# Exploring how green roof features attract birds in the city of Madison and conducting a hypothetical intensive green roof design

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## Abstract

With the development of urban systems, living in urban areas has become a global trend. The growing population, and the accompanying need for increased development, which brings with its problems such as flooding, decreased green space, fragmented habitats, the urban heat island effect, and air pollution. To help mitigate these problems and improve the urban environment, green technology is used to create roof gardens. These gardens benefit people by bringing them close to nature, and many can also provide habitat for birds. The purpose of this two-part study is to design bird-friendly green roofs for two proposed high-rise buildings which are part of a new downtown redevelopment project in the city of Madison, WI. The first part of the project includes a precedent study, in which I summarize available literature concerning green roof designs created to attract birds, and conduct a survey of the birds found on a the green roof garden located at Union South on the UW-Wisconsin Campus. To conduct the survey, I used a combination of checklists, maps and measuring tools to observe the number, species, and activities of the birds at each of the site's behavior settings. I observed 8 different bird species, the most numerous of which were house sparrows. The results show that 1) a of combination design elements including a water feature, plant species providing food and shelter for birds, and structures such as handrails and fences, 2) adjacent areas that provide habitat, and 3) adjacent areas that provide leftover human food –such as an adjacent picnic area– positively impact the birds on site; whereas people who move around close to the birds on site or bring dogs, keep the birds away.

## Introduction

The purpose of this thesis is to explore the relationships between green roof features with the context environment and the birds in the city of Madison. Green roofs can provide a series of functions for people and green space for birds in urban areas. It would be important to study how the green roofs attract more birds and positively impact them.

The movement of people from living in rural areas into cities has become a dominant trend which causes a big influence on population immigration and land transformation in the world. Currently it is estimated that 54.9% of the global population lives in urban areas (United Nations, U.S. Census Bureau); in 2050, 89.9% of the people in the United States is expected to live in cities (United Nations Population Division). The dramatic growth of urban population leads to the growth of cities, and increasing pressure on urban green space (Pickett, 2010; Dallimer et al. 2011). In addition, urbanization also results in the fragments of habitats, which might affect Avian community during migrating and breeding periods, and decrease the richness of other species from the development of human-dominated landscape (Beissinger, 1982; Mckinney, 2002; Jokimäki et al. 2014; Concepcon et al. 2015). Facing multiple environmental problems in urban cities, it is necessary to pay more attention to restoring and maintaining the green space as well as potential habitats for wildlife. To expand and develop the urban green space, establishing green infrastructures such as green roofs and green walls are considered the effective solutions.

## Background

**Definition of a green roof.**

A green roof is a vegetation layer which is installed on top of a flat or slightly sloped roof with a waterproofing system (U.S. Department of the Interior), in order to control the microclimate of buildings, manage the rainwater on roofs, and provide biological functions for wildlife in urban cities. There are two basic types of green roof systems - extensive green roofs and intensive green roofs. An extensive green roof has a shallow growing medium layer less than six inches deep with little or no irrigation and drainage systems. This type of lightweight green roof can save the cost of construction and maintenance. Extensive green roofs are suitable for limited plant species because the thin soil layer provides a stressful growing condition for plants (Coma, 2016). The plant selection for extensive green roofs are usually moss, grasses, herbs, and sedums (Butler, 2011). Extensive roofs are usually not accessible for people and not open to the public.

Compared to extensive green roofs, intensive green roofs have deeper growing mediums that can provide more moisture and nutrition. They can support a more diverse plant selection such as moss, grasses, sedums, shrubs, and trees. Intensive green roofs need more frequent irrigation and more complex drainage systems (Vijayaraghavan, 2016). They are usually accessible and are able to provide more recreation opportunities for the public (Coma, 2016).

Since green roofs can be accessible to human, the type of users and users' activities could be varied. Furthermore, the density and activities of users might also affect the green roof. For instance, some green roofs are installed on commercial buildings which are available to the public. In this case, the human behaviors tend to be more diverse and frequent. Therefore, the area of hardscape on this type of green roof would be boarder to support these activities. Comparatively, residential buildings' green roofs can only be accessible to the occupants. The human activities might be less diverse and less frequent. Thus, the ratio of planting area on this type of green roof would be higher. In addition, the elevation of a green roof can also affect the users. For instance, if the green roof is installed on a ground level, the human behaviors might be more active with a high diversity. People might bring their pets to the green roof or adjacent areas, and this behavior might affect the green roof elements and wildlife. When the green roof locates on a tall building, the human behaviors would be limited and less diverse.

**History of green roofs.**

Green roofs have existed for hundreds of years. People kept exploring the functions and benefits of green roofs, and the components and materials of a green roof were developed constantly. Many ancient cities faced the decrease of urban green space due to the expansion of development land (Holloway, 2003). To increase the area of green space, Green roofs were initially built as the hanging gardens of Babylon in the Roman Empire in urban areas (Farrar, 1996). Besides solving the problem of green space, green roofs also provided other functions. For instance, the Vikings installed roofs with turf to protect their homes from wind and rain (Donnelly, 1992). The thatched roofs were constructed above a wooden frame to keep the house dry and safe in winters or storms. To be protected by the elevated positions, some hill towns such as Urbino and San Gimignano constructed buildings on the hills based on the natural topographical levels in Italy (Pomeroy, 2014). During the Renaissance, Green roofs and steeply terraced gardens were common in the city of Genoa (Gorse,1983). These gardens were built on natural topographic or man-made levels, interconnected by steps to traverse the variations in elevation (Pomeroy, 2014). By creating the elevated green space, people could enjoy varied views of the surrounding landscape.

From the Sixteenth Century to the Nineteenth Century, applications of green roofs were common and in different countries such as Mexico and India. After entering the Twentieth century, some architects such as Le Corbusier and Frank Lloyd Wright began to consider applying green roofs in their architecture designs (Peck et al., 1999). The urbanization trend triggered a series of environmental problems in urban areas. To expand the green space and improve the quality of the urban environment, the usage of green roofs kept rising in Northern Europe until the middle of this century (Peck et al., 1999). In the later Twentieth century, many European states and cities incorporated the green roof concept and technology, and the total area of green roofs in each city were increasing constantly (Peck et al., 1999).

Numerous green roof projects and academic research in European countries proved the benefits of green roofs and developed the related guidelines and support policy. Currently green roofs are also widely installed in the United States. Several highly developed cities such as Chicago and New York have combined green roof systems with various architecture types. Besides, multiple universities in the United States conduct research to explore more potential possibilities of green roofs. For instance,

**Components of a green roof.**

A green roof usually consists of eight components from top to bottom. Each component has different functions and characteristics. These are:

1. The vegetation layer is the uppermost layer, which provides plants for the green roof system. The vegetation can help to absorb the solar radiation, provide oxygen and organics, and control the runoff on the roof. Moisture and nutrition are critical factors in determining whether a plant species can survive on the green roof (Vijayaraghavan, 2016). Because native species area adapted to local weather conditions, they tend to perform successfully on green roofs (Nektarios, 2011; Nagese, 2010).

2. The second layer provides the growing medium (substrate) within which the plants grow. The characteristics of the media influences the plant growth and performance of green roofs directly (Vijayaraghavan, 2016). Therefore, this layer can be considered as the most crucial component for the success of green roofs. Green roof growing substrates are generally a mixture of natural and artificial minerals, recycled or waste materials, and organic matter (Ampim, 2010). The ideal green roof substrate should be stable, lightweight, well-drained, permanent, and hold nutrients well (Friedrich, 2005).
3. The filter layer is used to separate the growth substrate from the drainage layer, and prevent growing medium particles entering and clogging the drainage layer (Vijayaraghavan, 2016). To withstand the load of the upper layers and allow water permeating in a certain direction without the movement of soil particles, geotextiles fabrics are typically applied in the filter layer (Townshend, 2007; Vijayaraghavan, 2015). A geotextile fabric is typically a permeable textile material used to improve soil stability. It is made of fabric and mostly buried under the growing medium as a barrier between the growing medium and the drainage layer.
4. To provide an aerated and non-water-logged substrate condition for most green roof vegetations, a drainage layer is necessary to remove excess water from substrate (Vijayaraghavan, 2016). In addition, this layer also protects the waterproofing membrane of a green roof (Townshend, 2007). Two major types of drainage layers are drainage modular panels and drainage granular materials (Vijayaraghavan, 2016).
5. The root barrier layer is mandatory for intensive green roofs. This layer provides the function of protecting the roof structure from the invasion of plant roots (Bianchini, 2012). Some plant species on intensive green roofs could penetrate from upper green roof layers and cause potential damage to the structure of roof (Bianchini, 2012). Comparatively, this layer is optional for extensive green roof because the roots of plants selected might not reach the roof structure. The available materials for a root barrier layer are usually hard plastic sheets and metal sheets (Townshend, 2007). These sheets could effectively block the plant roots to avoid them extending continuously.
6. The waterproofing membrane is used to separate the green roof components from the building roof, as well as prevent water leakage above (Narigon, 2013; Vijayaraghavan, 2016). The choice of a waterproofing layer material depends on the cost and expectation of a green roof. Available options for this layer include liquid-applied membranes, single-ply sheet membranes, modified-bitumen sheet, and thermoplastic membranes (Townshend, 2007; Vijayaraghavan, 2016).
7. The insulation layer is optional for a green roof system. This layer can help to regulate the temperature between the building interior and the stormwater collected above (Narigon, 2013). If the building needs temperature control function of a green roof system, this layer could be installed. In addition, it further protects the membrane from condensation and physical damage (Shafique, 2018).
8. The roof deck is below all the green roof components, and it is a traditional roof layer. The types of roof deck material include steel, concrete, cement, and wood. The choice of material types depends on the load above and the weight of other utility equipment.

