habitat connectivity within urban areas [29].

In conclusion, by introducing vegetated environments into urban environments, these structures provide additional habitats for a variety of species. Native plants on GRs/GWs attract birds and promote insect diversity. Moreover, these areas offer shelter and food for urban animal species, contributing to habitat connectivity and, therefore, to wildlife preservation in densely populated areas. As indirect benefits, GRs/GWs, can have a role in reducing urban heat, improving air quality, and managing stormwater, creating more favorable conditions for the development of microecosystems and contributing to the overall health of urban ecosystems.

## 5. Conclusions

The present work provides a review of the results across existing studies regarding green roofs and green walls and their importance for three taxonomic groups: arthropods, bats, and birds. The data evaluation allowed identifying the trend in studies in these nature-based solutions worldwide and existing research gaps.

Despite the recent increase in the number of publications, there are still some research gaps, namely the lack of quantitative robust knowledge on green roofs/walls benefits for urban biodiversity conservation. The results obtained show that green roofs are better analyzed than green walls. The studies address quite specific groups, and there are not many works that provide very comprehensive evidence of the advantages for biodiversity of these types of infrastructures. Future research simultaneously investigating the effects of green roofs and green walls on different taxa will be of paramount importance. Studies of this nature can reveal effects and patterns that are only apparent through multi-species analyses, particularly concerning the community as a whole, ultimately leading to more comprehensive recommendations concerning the installation, management, and maintenance of these infrastructures.

Another important missing issue is evaluations regarding long-term studies. Animal communities may need time to establish themselves in the new habitats created by GRs/GWs, so more years after implementation may be needed to understand their impacts on biodiversity. Cover area and spatial heterogeneity are known to be among the main factors influencing species richness in urban green areas [28,38]. Comparisons of GRs/GWs not only with other urban infrastructures but between GRs/GWs with different sizes and structural complexity would also be important to address future recommendations.

Future research should be more interdisciplinary. For example, citizen science can be used as a complementary approach since it can have the advantage of allowing the collection of biodiversity data at scales that professional science alone would be unable to accomplish. Moreover, the emergence of mobile applications and their widespread utilization have contributed to the engagement of citizens with science, which can be harnessed to involve citizens in understanding urban biodiversity, as well as valuing the advantages of implementing green roofs and walls and the importance that these structures may have in the conservation of biodiversity. The sampling of urban biodiversity using citizen science has been an increasingly applied methodological approach, and specifically regarding GRs/GWs, the fact that these can be widely dispersed throughout a city yet very close to people's daily lives makes this approach a great monitoring tool. Understanding which species are present in these green infrastructures in cities, with the help of the urban population, also makes people more aware of the species and the importance of their conservation.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/environments11040076/s1, Table S1: Papers on arthropods, bats and birds used to understand how green roofs and walls can contribute to urban biodiversity. References [18,19,21,22,24–27,29–37,39–95] are cited in the Supplementary Materials.

**Author Contributions:** Conceptualization, P.T., A.I.L. and C.M.S.; methodology, P.T., A.I.L. and C.M.S.; writing—original draft preparation, P.T., A.I.L. and C.M.S.; writing—review and editing, P.T., A.I.L. and C.M.S.; funding acquisition, C.M.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by the FCT (Portuguese Foundation for Science and Technology) through the GRAVITY project 2022.02093.PTDC (DOI: 10.54499/2022.02093.PTDC) and is part of the research activity carried out at Civil Engineering Research and Innovation for Sustainability (CERIS), also funded by the FCT in the framework of project UIDB/04625/2020. P.T. and A.I.L. received support from the FCT through the strategic project UIDB/00329/2020 (DOI: 10.54499/UIDB/00329/2020) granted to cE3c. P.T. received funding from the Scientific Employment Stimulus program CEECIND/02515/2021 (DOI: 10.54499/2021.02515.CEECIND/CP1654/CT0006), and A.I.L. received a contract through the program DL 57/2016/CP1479/CT0008 (DOI: 10.54499/DL57/2016/CP1479/CT0008).