**Green roof benefits.**

Stormwater management.

With the development of urban infrastructure, impermeable surfaces are more common. When it rains, the stormwater collects on these impermeable surfaces and forms runoff. The runoff tends to rush with carrying trash and pollutants into urban water drainage system, eventually dumping into rivers and streams (Subramanian, 2016). It is necessary to capture and manage the runoff because it could result in multiple problems. For instance, if the volume of rainfall is high, the excessive runoff might cause flooding in urban areas. In addition, since the sources of pollutants carried from urban landscape are complex, the runoff should be managed systematically before entering the rivers and streams to protect the natural environment (Subramanian, 2016). Based on several green roof research, green roofs tend to perform well on controlling runoff on the roof. Green roofs are shown to be an effective tool for stormwater retention and filtration at the roof scale (Carter & Rasmussen, 2006; Gregoire & Clausen, 2011). During the rainfall growing season, the green roof can effectively reduce runoff volumes, control peak flows, alter the timing of flows, and improve the quality of runoff on the roof (Seters et al., 2009). According to a green roof study, Green roofs have the ability of removing 50% of the annual rainfall volume from retention and evapotranspiration (Berghage et al., 2009). The vegetation layer and the growing medium layer on a green roof can effectively help to absorb a majority of rainwater during smaller storms and slow the runoff during larger storms (Berghage et al., 2009). Besides, the pollutant content in runoff can also be reduced and filtered by the plants on green roofs.

Reduction of heat island effect.

Compared to rural environment, Urban landscapes have distinct climate characteristics (Arnfield, 2003). For instance, one of the climate elements studied most is temperature difference, which is widely described as the term urban heat island (UHI) effect. The urban heat island effect typically refers to a situation that the temperature of an urban area is higher than surrounding rural areas (Shmaefsky, 2006). The urban Heat Island Effect is a global issue which affects the quality of life and the local urban environment (Grimmond, 2007). Due to the higher temperature in urban cities, the energy consumption tends to increase and cause economic loss. Besides, Heat islands also cause heat-related illness and death (GSA, 2011). To improve and maintain the sustainability of the urban system, certain solutions need to be performed based on the local conditions. Multiple green roof projects have shown that green roofs can reduce Urban Heat Island Effect through regulating the temperature of buildings and air. The plants on a green roof can absorb less sunlight than conventional roofs through the process of evapotranspiration and by providing shades (GSA, 2011). A study found that a coverage of 50% green roofs in the city of Toronto can reduce the temperature as great as 2°C in some areas by running a regional simulation model (Bass et al., 2002). Besides, green roof temperatures can be 30–40°F lower than those of black surfaces in the summer (GSA, 2011). According to a green roof research, green roofs can significantly reduce the roof surface temperature and regulate the context air temperature as well (Qin et al., 2012).

Noise reduction.

Green roofs can also effectively absorb noise so that improving the acoustics performance of a building. The Federal Technology Alert report shows that the growing medium layer of a green roof can absorb traffic and other common outdoors noises (Pearen et al., 2006). Green roofs can reduce the amount of noise transmitted the upper floors of a building without ceiling insulation (GSA, 2011). A research used a simulation model and found that the presence of a sufficient green roof surface area can significantly reduce noise of road traffic for the upper floors of the building (Renterghem & Botteldooren, 2009). Another study showed that a noise reduction of over 10 dB was observed on the green roof system, and dense leaves tend to have positive effects on noise migration at high frequencies (Yang et al., 2010).

Air quality.

The plants growing in urban environments can reduce and remove the air pollutants such as carbon dioxide, carbon monoxide, and smog-forming compounds. Since a green roof has the vegetation layers, it is also possible to improve the air quality depending on the type of plant and the depth of soil (GSA, 2011). For instance, the deeper soil layer can support a wider variety of plant species. In addition, the plants having greater leaf surface area tend to capture and reduce more particulate matter (GSA, 2011). A study conducted in Singapore indicated that the particle number concentration of particulate matter had declined by 6% with the installation of green roofs (Tan & Sia, 2005). Therefore, installing green roofs could potentially reduce the air pollutants and enhance the quality of context air.

Aesthetics and quality of human life.

Green roofs can create attractive space and provide quality views for the building occupants. The various plant species on green roofs can significantly improve the beauty of views. In addition, if the green roof is accessible for human, the open space with site amenities on green roofs can also provide a quality environment for building occupants. For instance, a collaboration of covert and overt space with hardscape pavement and essential outdoor furniture such as benches, tables, planters, recyclers, and other artificial infrastructure can provide opportunities for people to have various social activities. The aesthetic appeal and the associated activities created by green roofs can help to reduce people’s stress from work and boost their productivity.

Biodiversity.

The high density of population and buildings, the low proportion of green space, and the dominance of alien plant species may negatively impact the abundance and richness of native species in urban environments (Díaz and Armesto, 2003). It is critical to provide more green space as potential habitats for wildlife in urban cities. In the last decade, several studies had been conducted to explore the potential values of green roofs, and a few studies demonstrated the ecological benefits of green roofs. According to a study performed in Iowa, a total of 884 birds composed of 15 native species and 3 non-native species were observed on multiple green roofs (Narigon, 2013). Research in HongKong found 16 bird species on tropical extensive green roofs, the result shows that both plant species and common urban bird species can establish successfully on green roofs (Deng & Jim, 2017). Besides, the research operated in Zurich also found an Arthropod community on green roofs. The results suggest that green roofs can maintain the high functional diversity of the Arthropod community by increasing the diversity of the plant community (Obrist, 2017). According to research conducted in New York, green roofs can increase the richness of the birds and Arthropod community, and totally 41 bird species were observed using green roofs as habitat during the migrating and breeding periods (Partridge & Clark, 2018). All these studies indicate that green roofs can provide potential habitats for plant communities and wildlife. And installing green roofs can effectively improve biodiversity in urban areas.

## Research Summary

The intent and goal of this project is to explore how the green roof impacts birds by performing a literature review and a bird survey and conduct a hypothetical green roof design based on the results. The bird observation site locates on the Union South. It was selected among the green roofs on the campus of UW-Madison. The green roof design site was selected from the development projects in the city of Madison. The hypothetical green roof design showed the process of how to apply the survey results to an integrated design project.

# Research Objectives

The study purpose is to explore how the landscape features on green roofs positively impact birds in urban areas. The importance to the field of Landscape Architecture is that it contributes to the sustainable landscape design in urban cities. This project further develops the knowledge of the green roof design disciplines for attracting more birds and enhancing bird richness in urban areas. This study will combine the literature review and the bird observation to summarize the guideline, and then conduct a hypothetical green roof design based on it.

The study objectives are to:

1) Explore how the context environment and site elements impacts birds on the green roof.

2) Complete an integrated hypothetical green roof design.

**Case Study: Observations of Bird Activities on a Selection of Existing Green Roofs on the UW-Madison Campus**

The purpose of this survey is to explore how green roof attributes and the context objects affect avian variables. The green roof attributes include roof area, roof height, natural elements such as plants, rocks, water features, and artificial amenities such as handrails, pavements and outdoor furniture. Besides, other factors such as human activities and other wildlife are also considered as potential green roof attributes. The avian variables include avian moving routes within the site, avian moving routes between the site and surroundings, avian diversity and abundance. The results and conclusions of this survey will be applied to the green roof design.

## Methods

Study site selection.

*Initial survey of green roofs on the UW-Madison campus.*

I began the second part of my precedent study by locating all the green roofs found on the University of Wisconsin-Madison Campus. Using information provided by the UW-Madison Department of Campus Planning and Management, I located ten accessible roof gardens. I then visited each site and conducted an initial visual bird survey. I spent 1 hour on each site documenting the number and behavior of each of the birds that visited the site. I noted the environmental conditions during the time of my visit, described the activities of the human visitors (if any), and the hardscape and softscape landscape components. The survey was conducted from July 15th to July 30th, 2018. The location and descriptions of the green roofs in this survey are provided in Appendix I.