**Data Availability Statement:** No new data were created or analyzed in this study. Data sharing is not applicable to this article.

**Acknowledgments:** The authors thank the rest of the team from the GRAVITY project for their contribution to the project's development.

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

## References

1. Brook, B.W.; Ellis, E.C.; Perring, M.P.; Mackay, A.W.; Blomqvist, L. Does the Terrestrial Biosphere Have Planetary Tipping Points? *Trends Ecol. Evol.* **2013**, *28*, 396–401. [CrossRef] [PubMed]
2. Carpenter, S.R.; Mooney, H.A.; Agard, J.; Capistrano, D.; Defries, R.S.; Díaz, S.; Dietz, T.; Duraiappah, A.K.; Oteng-Yeboah, A.; Pereira, H.M.; et al. Science for Managing Ecosystem Services: Beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 1305–1312. [CrossRef] [PubMed]
3. Díaz, S.M.; Settele, J.; Brondízio, E.; Ngo, H.; Guèze, M.; Agard, J.; Arneth, A.; Balvanera, P.; Brauman, K.; Butchart, S.; et al. *The Global Assessment Report on Biodiversity and Ecosystem Services Summary for Policymakers of the IPBES Global Assessment Report on Biodiversity and Ecosystem Services*; IPBES Secretariat: Bonn, Germany, 2019; ISBN 9783947851133.
4. Díaz, S.; Fargione, J.; Chapin, F.S., III; Tilman, D. Biodiversity Loss Threatens Human Well-Being. *PLoS Biol.* **2006**, *4*, e277. [CrossRef] [PubMed]
5. Rastandeh, A.; Brown, D.; Pedersen Zari, K. Biodiversity Conservation in Urban Environments: A Review on the Importance of Spatial Patterning of Landscapes. In Proceedings of the Ecocity World Summit, Melbourne, Australia, 12–14 July 2017.
6. Chen, G.; Li, X.; Liu, X.; Chen, Y.; Liang, X.; Leng, J.; Xu, X.; Liao, W.; Qiu, Y.A.; Wu, Q.; et al. Global Projections of Future Urban Land Expansion under Shared Socioeconomic Pathways. *Nat. Commun.* **2020**, *11*, 537. [CrossRef] [PubMed]
7. Faivre, N.; Fritz, M.; Freitas, T.; De Boissezon, B.; Vandewoestijne, S. Nature-Based Solutions in the EU: Innovating with Nature to Address Social, Economic and Environmental Challenges. *Environ. Res.* **2017**, *159*, 509–518. [CrossRef] [PubMed]
8. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Razvan Nita, M.; Geneletti, D.; Calfapietra, C. A Framework for Assessing and Implementing the Co-Benefits of Nature-Based Solutions in Urban Areas. *Environ. Sci. Policy* **2017**, *77*, 15–24. [CrossRef]