Compared to other green roof sites, the Union South green roof had the most bird species and the most individual birds. The bird activities on this green roof also showed a highest diversity, which means the elements on this roof could provide more opportunities for bird behaviors. Besides avian species, the plant community was also in a good growing condition. In addition, the human density and frequency of human activities are high, which means more human disturbances might occur on this site. Hence, it would provide a good opportunity to explore how human disturbances affect avian community in urban environment. Based on these considerations, I decided to select this green roof as my observation site to perform my bird survey.

# Site map creation

Once I choose the Union South location for the bird survey, I created a map (plan) of the exiting features of the site. Using Google maps, the Union South site plan acquired from Campus planning department of UW-Madison, and onsite measurements using tape, I identified and measured the distances between each of the program elements, and the area covered by each. I measured the dimensions of each feature and documented the material used. A plan view of the site using AutoCAD and Adobe Photoshop.

Description of study site and context.

Union South is a public building which supports a wide variety of social events and recreational activities. There are three green roof sections: one on the 3rd floor, one on the 4th floor of the building, and one section was on the garage entry. This garage entry is a sloped structure. The southern edge locates 12 feet above the ground while the northern edge is located on the ground level. The average slope rate is 5%. All three sections were established in 2011. The total green roof area is 6,260 ft$^2$. The two green roof areas attached to the building are not accessible to human visitors. Sedums and perennials are planted on these two green roof areas. I observed these two green roofs from the ground-level plaza attached to Union South because I did not get the permission to access these green roofs. Based on my observation, a total of seven house sparrows visited these two green roofs. The birds perched on the handrail.

Most of my observations were of the green roof planted over the garage. (See Fig. 1) The total area of this green roof site is 2465ft$^2$. The site has a slight slope. The features that contribute most to bird habitat are grass, a water feature, shrubs, tree, and handrails. (Figs. 1),

The grass covers the most area. The tree is on the northern boundary and is not adjacent to any other features on site. The artificial handrails are on the western, eastern, and southern edges of the site. They are made of stainless steel and installed on the concrete parapets of the green roof site. The total length of the parapet with handrail is 189 feet. The handrails are composed of eight horizontal round bars (12mm) and are 3 feet 6 inches high.

The water feature surrounded by rocks is placed along the eastern boundary of site and is adjacent to shrubs. It is an outdoor waterfall fountain composed of running water and natural rocks. The waterfall fountain has three sections. The section on the green roof site is a 71ft$^2$ standing water with a depth of 3 inches. The rocks cover an area of 176 $ft^2$. The other standing water section is on the eastern planting area. A transitional section connects these two parts and forms a waterfall effect. The elevation of this waterfall is 7 feet. The running water is maintained by fountain pump fixtures.

The garage roof plantings are divided into two areas, concentrated on the eastern and southern parts of site. The plant species are Sienna Glen Maple (*Acer x freemanii 'Sienna'*), Brilliant Red Chokeberry (*Aronia arbutifolia 'Brilliantissima'*), Nannyberry (*Viburnum lentago*), Magnus Purple Coneflower (*Echinacea purpurea 'Magnus'*), Shenandoah Switch Grass (*Panicum virgatum 'Shenadoah'*), Forest Rouge Blackhaw Viburnum (*Viburnum prunifolium 'Forest Rouge'*), black medick (*Medicago lupulina*), Prostrate Knotweed (*Polygonum aviculare*).

At the time of my observations, the heights of Magnus Purple Coneflower and Shenandoah Switch Grass ranged from 3 feet to 5 feet. The heights of the woody species range from 4 feet to 9 feet.

No hardscape pavement is installed on the garage green roof. The average horizontal distances from handrails to the water feature, the tree, and the shrubs, and grasses are 36 feet, 16 feet, and 10 feet, respectively. The average distances from the tree to the water feature, and the shrub area are 42 feet and 46 feet. Lawn grass it is connects all of the green roof features.

There are also two planting areas and a plaza adjacent to the green roof site itself. See Figs. 1, 2, and 3), One of the plantings is east of the garage roof and the other is to the west. Both planting areas are established on the ground-level, just below the green roof. Since the garage-top garden has a slight slope, the elevation differences between it and the ground-level plantings vary. The southern boundary of site has the highest difference value, which is 12 feet. The elevation difference declines from south to north.

The planting area on the east covers an area of 2085$ft^2$. This planting area contains 150 Shenandoah Switch Grass (*Panicum virgatum 'Shenadoah'*), 1 Butter and Sugar Siberian Iris (*Iris siberica 'Butter and Sugar'*), 6 Black Snakeroot (*Cimicifuga racemosa*), 12 Brilliant Red Chokeberry (*Aronia arbutifolia 'Brilliantissima'*), 23 Beaver Creek Fothergilla (*Fothergilla gardenii 'Beaver Creek'*), 2 Forest Rouge Blackhaw Viburnum (*Viburnum prunifolium 'Forest Rouge'*), 2 Thornless Cockspur Hawthorn (*Crataegus crusgali 'inermus'*), 3 Princess Diana Serviceberry (*Amelanchier 'Princess Dianna'*), and 1 Shademaster Honeylocust (*Gleditsia triacanthos inermis 'Shademaster'*).

The planting area locating on the west covers 2311$ft^2$. It contains 6 Forest Rouge Blackhaw Viburnums (*Viburnum prunifolium 'Forest Rouge'*), 3 Pagoda Dogwoods (*Cornus alternifolia*), 1 Swamp White Oak (*Quercus bicolor*), 10 Old Gold Junipers (*Juniperus chinensis 'Old Gold'*), 16 Brilliant Red Chokeberries (*Aronia arbutifolia 'Brilliantissima'*), 80 Shenandoah Switch Grasses (*Panicum virgatum 'Shenadoah'*), 74 Prairie Dropseeds (*Sporabolus heterolepsis*).

There is also a 25604$ft^2$ plaza immediately adjacent to the green roof. (See Figs. 1 and 2) The plaza is mostly comprised of concrete pavement with movable metal outdoor tables and chairs It includes plantings covering a total of 3107$ft^2$. The plants include 58 Tufted Hair Grass (*Deschampsia cespitosa*), 34 Alaska Daisy (*Chrysanthemum maxima 'Alaska'*), 8 Swamp Milkweed (*Asclepias incarnata*), 2 Black Snakeroot (*Cimicifuga racemosa*), 1 Caesar's Brother Siberian Iris (*Iris siberica 'Caesar's Brother'*), 61 Lady's Mantle (*Alchemilla mollis*), 36 Red Sprite Winterberry (*Ilex verticillata 'Red Sprite'*), 7 Jim Dandy Winterberry (*Ilex verticillata 'Jim Dandy'*), 14 Cranberry Cotoneaster (*Cotoneaster apiculatus*), 2 Pagoda Dogwood (*Cornus alternifolia*), 3 Sienna Glen Maple (*Acer x freemanii 'Sienna'*) and 1 Shademaster Honeylocust (*Gleditsia triacanthos inermis 'Shademaster'*). The plantings are concentrated on the northern part of plaza close to the building. The distances from the garage green roof to these planting areas range from 49 feet to 155 feet.

The Union South building itself contains steel handrails installed on two outdoor decks located on the 2nd floor and the 3rd floors. The length of the 2nd floor handrail locating is 149 feet. The shortest distance from the garage roof to this handrail is 35 feet, and the longest distance is 191 feet. The distance from ground to bottom of handrail is 12 feet 6 inches. The height of handrail is 3 feet 6 inches. Horizontal railing is applied to the handrail which totally contains 9 round bars (12mm). The 3rd floor handrail has a length of 104 feet, and it has the same attributes with the one on the 2nd floor. The elevation of this handrail is 25 feet. The shortest distance from site to this handrail is 43 feet, and the longest distance is 141 feet.

Another context element is the street located on the southern side of the green roof. The main features providing alternative place for birds on street are street trees and house near the green roof site. Based on the survey, the house across the street is a three-story building with sloped roof. The street tree’s species is Honey locust (*Gleditsia triacanthos*).

The context of the green roof is important, because the birds move freely among the different areas and this context influences their usage of the green roof itself.

Survey methods.

I surveyed The Union South Green Roof twelve times from July 27th to September 11th. I conducted each survey starting at 3:00 PM and ending at 7:00PM. I only sampled on days in which sky was sunny, with no clouds and no wind.

To make my observations, I sat on a rock located on the northern boundary of the green roof site (See Figs. 1and 2). From this location I was able to see the condition of the birds and all of the elements on and adjacent to the site. I arrived at the site at 2:50 PM to allow the birds to become used to my presence. After sitting down, I began to record my observations using a marker, three checklists and a map.

Based on the results of my literature review the initial green roof survey, and the goals of my thesis, I decided to focus my observations on the following four factors, each of which can provide information about how best to design green roofs for the purpose of attracting birds.

*The movement of birds between the green roof and off-site locations.*

Besides the design of a green roof itself, the characteristics of the surrounding area can also influence whether birds can utilize the area. By documenting how birds move between on- site and off-site features can help us understand their resource preferences. Furthermore, the findings can suggest where to locate a green roof. The immediate behavior settings adjacent to the green roof are planting areas, the Union South building; the plaza consisting of a concrete surface, multiple planting areas, and a series of site amenities; and a street with an adjacent sidewalk. To record the observations, I used a checklist containing these four off-site locations and a map that presented the spatial locations of these features on and off the site. This checklist is organized to record the number of times birds moved from each off-site location to the green roof and the number of times birds moved from the green roof to each off-site area. I also counted and recorded the bird numbers and documented the bird activities on each surrounding feature.

I also created a map using a measuring tape and the measurement tool of Google Map (Google, n.d.) in order to measure the horizontal distances between the green roof and the building, plaza, plantings, and street. The purpose of this step is to explore if proximity will impact movement of the birds between the site and its surroundings. I measured multiple distances between each surrounding object and site, based on the four endpoints of site and the endpoints of those context elements. For the building, based on my observation, the birds only stayed on the artificial handrails located on the 2nd level outdoor deck of the building. Therefore, I measured the horizontal distances between site and the endpoints of this deck, rather than of the building itself.

To explore if the characteristics of the surrounding features can impact whether the birds visit them, I also measured each of these features. I measured the dimension of handrail established on the second-floor deck. I recorded the height, length, radius, and material of the handrail. For the planting areas adjacent to site, I measured the area and identified the plant species. In addition, I recorded the distances between the plants and site boundary. For the plaza, I documented the dimensions of site amenities such as outdoor furniture, planters, and food waste recycler, the area, and the materials of pavement. For the street, I measured the width of the street, recorded the species of street trees and the types of buildings along the street.

*The movement of birds within the site.*

Another factor that can inform the design of a garden meant to attract birds is to understand which features the birds use and how often they move among them. According to my inventory, the Union South Garage Green Roof program elements include lawn, grasses, perennials, deciduous shrubs, a deciduous tree, rocks, a water feature, and an artificial handrail installed on the green roof parapet. (See Figs. 2 and 3)

I used a checklist to document the frequencies with which birds moved between the different site features. I combined the site features (program elements) into 5 categories: handrails; shrubs and grasses; the tree; the water feature; and the grass. Then, I counted the number of times birds moved from one category to each of the others. For example, I observed the number of times birds traveled from the water feature to the tree, from the tree to the water feature, from a handrail to the tree; from the tree to a handrail, from one handrail to another, and so on.

In order to explore if there is any relationship between the frequency of the travel routes and the distances between them, I measured the horizontal distances between every the different program elements by with a tape measure. For example, I measured the distances from the four four corners of the water feature to the tree and them on the draft map I prepared. Besides the distances between different features, I also measured the distance between the handrails located on two sides of the roof.

*The spatial distribution of bird species within the site.*

It is critical to investigate the bird species using this green roof and the spatial distribution of species on site. The main purpose is to explore the potential relations between green roof program elements and bird species. The results can help to decide the selection of green roof features based on different bird species in green roof design. To collect this information, I recorded the program elements the birds visited every thirty minutes during my site survey. Therefore, during each visit I collected eight groups of data by using the checklist I prepared and the draft map.

The checklist for each survey was divided into nine columns: bird species list and eight observation periods. Each observation period contains five program elements: handrail, shrubs & grasses, water feature, tree and lawn. Based on this checklist, I identified and documented the bird species during the eight observation periods. Then I counted and recorded the number of birds of each species under the associated green roof feature category. When one group of bird species stayed on multiple features, I checked all the related features.

*Human -bird interactions.*

Human behavior can also potentially impact bird behavior. Therefore, it is necessary to record the human behavior occurring on or near the site. I prepared a checklist to document the related attributes of human activities. For instance, I observed and recorded the number of people, the time and description of human activities happening on the site or in an adjacent location such as the Union South plaza. In addition, I also recorded how these behaviors affected the birds on site.

I also identified and measured the associated attributes of site amenities frequently used by people on the plaza. For instance, I measured the dimensions of outdoor tables, chairs and food waste recycler. I also measured the distances between the outdoor furniture and the boundary of site in order to see if the green roof's proximity to the plaza will impact the birds' visiting.

## Data analysis.

After the site survey, I input the collected data to Excel separately based on these checklists. And then I created multiple graphic charts for each variable to explore the potential relations between green roof attributes and avian indexes. In addition, I organized and presented the dimension data on the maps to visualize the spatial information of these associated objects on site and within the immediate surroundings. For the last step, I combined the results of variables analysis and spatial maps to generate the final information product.

## Results

The spatial distribution of bird species within the site.

I observed a total of 8 bird species on the green roof site. They are American robin (*Turdus migratorius*), house sparrow (*Passer domesticus*), American goldfinch (*Spinus tristis*), common starling (*Sturnus vulgaris*), northern cardinal (*Cardinalis cardinalis*), gray catbird (*Dumetella carolinensis*), mourning dove (*Zenaida macroura*), and American crow (*Corvus brachyrhynchos*). Of these, house sparrow sightings were the most numerous, amounting to almost 87% of the total.

Figure 4 reflects the spatial distribution of each bird species on the site. Figure 5 shows the bird species associated with each green roof program element. According to the data, the American robins, northern cardinals, gray catbirds, and mourning doves tended to concentrate on the water feature and handrails. In contrast, the house sparrows visited all of the green roof features, being found most often on the grass, handrails, and the artificial fountain. The American goldfinches and the sparrows were the only birds found in the shrubs.

Common Starlings liked to visit the water feature and then leave the site. American crows tended to concentrate on the water feature, grass, and handrails. They visited the water feature the most frequently.

*Table 1: Summary of Birds' Spatial Distribution on the Green Roof*

**Spatial Distribution Summary of Bird Species on the Site**

| Bird Species | Artificial Fountain | shrub | Grass | Tree | Handrail |
|---|---|---|---|---|---|
| American Robin | 16 | 0 | 0 | 0 | 14 |
| House Sparrow | 345 | 80 | 829 | 4 | 683 |
| American Goldfinch | 20 | 12 | 0 | 0 | 7 |
| Common Starling | 20 | 0 | 0 | 0 | 0 |
| Northern Cardinal | 18 | 0 | 0 | 0 | 14 |
| Gray Catbird | 12 | 0 | 0 | 0 | 8 |
| Mourning Dove | 22 | 0 | 1 | 0 | 13 |
| American Crow | 38 | 0 | 31 | 0 | 32 |

The house sparrows, mourning doves and American crows tended to congregate on site in pairs or in groups. The group scales of these 3 species were different. House sparrows liked to flock on the site thus their group size is comparatively big. The number of American crows in their visiting group was around 4, while the mourning doves always were in a pair during all the observations. Common starlings, American robins, American goldfinches, northern cardinals, and gray catbirds visited the green roof individually.

The different bird species used the green roof program elements interactions in similar ways. When birds visited the water feature, their behaviors included perching, preening, drinking, and calling. They also visited the plant species with some common purposes. For example, sometimes when people or other animals approached, birds entered the area of shrubs or grasses to hide themselves. The Shenandoah Switch Grass, in particular, was used for this purpose. The Nannyberry was the shrub most often visited by birds. The dense, oval-shaped leaves and abundant fruits of this shrub provided shelter, food, and recreational space. Birds liked to perch, call, and feed on the branches.

On the other hand, certain species also had their own preferences. For instance, American goldfinches and northern cardinals liked to visit the purple coneflowers for the sweet nectar. American crows and house sparrows often flocked, foraged, fed and walked on the grass while other bird species seldom visited the grass.

Some special interactions among these bird species also happened depending on different conditions. For instance, since the water feature attracted various bird species, sometimes multiple species visited the feature simultaneously. When multiple species were present, the smaller-body birds such as American goldfinches, house sparrows and common starlings moved to the adjacent grass, handrails, or shrubs to wait for an available spot. In contrast, the bigger-body birds such as American crows, mourning doves, and American robins used the water directly. In addition, the bigger-body bird species seldom visited the shrubs while smaller-body birds liked to perch on the shrubs. When multiple bird species perched on the handrails, each species perched on a different level or kept a distance away from one-another on the same-level bars. Sometimes a group of birds flocked and then perched on the bars while other birds visited the handrails individually. When new birds joined, the existing birds would adjust the perching distance to prepare enough space for them.

Human -bird interactions.

Since Union South is a public place where a wide variety of events are held, humans engage in many different activities which may impact birds. Based on my observations, the people who visit the roof garden mainly influence birds by keeping them away. During my August 5th survey, three people visited the green roof site and stayed for 10 minutes near the water feature. No bird was visible during these 10 minutes. Birds returned to the site within 5 minutes after the people left. On August 23, two people brought their dog to the green roof site and they stayed besides the water feature for 33 minutes. During this period, no birds were observed on the site. When the people and dog approached, all the birds flew away or hid somewhere on the site. After they left the site, the birds reentered the roof within 10 minutes. However, compared with the previous population of birds, the number of birds declined significantly on the site. On August 27, a person lay on the lawn of the roof for 40 minutes. Only a few House Sparrows stayed on the water feature and handrails. After the person left, the number of birds gradually increased.