9. Lehmann, S. Growing Biodiverse Urban Futures: Renaturalization and Rewilding as Strategies to Strengthen Urban Resilience. *Sustainability* **2021**, *13*, 2932. [CrossRef]
10. Parizotto, S.; Lamberts, R. Investigation of Green Roof Thermal Performance in Temperate Climate: A Case Study of an Experimental Building in Florianópolis City, Southern Brazil. *Energy Build.* **2011**, *43*, 1712–1722. [CrossRef]
11. Mobilia, M.; Longobardi, A. Using SAR Satellite Imagery for Potential Green Roof Retrofitting for Flood Mitigation in Urban Environment. In Proceedings of the International Conference on Geographical Information Systems Theory, Applications and Management, GISTAM—Proceedings, Online, 23–25 April 2021; Volume 2021, pp. 59–66.
12. Wilkinson, S.J.; Reed, R. Green Roof Retrofit Potential in the Central Business District. *Prop. Manag.* **2009**, *27*, 284–301. [CrossRef]
13. Berardi, U.; GhaffarianHoseini, A.H.; GhaffarianHoseini, A. State-of-the-Art Analysis of the Environmental Benefits of Green Roofs. *Appl Energy* **2014**, *115*, 411–428. [CrossRef]
14. Manso, M.; Teotónio, I.; Matos Silva, C.; Oliveira Cruz, C. Green Roof and Green Wall Benefits and Costs: A Review of the Quantitative Evidence. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110111. [CrossRef]
15. Liberalesso, T.; Oliveira Cruz, C.; Matos Silva, C.; Manso, M. Green Infrastructure and Public Policies: An International Review of Green Roofs and Green Walls Incentives. *Land Use Policy* **2020**, *96*, 104693. [CrossRef]
16. Teotónio, I.; Matos Silva, C.; Oliveira Cruz, C. Economics of Green Roofs and Green Walls: A Literature Review. *Sustain. Cities Soc.* **2021**, *69*, 102781. [CrossRef]
17. Mcdonald, R.I.; Kareiva, P.; Forman, R.T.T. The Implications of Current and Future Urbanization for Global Protected Areas and Biodiversity Conservation. *Biol. Conserv.* **2008**, *141*, 1695–1703. [CrossRef]
18. Chiquet, C.; Dover, J.W.; Mitchell, P. Birds and the Urban Environment: The Value of Green Walls. *Urban Ecosyst.* **2013**, *16*, 453–462. [CrossRef]
19. Kyrö, K.; Brenneisen, S.; Kotze, D.J.; Szallies, A.; Gerner, M.; Lehvävirta, S. Local Habitat Characteristics Have a Stronger Effect than the Surrounding Urban Landscape on Beetle Communities on Green Roofs. *Urban For. Urban Green.* **2018**, *29*, 122–130. [CrossRef]