Although people using the site itself discourage birds from visiting, people who visit the areas adjacent to the roof often serve to attract some birds. For instance, people sometimes ate food on the plaza and left uneaten food on the outdoor tables or on the ground. In addition, some people liked to feed birds on plaza House sparrows and American crows often left the green roof and moved to the plaza to eat the leftovers. Therefore, the composition and numbers of bird species on the green roof is influenced by onsite and off-site human behavior.

The movement of birds between the green roof and off-site locations.

Table 2 and Figs. 6 and 7 show how often birds move between the Union South Green Roof and several off-site locations. The results indicate that the planting areas adjacent to site was the most popular surrounding feature. Most birds arriving on the roof come from these adjacent plantings and move to them when they leave. The building is the second most popular surrounding feature.

*Table 2: Summary of Birds' Moving Routes between the Green Roof and Off-Site Locations*

**Frequency Summary of Birds' Moving Routes between the Context Features to the Site**

| Moving Route | Total Frequency | Moving Route | Total Frequency |
|---|---|---|---|
| Building to Site | 185 | Site to Building | 308 |
| Planting areas to Site | 591 | Site to Planting Areas | 414 |
| Plaza to Site | 80 | Site to Plaza | 154 |
| Street to Site | 106 | Site to Street | 73 |
| Total | 962 | Total | 949 |

From the data, it appears more birds come to the roof from the adjacent plantings (591) than from the other parts of the surroundings (371, remaining 3 sites combined). When birds leave the roof, many moves to the planting areas (414), but many also move to the building (308). Additionally, compared with the number of birds entering the site from the plaza (80), birds preferred to visit the plaza after leaving the site (154). The number of birds moving between street to site (106) and from site to street (73) is smaller than those using other routes.

In addition to recording the numbers of birds moving between the roof and the various surrounding areas, I also observed their behaviors. Based on my observation records, birds especially house sparrows tended to eat food residue left on the plaza's outdoor tables, food waste recycler, and ground after leaving the green roof site, or they sometimes perched on the outdoor furniture. When house sparrows and crows flew to the Union South building after leaving the site, they preferred to perch on the handrail on the second floor and call, and they tended to stay for a long time.

When smaller birds such as house sparrows, and American robins preferred street trees. Mourning doves and American crows tended to perch on the handrails of house along the street. When birds stayed on the planting areas before entering or after leaving the site, they perched on the plants, called, or ate food. Based on my observations, the adjacent planting areas supported a wide variety of birds. All the bird species observed on green roof site were found in the planting areas.

The characteristics of the surrounding areas also influence the results of bird survey. Each area has different components which are attractive to different species of birds.

Each of the two planting areas that are adjacent to the roof gardens has a complex plant structure due to the diverse plant species. These plant species provide a complex, multifunctional green space for birds. Based on the bird activities, the plant community provided food, shelter, and recreational space for birds. Since the planting areas are adjacent to the green roof site, the birds frequently shifted between the handrail on site and the plant species next to the handrail. When people or wildlife approached the site, birds tended to shift to the planting areas. Besides plants, the planting area locating on the east also has a water feature which is connected to the one on site. This is also an attractive element for birds. Many birds visited the water feature and stayed for a long time.

The movement of birds within the site.

*Table 3: Summary of Birds' Moving Routes on the Green Roof*

**Frequency Summary of Birds' Moving Routes on the Site**

| Green Roof Features | Frequency |
|---|---|
| **Artificial Fountain** | 411 |
| Shrub - Artificial Fountain | 363 |
| Handrail - Artificial Fountair | 321 |
| Grass - Artificial Fountain | 62 |
| Tree - Artificial Fountain | 23 |
| **Handrail** | 571 |
| Artificial Fountain - Handrai | 390 |
| Shrub - Handrail | 123 |
| Grass - Handrail | 428 |
| Handrail - Handrail | 174 |
| Tree - Handrail | 24 |
| **Shrub** | 337 |
| Artificial Fountain - Shrub | 401 |
| Handrail - Shrub | 95 |
| Grass - Shrub | 21 |
| Tree - Shrub | 13 |
| **Grass** | 103 |
| Artificial Fountain - Grass | 60 |
| Handrail - Grass | 460 |
| Shrub - Grass | 43 |
| Tree - Grass | 27 |
| **Tree** | 50 |
| Handrail - Tree | 32 |
| Artificial Fountain - Tree | 25 |
| Shrub - Tree | 18 |
| Grass - Tree | 30 |

Figure 8 describes the 26 travel routes on the roof; each green roof feature has 5 or 6 possible pathways. The handrails, water feature and shrubs are all important program elements for attracting birds to the roof, as well as facilitating movement of birds within the site Based on the observational data, the most frequent onsite movement was from handrail to handrail. The second highest connection was between the handrails and the grass. Most birds perched on handrails and then left the site. The water feature was also visited frequently by birds on site, and birds often shifted between the water feature and other green roof features such as handrails and shrubs.

## Conclusions And Discussion

**Site context.**

The make-up of the land surrounding a green roof is critical in being able to attract birds to green roof site. The more birds that are attracted to the features of its environment, the more birds might visit the green roof site. In this study, the planting areas adjacent to the Union South roof supported a high abundance and a wide variety of birds. Birds tended to visit the green roof site from these planting areas. They preferred to stay on these planting areas before entering the site and after leaving the site. This result corresponds with the finding that the area of vegetation cover is positively related to bird species richness and abundances in urban environment (MacGregor-Fors & Schondube, 2011).

In addition, the adjacent planting areas are composed of diverse plant species. This is also consistent with previous studies that found that the vegetation complexity can be positively related to abundance and richness of bird community (For example, Kang et al. 2015), and that that bird community richness is enhanced by small landscape patches within the urban matrix (Loss et al., 2009).

One of the planting areas next to the Union South roof garden also has an artificial waterfall fountain which attracted a great number of birds.

Based on the results of the literature review and of the bird observation study indicates that the potential of a green roof to attract birds is enhanced by being located near or surrounded by large areas of diverse and complex plantings that provide food and shelter.

Another important feature of the surrounding built environment that can also attract birds is providing places for birds to perch. In my study, the infrastructure feature that was most heavily utilized was handrails, often associated with the tops of walls or fences. The more buildings surrounding a green roof site that provide perching sites, the more birds will be in the area and likely to visit the green roof.

A third context feature that influences the numbers of birds in an area is the presence of people. In the Union South example, the plaza adjacent to the roof garden attracted a great number of some common urban bird species such as house sparrow and American crow due to the abundant food residue left by people. The population and activeness on the plaza are both high. Sometimes people also feed the birds on plaza which significantly enhanced the abundance of these bird species. Birds also liked to perch on the site amenities such as the outdoor furniture, and food waste recycler.

This result corresponds with the finding by MacGregor-Fors and Schondube (2011) that the bird abundance is positively related to human populations. It is also consistent with the finding that feeding regime can potentially restructure the composition of avian community in urban areas (Galbraith et al., 2015).

In contrast, other human behaviors such as walking, running, and walking dogs tend to negatively impact the quantity of birds on plaza and the green roof. My observations of birds leaving the roof when people arrive are consistent this result. (However, roof gardens are often out of the way of typical street traffic; the Union South roof was above street level, but easily accessed.) This result also verifies the finding that the presence of pets such as cats and dogs will negatively impact the abundances of urban avian community (MacGregor-Fors & Schondube, 2011; Paker, 2014).

To attract and maintain bird activities on green roofs, limiting the numbers of people allowed on site at any one time and controlling some activities such as walking dogs should be considered.

**Green roof features.**

The five program elements that are found on the Union South green roof are a grass lawn, an artificial waterfall fountain, a tree, a parapet with handrails, and planting areas dominated by shrubs. Each feature has unique physical and spatial characteristics which are associated with avian distribution, moving routes, and behaviors on the site. Based on the green roof survey in Madison, all these features contributed to the high quantity and diversity of birds attracted to the Union South green roof site. Therefore, the attributes of these green roof features could be used as the reference of the future green roof design.

Based on the survey result, the artificial waterfall fountain supported the highest diversity of birds. All the bird species observed were attracted to this water feature on the site. This result indicates that the water feature provided essential functions for these bird species. It directly corresponds to Clifford's (2020) suggestions of ways of attracting birds. The water meets the birds' physical demand such as drinking and bathing, and preening. The rocks surrounding the water provided a perching place for birds to prepare for jumping into the water or preening. Besides, the artificial natural waterfall connected to the water area on the green roof also attracted a great number of birds.