20. Blank, L.; Vasl, A.; Levy, S.; Grant, G.; Kadas, G.; Dafni, A.; Blaustein, L. Directions in Green Roof Research: A Bibliometric Study. *Build Environ.* **2013**, *66*, 23–28. [CrossRef]
21. Filazzola, A.; Shrestha, N.; MacIvor, J.S. The Contribution of Constructed Green Infrastructure to Urban Biodiversity: A Synthesis and Meta-Analysis. *J. Appl. Ecol.* **2019**, *56*, 2131–2143. [CrossRef]
22. Coulibaly, S.F.M.; Aubry, C.; Provent, F.; Rousset-Rouvière, S.; Joimel, S. The Role of Green Roofs as Urban Habitats for Biodiversity Modulated by Their Design: A Review. *Environ. Res. Lett.* **2023**, *18*, 073003. [CrossRef]
23. Colding, J. 'Ecological Land-Use Complementation'for Building Resilience in Urban Ecosystems. *Landsc. Urban Plan.* **2006**, *81*, 46–55. [CrossRef]
24. Deng, H.; Jim, C.Y. Spontaneous Plant Colonization and Bird Visits of Tropical Extensive Green Roof. *Urban Ecosyst.* **2017**, *20*, 337–352. [CrossRef]
25. Eakin, C.J.; Linden, D.W.; Roloff, G.J.; Rowe, D.B.; Westphal, J. Avian Response to Green Roofs in Urban Landscapes in the Midwestern USA. *Wildl. Soc. Bull.* **2015**, *39*, 574–582. [CrossRef]
26. Salman, I.N.A.; Blaustein, L. Vegetation Cover Drives Arthropod Communities in Mediterranean/Subtropical Green Roof Habitats. *Sustainability* **2018**, *10*, 4209. [CrossRef]
27. Kyrö, K.; Kotze, D.J.; Müllner, M.A.; Hakala, S.; Kondorosy, E.; Pajunen, T.; Vilisics, F.; Lehvävirta, S. Vegetated Roofs in Boreal Climate Support Mobile Open Habitat Arthropods, with Differentiation between Meadow and Succulent Roofs. *Urban Ecosyst.* **2020**, *23*, 1239–1252. [CrossRef]
28. Beninde, J.; Veith, M.; Hochkirch, A. Biodiversity in Cities Needs Space: A Meta-Analysis of Factors Determining Intra-Urban Biodiversity Variation. *Ecol. Lett.* **2015**, *18*, 581–592. [CrossRef] [PubMed]
29. Braaker, S.; Obrist, M.K.; Ghazoul, J.; Moretti, M. Habitat Connectivity and Local Conditions Shape Taxonomic and Functional Diversity of Arthropods on Green Roofs. *J. Anim. Ecol.* **2017**, *86*, 521–531. [CrossRef]
30. Tonietto, R.; Fant, J.; Ascher, J.; Ellis, K.; Larkin, D. A Comparison of Bee Communities of Chicago Green Roofs, Parks and Prairies. *Landsc. Urban Plan.* **2011**, *103*, 102–108. [CrossRef]
31. Belcher, R.N.; Sadanandan, K.R.; Goh, E.R.; Chan, J.Y.; Menz, S.; Schroepfer, T. Vegetation on and around Large-Scale Buildings Positively Influences Native Tropical Bird Abundance and Bird Species Richness. *Urban Ecosyst.* **2019**, *22*, 213–225. [CrossRef]
32. Partridge, D.R.; Clark, J.A. Urban Green Roofs Provide Habitat for Migrating and Breeding Birds and Their Arthropod Prey. *PLoS ONE* **2018**, *13*, eo202298. [CrossRef]
33. Wang, J.W.; Poh, C.H.; Tan, C.Y.T.; Lee, V.N.; Jain, A.; Webb, E.L. Building Biodiversity: Drivers of Bird and Butterfly Diversity on Tropical Urban Roof Gardens. *Ecosphere* **2017**, *8*, e01905. [CrossRef]
34. Ştefania Ivan, E.; Ciceoi, R.; Cornelia Butcaru, A.; Maria Stanciu, A.; Alina Nitu, O.; Stănică, F. Green Wall Impact on Beneficial Insects in an Urban Fruit Ecosystem. *Sci. Papers. Ser. B. Hortic.* **2022**, *66*, 326–331.
35. Madre, F.; Clergeau, P.; Machon, N.; Vergnes, A. Building Biodiversity: Vegetated Façades as Habitats for Spider and Beetle Assemblages. *Glob. Ecol. Conserv.* **2015**, *3*, 222–233. [CrossRef]
36. Partridge, D.R.; Clark, J.A. Small Urban Green Roof Plots near Larger Green Spaces May Not Provide Additional Habitat for Birds. *Front. Ecol. Evol.* **2022**, *10*, 779005. [CrossRef]
37. Kyrö, K.; Kankaanpää, T.; Vesterinen, E.J.; Lehvävirta, S.; Kotze, D.J. Arthropod Communities on Young Vegetated Roofs Are More Similar to Each other than to Communities at Ground Level. *Front. Ecol. Evol.* **2022**, *10*, 785448. [CrossRef]
38. Chiron, F.; Lorrillière, R.; Bessa-Gomes, C.; Tryjanowski, P.; Casanelles-Abella, J.; Laanisto, L.; Leal, A.; Van Mensel, A.; Moretti, M.; Muyshondt, B.; et al. How Do Urban Green Space Designs Shape Avian Communities? Testing the Area–Heterogeneity Trade-Off. *Landsc. Urban Plan.* **2024**, *242*, 104954. [CrossRef]
39. Schrader, S.; Böning, M. Soil Formation on Green Roofs and Its Contribution to Urban Biodiversity with Emphasis on Collembolans. *Pedobiologia* **2006**, *50*, 347–356. [CrossRef]
40. Fernández Cañero, R.; González Redondo, P. Green Roofs as a Habitat for Birds: A Review. *J. Vet. Adv.* **2010**, *9*, 2041–2052.
41. MacIvor, J.S.; Lundholm, J. Insect Species Composition and Diversity on Intensive Green Roofs and Adjacent Level-Ground Habitats. *Urban Ecosyst.* **2011**, *14*, 225–241. [CrossRef]
42. Snep, R.P.H.; WallisDeVries, M.F.; Opdam, P. Conservation Where People Work: A Role for Business Districts and Industrial Areas in Enhancing Endangered Butterfly Populations? *Landsc. Urban Plan.* **2011**, *103*, 94–101. [CrossRef]
43. Pearce, H.; Walters, C.L. Do Green Roofs Provide Habitat for Bats in Urban Areas? *Acta Chiropt.* **2012**, *14*, 469–478. [CrossRef]
44. Rumble, H.; Gange, A.C. Soil Microarthropod Community Dynamics in Extensive Green Roofs. *Ecol. Eng.* **2013**, *57*, 197–204. [CrossRef]
45. Madre, F.; Vergnes, A.; Machon, N.; Clergeau, P. A Comparison of 3 Types of Green Roof as Habitats for Arthropods. *Ecol. Eng.* **2013**, *57*, 109–117. [CrossRef]
46. Benvenuti, S. Wildflower Green Roofs for Urban Landscaping, Ecological Sustainability and Biodiversity. *Landsc. Urban Plan.* **2014**, *124*, 151–161. [CrossRef]
47. Nagase, A.; Nomura, M. An Evaluation of One Example of Biotope Roof in Japan: Plant Development and Invertebrate Colonisation after 8 Years. *Urban For Urban Green* **2014**, *13*, 714–724. [CrossRef]
48. Muller, J.N.; Loh, S.; Braggion, L.; Cameron, S.; Firn, J.L. Diverse Urban Plantings Managed with Sufficient Resource Availability Can Increase Plant Productivity and Arthropod Diversity. *Front Plant Sci.* **2014**, *5*, 517. [CrossRef]