However, the size of the water feature matters. The current water area at Union South is not big enough to support all the birds visiting the site. Some birds had to wait for the available spots while other bird species using the water. Therefore, the water area could be expanded to provide more space for more bird species in the context area. The total area of this current water feature on the green roof is 247ft$^2$. It covers a 10% proportion of the whole green roof. In the future green roof design, the ratio of water cover to the green roof could be higher.

Another critical feature is planting vegetation near the water feature. Based on my observations, the numbers of bird visiting both the water feature and the shrubs are high, and the birds tended to shift frequently between these two features. The trees in the eastern off-site planting area are also near the water. The clustered spatial distribution of these features might effectively contribute to the attractiveness of birds. This is consistent with coincides the finding that riparian habitats with woody plants can enhance the species richness of bird communities (Stauffer & Best, 1980).

For a green roof design, it might be difficult to plant a great number of trees on a green roof due to the amount and weight of the soil needed. However, large shrubs could also provide similar functions and survive with a comparatively shallow soil layer. At Union South, the shrub attracting the most birds on the green roof site is Nannyberry (*Viburnum lentago*). This 9-foot high large shrub provides dense leaves and branches for birds to perch and hide, and it attracted a high quantity and diversity of birds. Therefore, including large shrubs in a green roof design might provide essential functions and support a rich bird community. If planted near a water feature, this combination could together greatly enhance bird habitat.

Another important benefit the plants provided for birds on the site is a food source. The shrub species used at Union South (Nannyberry, Brilliant Red Chokeberry, and Forest Rouge Blackhawk Viburnum) provided many berries, and this abundant food source indeed attracted a great number of birds. The herbaceous species on the site also provided food for birds. Purple Coneflower attracted the American goldfinch and northern cardinal. Besides birds, nectar and the berries can also attract insect species which also are a potential bird food source. Therefore, planting shrubby species or grasses species which can provide food for insects and birds might be possible to form a sustainable ecosystem on the green roof.

In addition to being a desired feature in the areas surrounding a green roof, as discussed above, artificial infrastructure features such as parapets and the handrails attached to them found at Union South them are also attractive to birds visiting the site.

The handrails on the Union South Green roof were frequently used by a wide variety of birds and bird species. There are likely many reasons for this result. First, the diameters of round bars of the handrail range from ¼ inches to 2 inches, which are suitable for birds' feet. The bird species having large bodies such as American crow, American robin and mourning dove tended to perch on the 2-inch round bars, while other smaller bird species liked to stay on the ¼-inch round bars.

Second, the long round bars provided enough space to accommodate many different birds and they are comparatively permanent on the site. Shrubs can also provide horizontal branches for birds to perch, but it is difficult for a shrub to support a great number of birds. Some bird species, especially house sparrows tended to flock together and perch on the same feature. The linear infrastructures were built along three edges of the site, and the total length is long enough to support the birds visiting the site. The stainless-steel material of the handrail and the concrete material of the parapet can last for many years, while the shrubs will likely require pruning to maintain their shape and thus their perching effectiveness.

Third, the parapets and handrails are adjacent to other features which are attract birds. For instance, the artificial infrastructure located on eastern edge of the green roof is adjacent to the off-site shrubs and trees, the artificial waterfall fountain, and the shrubs on the site. Those on the western edge are adjacent to the grass species on the site and the shrubs in the adjacent off-site planting areas. Like the combination of water and shrubs, the artificial infrastructure and other adjacent green roof features also work together to support a large number and diversity of birds.

For green roof design, it is important to consider the physical attributes and spatial location of the artificial infrastructures. For instance, the dimension of infrastructure components should be suitable for perching. The horizontal round bars are more appropriate than vertical square bars, and diameters could vary for different bird species. In addition, the horizontal bars should be long enough to support a large number of birds. The material should be stable and tend not to be impacted by the environmental condition. To maximize the function of artificial infrastructures, other green roof features such as vegetation and water should be located nearby.

**Bird species on green roof.**

Based on my observations, it appears that the bird species are not distributed evenly across the site, most likely because of differences in biology and habitat preferences. For example, the house sparrows observed on the site flock together and visit all the green roof features. It was the dominant bird species on the site. The house sparrow is a common urban bird species and well- adapted to the urban environment. Their main diet is seeds and insects. On the Union South green roof, the sparrows foraged and fed on the grasses, and on Prostrate Knotweed which was abundant on the roof. Sparrows are small and the birds can fit in the spaces between the two round bars of the handrails and the spaces in the shrubs.

Another dominant bird species on the site was the American crow. The American crow is also a bird species well-adapted to the urban systems. Crows have a wide diet, and they are familiar with various human behaviors. Similar to the house sparrows on the site, the crows also occur in groups. Since the crows are large and work together, other smaller bird species stay way while the crows were using the water feature. It is important to maintain the balance of proportions of all the bird species on the green roof. It might not be sustainable that one or some bird species occupied all the green roof resources. Therefore, it might be necessary to limit the quantity of crows in the green roof design. The crows on the site hardly visited shrubs, perhaps because of they are large and relatively heavy. In addition, the crows only perched on the top bar of the handrail because their bodies could not fit the gap space between those round bars below. Therefore, it might be possible to control the number of American crows on green roofs by adjusting the dimensions of the artificial infrastructures and the types of vegetation.

In addition to the house sparrow and American crow, the other bird species that visited the site were American goldfinch, northern cardinal, common starling, gray catbird, and mourning dove. Each of these species has different preferences on the green roof site. For instance, the gray catbirds and the mourning doves visited the artificial fountain for preening and did not visit other parts of the roof. By contrast, the American goldfinches, northern cardinals, and common starlings visited several features for different aims. The cardinals and the goldfinches visited and fed on the on the purple coneflowers. The starlings preferred to stay under the Nannyberry and preen while waiting for their turn at the water.

To enhance and maintain the richness of bird species on green roofs, it is necessary to provide the essential features which can meet the demands of different bird species. Therefore, based on different bird species diets, those plants producing nectar, fruits, or berries could be preferred in the future design.

**Human disturbances.**

The urban environment is complicated for birds due to the presence of people. Different interactions between human and birds might cause different types of impacts to birds in urban areas. Humans on the Union South green roof impacted birds on the site directly and indirectly.

For instance, birds tended to leave the site or hide into vegetation on the site when people approached them. If people lay or sat on the site without conducting any obvious actions, the birds would return to the site or appear visibly on the site in around 15 minutes. Comparatively, if pets especially dogs were brought to the site by people, no birds were visible on the site no matter what actions conducted during this period. The presence of birds is negatively associated with the quantity of cats and dogs in urban open space (MacGregor-Fors & Schondube, 2011; Paker, 2014). To avoid affecting the birds' usage of green roofs, it might be necessary to limit the appearance of pets and the spatial range of human activities. Warning signs or landscape features could be used to limit the human activities. Bringing pets to green roofs could be forbidden.

Human behavior can also impact birds indirectly. The Union South plaza is adjacent to the site. People often visit this area to conduct private or public activities. For instance, when a few people ate food or fed birds on the plaza, most house sparrows and American crows on the green roof site would be attracted to the outdoor furniture. As these birds left the site, the presence of other bird species got higher and the composition of the avian community on the site changed. Comparatively, when people held some public social activities on the plaza, the birds preferred staying on the site rather than entering the plaza area due to the dense human disturbances. Therefore, in the green roof design, the layout and scale of the hardscape area is important because it might potentially determine the human density and the type of human behaviors.

## Conclusion

**Main Findings**

The bird survey indicates that birds indeed visit and use the green roofs in the city of Madison. Among these green roof sites, the Union South attracted the most birds based on multiple factors. For instance, the surroundings of the site include planting areas, buildings, and plazas, all of which contribute to the diverse group of birds that visit the site. Furthermore, based on the bird observation of the Union South, the landscape features and their layout on the site indeed impacted the distribution of bird species and bird behaviors. For instance, the combination of a water feature, plants, and railings attracted a great number of birds and a high diversity of bird species. Plant species that provide food or shelter for birds and the water feature the most bird species. Therefore, when designing a green roof, it is important to consider these landscape features and their spatial distributions on the site.

**Suggestions for Monitoring the Green Roof**

It is critical to test the completed green roof's functions and evaluate if it is successful. Multiple monitoring methods should be used to see if the design goals and objectives are being met. As a reminder, the goals and objectives of my project are:

Goals.

- Runoff formed by stormwater on the green roof is reduced.
- Temperature of the roof surface and ambient air is reduced and regulated.
- Noise of the upper floors is reduced and migrated.

- Air pollutants are reduced on the green roof.
- Building occupants use the green roof as a high-quality open space.
- Several bird species visit and use the green roof as a qualified habitat during summer seasons.

Objectives.

- The volume of runoff formed by stormwater on the green roof is reduced by 50%.
- The temperature of the green roof surface and ambient air is reduced as great as 2℃.
- The noise is reduced by 10 dB for the upper floors.
- The air pollutants are reduced by 6% on the green roof.
- At least 50% building occupants use the green roof and perform a minimum of 4 different human behaviors.
- At least 4 bird species visit and use the green roof and perform a minimum of 4 different bird behaviors from June to September each year.