49. Williams, N.S.G.; Lundholm, J.; Scott Macivor, J. Do Green Roofs Help Urban Biodiversity Conservation? *J. App. Ecol.* **2014**, *51*, 1643–1649. [CrossRef]
50. Braaker, S.; Ghazoul, J.; Obrist, M.K.; Moretti, M. Habitat Connectivity Shapes Urban Arthropod Communities: The Key Role of Green Roofs. *Ecology* **2014**, *95*, 1010–1021. [CrossRef] [PubMed]
51. Parkins, K.L.; Clark, J.A. Green Roofs Provide Habitat for Urban Bats. *Glob. Ecol. Conserv.* **2015**, *4*, 349–357. [CrossRef]
52. Nash, C.; Clough, J.; Gedge, D.; Lindsay, R.; Newport, D.; Ciupala, M.A.; Connop, S. Initial Insights on the Biodiversity Potential of Biosolar Roofs: A London Olympic Park Green Roof Case Study. *Isr. J. Ecol. Evol.* **2016**, *62*, 74–87. [CrossRef]
53. MacIvor, J.S. Building Height Matters: Nesting Activity of Bees and Wasps on Vegetated Roofs. *Isr. J. Ecol. Evol.* **2016**, *62*, 88–96. [CrossRef]
54. Washburn, B.E.; Swearingin, R.M.; Pullins, C.K.; Rice, M.E. Composition and Diversity of Avian Communities Using a New Urban Habitat: Green Roofs. *Environ. Manag.* **2016**, *57*, 1230–1239. [CrossRef] [PubMed]
55. Wong, G.K.L.; Jim, C.Y. Do Vegetated Rooftops Attract More Mosquitoes? Monitoring Disease Vector Abundance on Urban Green Roofs. *Sci. Total Environ.* **2016**, *573*, 222–232. [CrossRef] [PubMed]
56. Fairbrass, A.J.; Rennett, P.; Williams, C.; Titheridge, H.; Jones, K.E. Biases of Acoustic Indices Measuring Biodiversity in Urban Areas. *Ecol. Indic.* **2017**, *83*, 169–177. [CrossRef]
57. Rumble, H.; Gange, A.C. Microbial Inoculants as a Soil Remediation Tool for Extensive Green Roofs. *Ecol. Eng.* **2017**, *102*, 188–198. [CrossRef]
58. Blank, L.; Vasl, A.; Schindler, B.Y.; Kadas, G.J.; Blaustein, L. Horizontal and Vertical Island Biogeography of Arthropods on Green Roofs: A Review. *Urban Ecosyst.* **2017**, *20*, 911–917. [CrossRef]
59. Joimel, S.; Grard, B.; Auclerc, A.; Hedde, M.; Le Doaré, N.; Salmon, S.; Chenu, C. Are Collembola "Flying" onto Green Roofs? *Ecol. Eng.* **2018**, *111*, 117–124. [CrossRef]
60. Schindler, B.Y.; Blaustein, L.; Lotan, R.; Shalom, H.; Kadas, G.J.; Seifan, M. Green Roof and Photovoltaic Panel Integration: Effects on Plant and Arthropod Diversity and Electricity Production. *J. Environ. Manag.* **2018**, *225*, 288–299. [CrossRef] [PubMed]
61. Rumble, H.; Finch, P.; Gange, A.C. Green Roof Soil Organisms: Anthropogenic Assemblages or Natural Communities? *App. Soil Ecol.* **2018**, *126*, 11–20. [CrossRef]
62. Kratschmer, S.; Kriechbaum, M.; Pachinger, B. Buzzing on Top: Linking Wild Bee Diversity, Abundance and Traits with Green Roof Qualities. *Urban Ecosyst.* **2018**, *21*, 429–446. [CrossRef]
63. Pétremand, G.; Chittaro, Y.; Braaker, S.; Brenneisen, S.; Gerner, M.; Obrist, M.K.; Rochefort, S.; Szallies, A.; Moretti, M. Ground Beetle (Coleoptera: Carabidae) Communities on Green Roofs in Switzerland: Synthesis and Perspectives. *Urban Ecosyst.* **2018**, *21*, 119–132. [CrossRef]
64. Nagase, A.; Kurashina, M.; Nomura, M.; MacIvor, J.S. Patterns in Urban Butterflies and Spontaneous Plants across a University Campus in Japan. *Pan-Pac Entomol.* **2019**, *94*, 195–215. [CrossRef]
65. Hofmann, M.M.; Renner, S.S. Bee Species Recorded between 1992 and 2017 from Green Roofs in Asia, Europe, and North America, with Key Characteristics and Open Research Questions. *Apidologie* **2018**, *49*, 307–313. [CrossRef]
66. Wong, G.K.L.; Jim, C.Y. Abundance of Urban Male Mosquitoes by Green Infrastructure Types: Implications for Landscape Design and Vector Management. *Landsc. Ecol.* **2018**, *33*, 475–489. [CrossRef]
67. Schindler, B.Y.; Vasl, A.; Blaustein, L.; Gurevich, D.; Kadas, G.J.; Seifan, M. Fine-Scale Substrate Heterogeneity Does Not Affect Arthropod Communities on Green Roofs. *PeerJ* **2019**, *7*, e6445. [CrossRef]
68. Ksiazek-Mikenas, K.; Fant, J.B.; Skogen, K.A. Pollinator-Mediated Gene Flow Connects Green Roof Populations Across the Urban Matrix: A Paternity Analysis of the Self-Compatible Forb Penstemon Hirsutus. *Front Ecol. Evol.* **2019**, *7*, 299. [CrossRef]
69. Sánchez Domínguez, M.V.; González, E.; Fabián, D.; Salvo, A.; Fenoglio, M.S. Arthropod Diversity and Ecological Processes on Green Roofs in a Semi-Rural Area of Argentina: Similarity to Neighbor Ground Habitats and Landscape Effects. *Landsc. Urban Plan.* **2020**, *199*, 103816. [CrossRef]
70. Partridge, D.R.; Parkins, K.L.; Elbin, S.B.; Clark, J.A. Bat Activity Correlates with Moth Abundance on an Urban Green Roof. *Northeast Nat.* **2020**, *27*, 77–89. [CrossRef]
71. Passaseo, A.; Pétremand, G.; Rochefort, S.; Castella, E. Pollinator Emerging from Extensive Green Roofs: Wild Bees (Hymenoptera, Antophila) and Hoverflies (Diptera, Syrphidae) in Geneva (Switzerland). *Urban Ecosyst.* **2020**, *23*, 1079–1086. [CrossRef]
72. Dusza, Y.; Kraepiel, Y.; Abbadie, L.; Barot, S.; Carmignac, D.; Dajoz, I.; Gendreau, E.; Lata, J.C.; Meriguet, J.; Motard, E.; et al. Plant-Pollinator Interactions on Green Roofs Are Mediated by Substrate Characteristics and Plant Community Composition. *Acta Oecol.* **2020**, *105*, 103559. [CrossRef]
73. Fabián, D.; González, E.; Sánchez Domínguez, M.V.; Salvo, A.; Fenoglio, M.S. Towards the Design of Biodiverse Green Roofs in Argentina: Assessing Key Elements for Different Functional Groups of Arthropods. *Urban For Urban Green* **2021**, *61*, 127107. [CrossRef]
74. Youl Baek, K.; Kim, H.G.; Kil, S.-H. Analysis of Changes in Suitable Habitat Areas of Pari-dae through Rooftop Greening Simulation-Case Study of Suwon-Si, Gyeonggi-Do, Republic of Korea. *Sustainability* **2021**, *13*, 4514. [CrossRef]
75. Baek, K.Y.; Kim, H.G. Analyzing the Efficiency of Increasing Suitable Habitat Area for Paridae by Roof Greening Method Based on Building Type: Case Study of Suwon City, Republic of Korea. *Sens. Mat.* **2022**, *34*, 4855. [CrossRef]
76. Wang, L.; Wang, H.; Wang, Y.; Che, Y.; Ge, Z.; Mao, L. The Relationship between Green Roofs and Urban Biodiversity: A Systematic Review. *Biodivers. Conserv.* **2022**, *31*, 1771–1796. [CrossRef]