To monitor the green roof's regulation of temperature, several temperature sensors connected to a computer can be installed in different locations on the roof surface. People can now download and collect the data. To monitor if stormwater control is meeting the design objectives, it is necessary to calculate the volume of runoff collected by the green roof. Berghage et al. (2009) suggest that installing a covered gutter and downspout attached to the lower end of the green roof to collect the runoff. The downspout drains into a barrel connected to a pressure transducer to provide continuous measurement of the water level. Building managers can download and record the data to a computer.

The sound insulation ability of the green roof also needs to be tested. Based on Galbrun and Scerri's (2017) experiment, a source room and a receiving room inside the building can be used to test the transmission of sounds. The idea to measure the sound pressure level in both the rooms, and then the sound reduction needs to be calculated.

In order to monitor the air quality status, multiple sensors and air pollutant collection equipment can be installed before the construction of the green roof. The data collected in the process from the traditional roof stage to the installed green roof stage can reflect the air pollutant removal by the green roof.

To assess how people and birds are using the roof, an observation checklist method similar to the one I used for this thesis would work well. Depending on the design goals/objectives. Things to look for with regard to the birds: include the number of species present, where the birds are found on site, their behaviors, how they move within and to and out of the site, and any other special situations such as the invasion of predators. The interactions between birds and human also need to be recorded.

It is also important to ask the building occupants to fill out a user survey and/or participate in an interview for the building occupants to explain how they use (or do not use) the roof and if they have any suggestions for improvements.

**Possible Improvements of the Survey Methods**

The survey methods can be improved in several ways. First, the frequency of observations could be higher. For instance, I collected 12 groups of data from July 27th to September 11th. The average frequency of data collection is 6 times a month. In order to enhance the data accuracy, it might be better to add more observations such as collecting the data 8 times a month. Besides, for the spatial patterns of bird species, the sampling frequency can also be higher during each observation. I observed and recorded the birds on the green roof every 30 minutes. To make the result more accurate, it would be better to shorten the interval to 20 minutes or less.

Second, the whole process of observations could cover a wider time range. I conducted the observations from July to September, which only covers 2 months. It would be better to cover the full cycle of birds such as the seasons of breeding, migrating, and overwintering. Birds might have different behaviors, moving routes, and spatial patterns on the green roof during these seasons. For instance, the water feature will not be available during winter, and the plant species will become dormant.

In addition, the migration season could change the composition of bird species visiting the site. Considering providing essential green roof features for the migrants is also important. The migrants could also impact the spatial patterns and behaviors of the permanent resident birds. For example, if a predator species were to visit the green roof, the resident birds might hide or avoid the area. It is necessary to record the impacts so that the green roof features and associated management methods could be modified in order to maintain the green roof for birds during the whole year.

Third, more information could be captured and recorded during the observation. More detailed information of birds such as genders, ages, body sizes, calling sounds could be recorded. Associated equipment such as Sennheiser ME66/K6, the Nagra Seven, and other recorders can assist collecting the bird vocalizations (Bartels, 2017). The birds' sounds can reflect their status changes under different conditions. By recording these details, it is possible to acquire more information about the relationships between the green roof and birds. For example, the food types inside the bird feeders might be different based on the diverse bird ages. In addition, it could be better to add more sub-classifications of birds' moving routes. For instance, when recording a bird's moving route between the shrubs and the water feature, it might be better to indicate the specific shrub species the bird visits. For the moving routes between the site and the surrounding environment, recording the specific features such as the outdoor tables on the plaza, the 2nd level parapet, and the detailed plant species in the adjacent planting areas birds visit. The record of the interactions between birds and human can also be more explicit. For instance, it might be better to document the safe distances between different human behaviors such as running, walking, eating, talking, feeding and birds. By adding these details, the survey results could be more accurate and informative.

#### Suggestions for Future Study

To increase our understanding findings of how green roofs might provide habitat for birds in urban areas, it is essential to investigate more green roofs visited by birds in more cities. When selecting the study sites, it would be helpful to choose designs that include the features might be essential to include roofs in the expanded survey that contain the same program setting/program elements found in this study.

For example, in this study, the water feature supported a high diversity of birds. However, the specific relation between the area of water and bird diversity is not clear. More observations need to be conducted to collect more data. In addition, how the spatial arrangement of the program elements impacts bird richness still needs to be explored. For example, the relation between the distances among these landscape features on a green roof and the bird richness can be studied further.

Besides the features of a green roof site itself, the features surrounding the roof are also critical. More green roof sites need to be surveyed to explore how the context impacts the birds on site. For instance, the distances between surrounding features such as buildings, planting areas, and hardscape areas and the green roof can be collected for more green roof projects. Moreover, it is also important to summarize the characteristics of each context features for more green roofs. For instance, the area of a planting area, the plant species within a planting area, the materials of a plaza, and the height and area of a building might potentially impact the birds on the green roof site.

By collecting more data of the relations between green roofs and birds in urban areas, more green roof design principles could be generated. For instance, the range of a green roof water feature area which has positive impact on bird richness can be used as a design reference in the future green roof projects. The spatial pattern of green roof features is also critical for green roof design. By applying these design disciplines, the bird richness in urban areas might be improved constantly.

## Declarations

#### Funding (information that explains whether and by whom the research was supported)

Not applicable

#### Conflicts of interest/Competing interests (include appropriate disclosures)

I would like to declare that I have no conflicts of interests. I stand to make no financial or political gains by writing this work.

#### Availability of data and material (data transparency)

I confirm that the data supporting the findings of this study are available within the article and its supplementary material. The data can be accessed and shared publicly.

#### Code availability (software application or custom code)

Not applicable

#### Authors' contributions (optional: please review the submission guidelines from the journal whether statements are mandatory)

I declare that I completed the literature review, data collection, data analysis, data visualization, and writing for this work.

#### Additional declarations for articles in life science journals that report the results of studies involving humans and/or animals

Not applicable

#### Ethics approval (include appropriate approvals or waivers)

Not applicable

#### Consent to participate (include appropriate statements)

Not applicable

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## Figures

**Figure 1**

Plan view of the study site located on the Union South, this map is made by AutoCAD and Photoshop after the site survey. The base map is obtained from the official website of City of Madison: https://www.cityofmadison.com/dpced/planning/210-s-pinckney-street/2450/

**Figure 2**

Photo of the study site and the context environment, this is taken from the 3rd floor of the Union South.

**Figure 3**

photo of green roof features on the study site.