77. Rumble, H.; Finch, P.; Gange, A.C. Can Microbial Inoculants Boost Soil Food Webs and Vegetation Development on Newly Constructed Extensive Green Roofs? *Urban For Urban Green* **2022**, *75*, 127684. [CrossRef]
78. Diethelm, A.C.; Masta, S.E. Urban Green Roofs Can Support a Diversity of Parasitoid Wasps. *Front Ecol. Evol.* **2022**, *10*, 983401. [CrossRef]
79. Joimel, S.; Grard, B.; Chenu, C.; Cheval, P.; Mondy, S.; Lelièvre, M.; Auclerc, A.; Vieublé Gonod, L. One Green Roof Type, One Technosol, One Ecological Community. *Ecol. Eng.* **2022**, *175*, 106475. [CrossRef]
80. Wooster, E.I.F.; Fleck, R.; Torpy, F.; Ramp, D.; Irga, P.J. Urban Green Roofs Promote Metro-politan Biodiversity: A Comparative Case Study. *Build. Environ.* **2022**, *207*, 108458. [CrossRef]
81. Gonsalves, S.; Starry, O.; Szallies, A.; Brenneisen, S. The Effect of Urban Green Roof Design on Beetle Biodiversity. *Urban Ecosyst.* **2022**, *25*, 205–219. [CrossRef]
82. Jacobs, J.; Berg, M.; Beenaerts, N.; Artois, T. Biodiversity of Collembola on Green Roofs: A Case Study of Three Cities in Belgium. *Ecol. Eng.* **2022**, *177*, 106572. [CrossRef]
83. Lin, B.S.; Chen, T.W. The Plant and Faunal Species Composition and Diversity on Rooftop Farms: Seasonal Variation and the Effects of Site and Surrounding Characteristics. *Landsc. Urban Plan.* **2022**, *226*, 104483. [CrossRef]
84. Ridzuan, N.H.; Farouk, S.A.; Razak, S.A.; Avicor, S.W.; Taib, N.; Hamzah, S.N. Insect Bio-Diversity of Urban Green Spaces in Penang Island, Malaysia. *Int. J. Trop. Insect Sci.* **2022**, *42*, 275–284. [CrossRef]
85. Boeing, J.; Cuper, K.; Menke, S.B. Ant Species Richness in the Urban Mosaic: Size Is More Important than Location. *Urban Ecosyst.* **2023**, *26*, 605–615. [CrossRef]
86. Jacobs, J.; Beenaerts, N.; Artois, T. Macro-Invertebrate Abundance on Green Roofs versus Ground Level Sites in the City of Antwerp, Belgium. *Belg. J. Zool.* **2023**, *153*, 1–14. [CrossRef]
87. Correia Da Rocha-Filho, L.; Whittinghill, L.; Grossmann, A.J.; Fogel, N.S.; Riehn, J.K.; Hathaway, J.N.; Camilo, G.R. Bee Diversity on Urban Rooftop Food Gardens. *Front. Sustain. Cities* **2023**, *5*, 1100470.
88. Hussain, R.I.; Frank, T.; Kratschmer, S. More Insect Species Are Supported by Green Roofs near Public Gardens. *J. Insect. Conserv.* **2023**, *27*, 941–946. [CrossRef]
89. Fenoglio, M.S.; González, E.; Tavella, J.; Beccacece, H.; Moreno, M.L.; Fabian, D.; Salvo, A.; Estallo, E.L.; Calviño, A. Native Plants on Experimental Urban Green Roofs Support Higher Community-Level Insect Abundance than Exotics. *Urban For Urban Green* **2023**, *86*, 128039. [CrossRef]
90. Berthon, K.; Thomas, F.; Baumann, J.; White, R.; Bekessy, S.; Encinas-Viso, F. Floral Resources Encourage Colonisation and Use of Green Roofs by Invertebrates. *Urban Ecosyst.* **2023**, *26*, 1517–1534. [CrossRef]
91. MacKinnon, M.; Pedersen Zari, M.; Brown, D.K. Improving Urban Habitat Connectivity for Native Birds: Using Least-Cost Path Analyses to Design Urban Green Infrastructure Networks. *Land* **2023**, *12*, 1456. [CrossRef]
92. Van Dijck, T.; Klerkx, H.; Thijs, S.; Rineau, F.; Van Mechelen, C.; Artois, T. Sedum as Host Plants for Caterpillars? Introducing Gut Content Metabarcoding to Green Roof Research. *Urban Ecosyst.* **2023**, *26*, 955–965. [CrossRef]
93. Jacobs, J.; Beenaerts, N.; Artois, T. Green Roofs and Pollinators, Useful Green Spots for Some Wild Bee Species (Hymenoptera: Anthophila), but Not so Much for Hoverflies (Diptera: Syrphidae). *Sci. Rep.* **2023**, *13*, 1449. [CrossRef] [PubMed]
94. Benedito Durà, V.; Meseguer, E.; Hernández Crespo, C.; Martín Monerris, M.; Andrés Do-ménech, I.; Rodrigo Santamalia, M.E. Contribution of Green Roofs to Urban Arthropod Biodiversity in a Mediterranean Climate: A Case Study in València, Spain. *Build. Environ.* **2023**, *228*, 109865. [CrossRef]
95. McNamara Manning, K.; Coffman, R.R.; Bahlai, C.A. Insect Pollinator and Natural Enemy Communities in Green Roof and Ground-Level Urban Habitats. *Urban Ecosyst.* **2024**. [CrossRef]