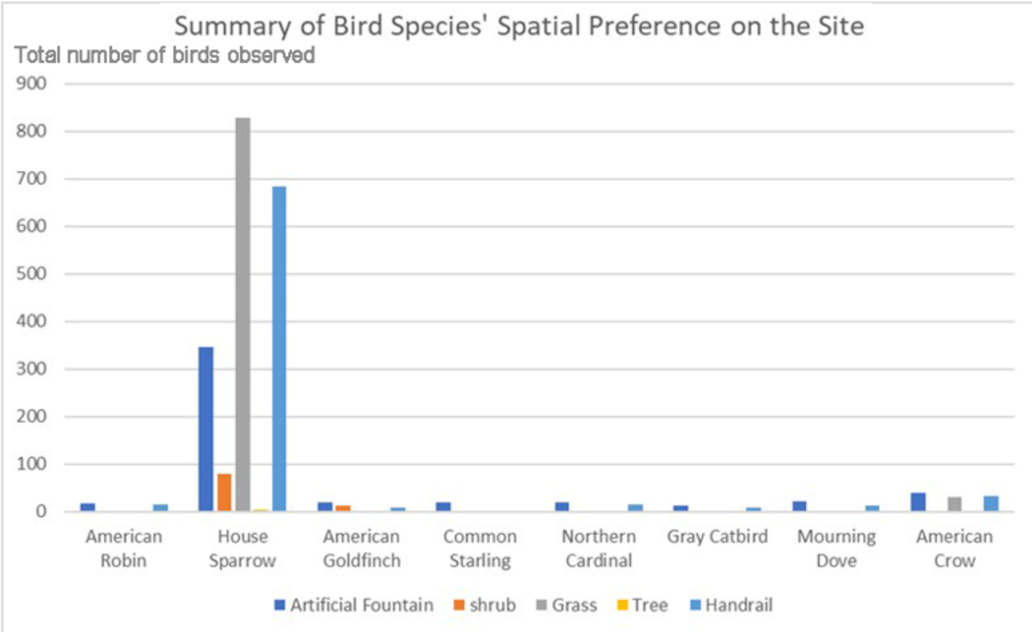


**Figure 4**

Summary of Bird Species' Spatial Distribution on the Green Roof

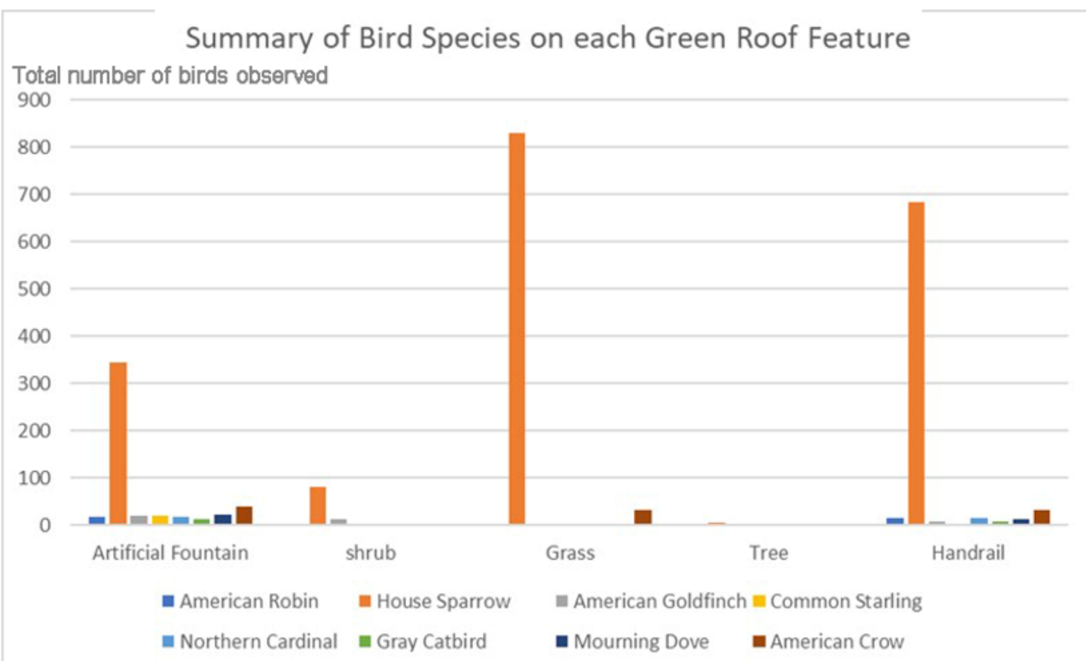


**Figure 5**

Summary of Bird Species on each Green Roof Feature. Most observations occurred on the grass (39%) and the fountain (35%), the fewest on the tree (<1%)

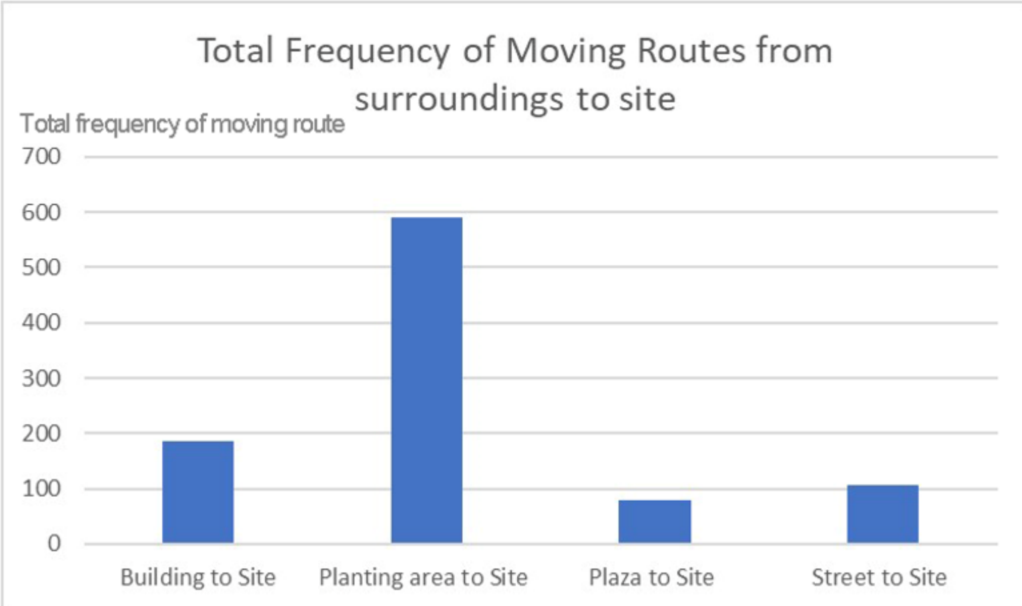


**Figure 6**

Summary of Birds' Moving Routes from Off-site Locations to the Green Roof

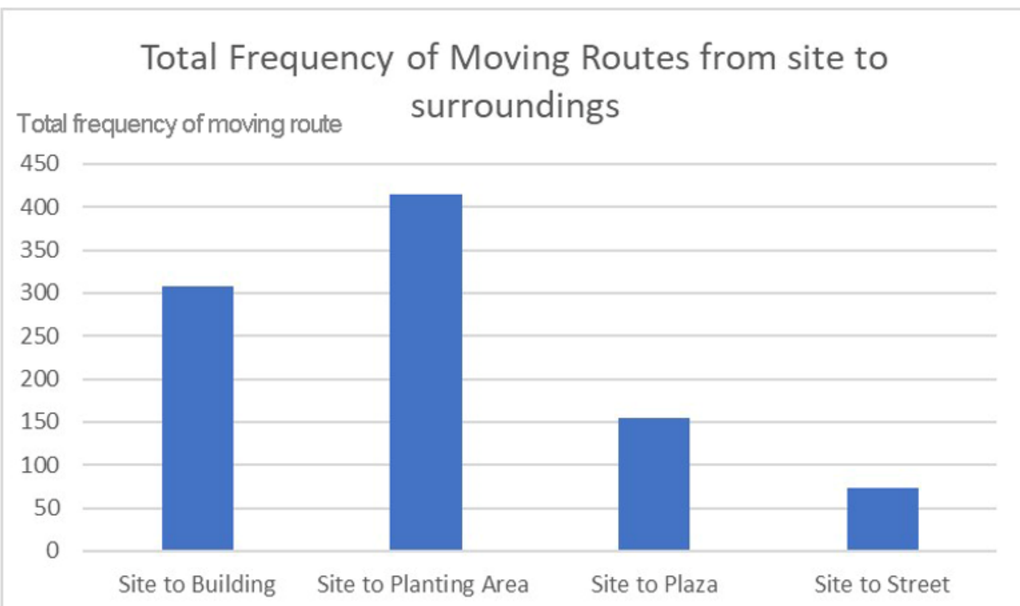


**Figure 7**

Summary of Birds' Moving Routes from the Green Roof to Off-site Locations

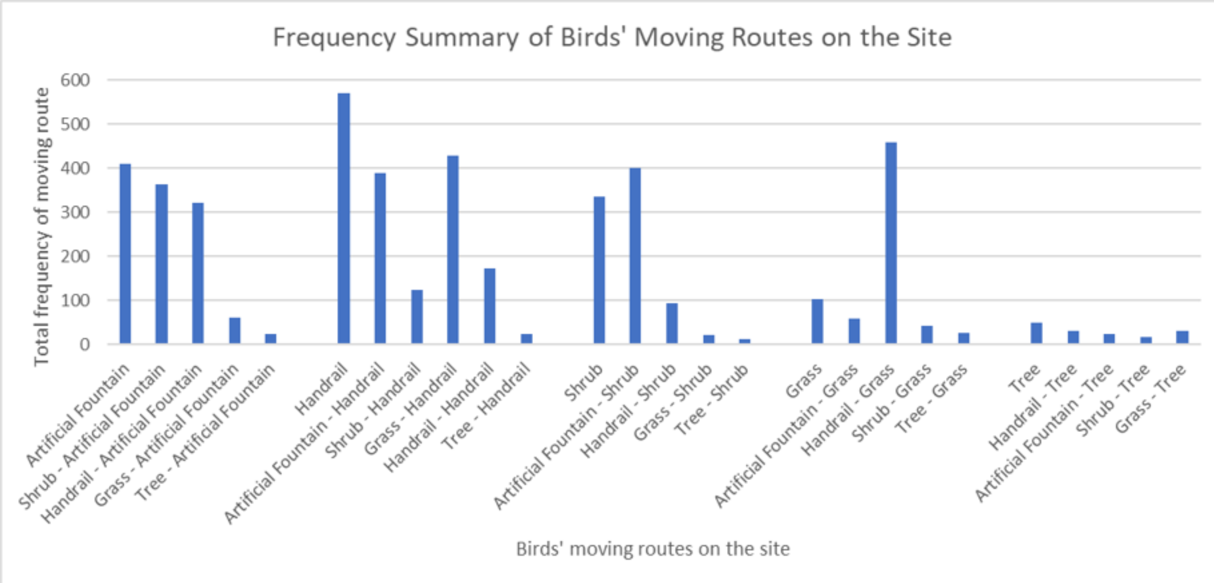


**Figure 8**

Summary of Birds' Moving Routes on the Green Roof

## Supplementary Files

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